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DOE STANDARD

APPLICATION OF BEST AVAILABLE TECHNOLOGY FOR RADIOACTIVE EFFLUENT CONTROL

U.S. Department of Energy
Washington, D.C. 20585

AREA

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) has established requirements for the release of liquid wastes and effluents and requires compliance with the applicable U.S. Environmental Protection Agency (EPA) and other Federal and State regulations. The requirements for controlling the release of liquid wastes and effluents are established in DOE 5400.5, entitled Radiation Protection of the Public and the Environment, and subsequently, in 10 CFR Part 834, also entitled Radiation Protection of the Public and the Environment. Among other things, the Order requires application of the Best Available Technology for Radioactive Effluent Control (BATREC) prior to the discharge of contaminated liquid effluents from certain processes. This document provides guidance to field offices to help them perform the analyses and select the BATREC as required by DOE 5400.5 and 10 CFR Part 834. Because these DOE directives address the control of radiological releases, this guidance manual addresses BATREC for the control of radionuclides in liquid effluents. However, because it is necessary to incorporate the control of nonradiological contaminants when designing treatment systems, the manual also takes into consideration the regulatory limits for nonradiological contaminants in liquid effluent streams.

1.1 BACKGROUND

In addition to requiring that the dose to members of the public (onsite or offsite) be limited, in accordance with the radiation protection standards established in the Directives, DOE 5400.5 (page I-2, paragraph 5a) and 10 CFR Part 834 (Subpart D) impose further requirements on the control of liquid releases to protect such resources as land, surface water, ground water, and the associated ecosystems from contamination. This requirement implies not only that a facility should comply with applicable standards and regulations, but that an effort should be made to reduce the potential for radiological contamination of the environment in accordance with the "as low as reasonably achievable" (ALARA) policy.

The Order prescribes the use of BATREC for liquid effluents containing radio-nuclides from DOE activities that are discharged to surface water, to prevent the surface waters from receiving radioactive material at annual average concentrations greater than the derived concentration guide (DCG) values [DOE 5400.5, paragraph 3a(1) and 10 CFR Part 834.211]. With regard to releases to surface waters, the Directives state that implementation of the BATREC process for liquid radioactive effluents is not required where the annual average concentration of radionuclides is less than the DCG level [page II-8, paragraph 3a(2) and §834.211(a)(2)(i)].
For nonradioactive contaminants, Best Available Technology (BAT) is prescribed by State and Federal laws and regulations related to the Clean Water Act. By incorporating BATRECto these Directives, DOE intends to provide a level of protection for radionuclides that is consistent with the Clean Water Act.

In addressing liquid radioactive discharges to aquifers and soil columns, the Directives require that the use of soil columns (i.e., trenches, cribs, ponds, and drain fields) to retain suspended or dissolved radionuclides from untreated liquid effluent streams be discontinued as soon as practicable in favor of an acceptable alternative disposal means. The Directives require that the BAT selection process be applied to those liquid effluent streams that continue to be discharged to soil columns and that contain process-derived radionuclides [page II-8, paragraph 3b(1)]. **10 CFR Part 834.212 retains the prohibition on continued use of soil columns for liquid waste streams, except for liquid wastes that have been treated by a BATREC process and where the discharge of the treated effluent to the soil column is demonstrated to be the lowest risk alternative management practice.**

The Directives address the discharge of liquid effluents to sanitary sewerage systems by requiring that the BATREC selection process be implemented whenever discharges from DOE activities contain radionuclides at concentrations that, averaged monthly, would be more than five times the DCG values for liquids at the point of discharge (DOE 5400.5, paragraph 3d and 10 CFR Part 834.213).

Table 1.1 summarizes the radionuclide levels at which the BATREC selection process must be applied in accordance with these Directives.

For purposes of determining compliance with the Directives, DOE defines the point of compliance as the undiluted outfall of the process stream. This point is the physical location where the process stream enters the environment. It is not the site boundary, or the point where physical security control of the process ends. It is important to ensure that the proper point of compliance is identified, so that process wastes are not diluted with other low-concentration, high-volume liquid streams, thereby precluding application of the BATREC selection process.[a]

(a) Pelletier, R. F. 1992. Implementation Guidance for DOE 5400.5, Section II.3 ("Management and Control of Radioactive Materials in Liquid Discharges and Phaseout of Soil Columns"), attachment to DOE memorandum dated June 17, 1992, from Raymond F. Pelletier to Distribution, "Guidance regarding water protection elements of DOE 5400.5."

TABLE 1.1. Liquid Waste Stream Radionuclide Levels at Which the BATREC Selection Process Is Applied

Discharge Destination	Radionuclide Concentration
Surface water	> 1 DCG[a]
Soil column[b] (soil, ground water)	Any active soil column
Sanitary sewerage system	> 5 DCG[a]

(a) Where DCG is the Derived Concentration Guide as listed in DOE 5400.5, Chapter III, applied to the monthly average concentration using a sum of fractions method for all radionuclides in the process waste stream.

(b) Use of soil columns (cribs, trenches, ponds, drain fields, etc.) is considered an interim control strategy under DOE 5400.5. Where the period of interim use is indefinite, use of the BATREC selection process is required. In 10 CFRPart 834, discharge to the soil column is only permitted where it is the least risky alternative.

1.2 PURPOSE AND SCOPE

The purpose of this manual is to provide guidance on the process to be used for determining BATREC. The guidance presents a method for providing a structured approach that will encourage objective evaluation and accountability while providing the flexibility required to accommodate the very different and specific needs of the various DOE sites and facilities. The method recognizes the need for strong reliance on the "best professional judgment" of the qualified individuals performing the analysis and provides a framework for incorporating and documenting this input. The guidance provides a uniform basis for determining BATREC throughout DOE for control of radionuclides in liquid waste streams, and will assist in evaluating BAT determinations during programmatic audits. The Directives require that an evaluation of BATREC be conducted on all facilities having a liquid effluent (radioactive) discharge with an average annual concentration that exceeds the DCG level. The BATREC for a facility should be periodically reevaluated as necessary, consistent with DOE's ALARA policy and guidance. The manual does not, however, address when periodic BATREC evaluations are necessary.

This manual is designed to be used for case-specific BATREC analyses at DOE facilities and not for generic evaluations of facilities or processes. It provides guidance in support of the Directives, which focus on the radioactive components of a liquid effluent stream. Consideration must also be given to the standards and regulations for the nonradioactive components of the liquid effluent stream, i.e., reduction in radioactive liquid effluents cannot be achieved by ignoring resultant increases in nonradioactive liquid effluents. The manual addresses the establishment of BATREC for the radioactive components of a liquid effluent stream, as part of an overall control system that effects compliance with the applicable standards and regulations for both the radioactive and nonradioactive components of the liquid effluent stream. Although the manual does not specifically address the BAT requirements for nonradioactive components established in 40 CFR Part 125 (Criteria and Standards for the National Pollutant Discharge Elimination System), these requirements must also be integrated into the BATREC evaluation process. Given this need for an overall control system (i.e., one that controls both the radioactive and the nonradioactive components of the liquid effluent stream), the manual addresses economic, operational, and other pertinent factors that would be associated with the entire control system. These overall considerations are an integral part of the process of assessing alternative control methods in the selection of BATREC for the radiological component.

This manual also specifies the format and general content of the documentation to be developed in support of each BATREC evaluation. The manual specifies only general content elements, because the specific content of BATREC evaluations will vary considerably depending on the specific characteristics of the facilities being evaluated. The manual does not address how or to whom this documentation should be submitted or filed.

Establishing cost in evaluating BATREC, as described in this manual, is only for comparative purposes. It is extremely difficult to establish generalized bottom-line cost criteria, because a host of variables associated with any given facility affect the cost of controlling effluents from that facility.

1.3 DEFINITION OF TERMS

The following terms are used throughout the BATREC determination and analysis process described in this manual. As defined here, they relate specifically to the application of BATREC for DOE facilities.

Best Available Technology for Radioactive Effluent Control (BATREC) is defined in the Directives as the preferred technology for treating a particular process liquid effluent, selected from among others after taking into account factors related to technology, economics, public policy, and other parameters. As used in the Directives, BATREC is not a specific level of treatment, but the conclusion of a selection process that includes several treatment alternatives. The Directives are specifically concerned with BATREC applied to the treatment of liquid waste streams, which includes source controls as well as any systems added to control the release of contaminants to the liquid effluent stream.

Significant modifications are any physical or operational changes to a facility that result in a significant change (i.e., ±10%) in the rate at which contaminants are discharged to the environment. Maintenance, repair, and replacement activities that are routine and do not result in a significant change (i.e., ±10%) in the contaminant discharge from the facility are not considered significant modifications.

Noncompliance refers to failure to meet the limits specified in applicable Orders, standards, and regulations. The DCG values in DOE 5400.5 are not limits but are provided as reference or screening values for conducting radiological environmental protection programs. The DCG values were generated assuming worst-case conditions for individual exposure pathways. Thus, a facility that does not meet a DCG reference value is not necessarily out of compliance with the applicable limits (i.e., the limits of applicable Orders, standards, and regulations). Conversely, a facility meeting a DCG reference value is not necessarily in compliance with the applicable limits.

Derived Concentration Guides (DCGs) are the concentrations of a radionuclide in air or water that, under conditions of continuous exposure for one year by one exposure mode (e.g., ingestion of water, submersion in air, or inhalation), would result in an effective dose equivalent equal to the annual dose limit applicable to the group exposed.

As Low As Reasonably Achievable (ALARA) refers to an approach to radiation protection for controlling or managing exposures (both individual and collective to the work force and the general public) and releases of radioactive material to the environment, so that the levels are as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations. As used in this manual, ALARA is not a dose limit but rather a process, the objective of which is to attain dose levels as far below the applicable compliance limits as is reasonably achievable.

A process stream is a flow of liquid waste from a process that may need treatment or control before it is released to the environment. Thus, the contaminant concentration levels for a process liquid stream are those present before treatment or control measures are applied.

A treated process stream is a flow of liquid waste to be discharged to the environment from a process after treatment or control measures have been applied. Thus, the contaminant concentration levels for a treated process stream are those present after treatment or control measures have been applied but before the stream is released to the environment.

1.4 BATREC, THE ALARA PROCESS, AND BEST MANAGEMENT PRACTICE

The DOE standards for contaminants in liquid effluent discharges are driven by DOE's ALARA policy, with the objective of minimizing, to the extent practicable, doses to the public and contamination in the environment. The Department has produced interim guidance on application of the ALARA process to environmental protection for compliance with the Directives.[(a)]

The BATREC selection process is derived from the ALARA process and may be considered to be a subset thereof. The principal difference between the ALARA process and the BATREC selection process is that the ALARA process includes consideration of actual and potential doses to the public or the environment, whereas the BATREC selection process considers the source term, but not potential radiation exposures from the source. A BATREC analysis typically examines the activity concentration of a liquid process stream (source term) before and after a treatment technology is applied, as a basis for selecting the BATREC.

Implementation of the BATREC analysis process is required whenever the annual average concentration at the point of discharge exceeds DCG-based levels established in DOE 5400.5 [page II-8, paragraph 3a(2)]. However, the ALARA provisions of the Directives apply regardless of the discharge concentration. The ALARA provisions may be considered to encompass the requirements for BATREC analysis. A BATREC analysis may be included as part of a broader-scope ALARA evaluation and even as part of an environmental dose assessment that examines compliance with the primary dose limit or media-specific dose limits. Figure 1.1 shows the relationship of BATREC analysis to the dose limits and ALARA provisions of the Directives.

(a) "DOE Guidance on the Procedures in Applying the ALARA Process for Compliance with DOE 5400.5," March 8, 1991, attachment to: Raymond F. Pelletier, "Guidance for Implementation of ALARA Requirements for Compliance with DOE 5400 Series Orders: For Interim Use and Comment," DOE memorandum dated March 14, 1991.

Order DOE 5400.5 & 10 CFR Part 834	
Primary Dose Limit • 100 mrem EDE	**Apply to All Facility Operations and Radioactive Liquid Effluents**
Medium-Specific Limits • Public Drinking Water Systems (EPA) - (4 mrem/yr organ, WB) • DOE Drinking Water Systems - (4 mrem/yr EDE) • Sedimentation Limit - (5 pCi/g alpha, 50 pCi/g beta) • Native Animal Aquatic Organism Dose - (1 rad/day)	
ALARA Process	
Best Available Technology for Radioactive Effluent Control (BATREC)	**Applies in Special Circumstances:** • Approaching Limits • Exceeding Specific Guidelines: i. Surface Water > 1 DCG ii. Active Soil Column iii. Sanitary Sewerage > 5 DCG

FIGURE 1.1. The Role of BATREC in the Directives

DOE also recommends that, as a best management practice, the BATREC selection process be applied in several other situations. These situations, which typically occur only for surface-water discharges, are as follows:[a]

1. When liquid discharge is a major contributor (i.e., 40% of the dose), and

   - the total annual effective dose equivalent (EDE) to any member of the public exceeds 10 mrem (0.1 mSv), or

   - the annual collective dose exceeds 100 person-rem EDE (1 person-Sv),

2. When a facility's radionuclide discharges have significant potential to cause downstream water treatment facilities to exceed the radionuclide drinking water Maximum Contaminant Levels in 40 CFR Part 141 (National Primary Drinking Water Regulations).

An important exemption to the use of the BATREC selection process involves the presence of tritium in liquid waste streams. The Directives recognize that there is no practical treatment method for removal of low concentrations of tritium. They do, however, require that process alternatives be reviewed to ensure that tritium releases are ALARA.

1.5 DOCUMENTATION AND AUDITABILITY OF EVALUATION OF BATREC

The entire process of BATREC evaluation must be documented. Documentation should begin at the first step of the process and be finalized on completion of the last step. The format and general content of the required documentation are discussed in Section 6.0. It is important that records be kept regarding each BATREC evaluation, to be used in future BATREC determinations, to assist other field offices in their BATREC determinations, and to provide auditable records that will both defend the environmental compliance actions taken for each facility and meet applicable DOE quality assurance (QA) requirements.

(a) Pelletier, R. F. 1992. Implementation Guidance for DOE 5400.5, Section II.3 ("Management and Control of Radioactive Materials in Liquid Discharges and Phaseout of Soil Columns"), attachment to DOE memorandum dated June 17, 1992 from Raymond F. Pelletier to Distribution, "Guidance regarding water protection elements of DOE 5400.5."

Quality assurance procedures should be employed from the beginning to shape the decision process and to prevent unsubstantiated conclusions or unacceptable lapses in support materials. The QA process is a tool that should be employed to support "best engineering judgments" and other professional decisions.

2.0 GENERAL EVALUATION PROCESS FOR BATREC

The review process for determining BATREC involves characterizing the source (i.e., the process that produces the liquid effluent and radioactive constituents); identifying and examining candidate control technologies to control that source, including the existing control technology (i.e., the no-action alternative); evaluating the potential impacts of each candidate technology and accepting or rejecting them for further evaluation, using a defined set of evaluation parameters; organizing the results of the examination of each technology option in a matrix format and selecting BAT on the basis of the evaluation matrix; and documenting the evaluation. Throughout the process, technical analysis and best professional judgment are required. Figure 2.1 is a diagram showing the flow of information and the general process for evaluating BATREC.

2.1 APPLYING BATREC

The BATREC evaluation process may be initiated by several mechanisms. A BATREC analysis may be required for discharges to surface water, soil columns, or sanitary sewers. Screening criteria for determining when BATREC analysis is required for discharges to surface water and sanitary sewers are based on the DCGs in DOE 5400.5. A BATREC analysis should also be considered when any of the DCG limits are even approached. For the purposes of this manual, approaching a specific limit is defined as follows: 40% of the allowable dose to a member of the public from all exposure pathways (page II-1, paragraph 1a), where liquid effluent pathways contribute a significant fraction ($\geq$40%) of the total dose; 40% of the limit on sedimentation [page II-8, paragraph 3a(4)]; or 40% of the allowable dose to native aquatic organisms [page II-8, paragraph 3a(5)]. Furthermore, a BATREC analysis should be considered when the collective dose approaches 100 person-rem and the liquid effluent exposure pathways contribute a significant fraction ($\geq$40%). A BATREC analysis may also be

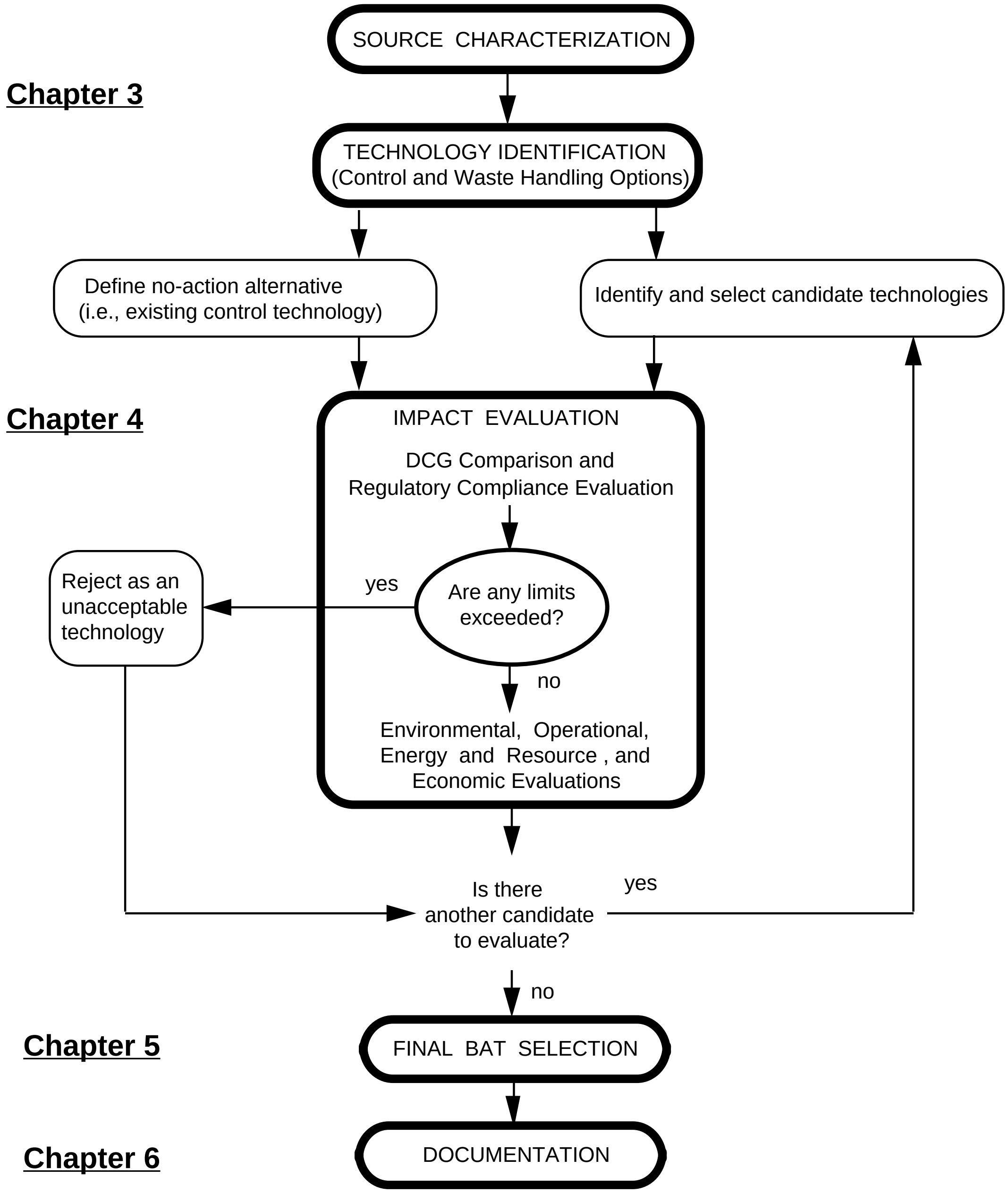

FIGURE 2.1. General Evaluation Process for BAT

performed as part of a routine, periodic ALARA evaluation of a site or facility, as discussed above in Section 1.4.

2.2 THE BATREC ANALYSIS PROCESS

Step 1 in the process of evaluating BATREC is to characterize the source. It is necessary first to become familar with the facility operations, to understand the process and operational parameters and how radionuclides enter the process stream. This helps in defining the source limitations and understanding the contaminants that need to be controlled and their levels in the process stream. A well-characterized radioactive effluent source is a fundamental part of the BATREC analysis, but guidance on the actual characterization of the source is outside the scope of this manual. Because source information is necessary before potential control technologies can be identified, Chapter 3 contains a brief description of the types of information needed.

Step 2 is to identify available technologies for controlling the process stream, including the existing control technology (i.e., the no-action alternative). These control technology options should be identified and selected for further evaluation based on their appropriateness for controlling the source characterized in the first step. This second step includes defining and understanding any control systems for the source already in use. The identification and selection of new technology options are discussed in Chapter 3.

Step 3 is to evaluate the environmental, socioeconomic, operational, and energy and resource impacts of each control technology. Initially, each control technology is examined to see whether it merits further consideration. The estimated effluent concentration resulting from application of each technology option (including the existing control technology) is compared with the appropriate DCG value(s). This provides a basis on which to examine differences among technology options with respect to their ability to reduce concentrations of contaminants in the treated process streams. After this comparison, the regulatory environmental compliance aspects of each technology option are evaluated to determine whether each option can control effluent concentrations to meet applicable regulatory limits. These limits are mainly those in the Directives and 40 CFR Part 141 (National Primary Drinking Water Regulations), but other Federal, State, and local regulations may also apply. The initial environmental compliance evaluation involves making realistic dose estimates using appropriate models and computer codes for all applicable exposure pathways and comparing the results to applicable regulatory limits. If the technology under review does not meet regulatory limits, it must be rejected and excluded from further consideration. If the candidate technology meets regulatory limits, the environmental, economic, operational, energy, and resource evaluations are conducted. The process for evaluating the impacts of each identified control technology option is described in detail in Chapter 4.

Step 4 in the process of the BAT evaluation is to develop a matrix of evaluation parameters and, ultimately, to select the BATREC. The matrix can usually best be developed progressively, during the various stages of the impact evaluation, as each technology option is considered. Then, using the matrix, BATREC for the system can be selected. Matrix development and the process of selecting BATREC are discussed in Chapter 5.

Step 5 is to document the entire BATREC evaluation and selection process. Guidelines for documentation are provided in Chapter 6.

3.0 CONTROL TECHNOLOGY IDENTIFICATION AND SELECTION

This chapter provides information on identifying and selecting control technologies that can be evaluated as candidates in the BATREC evaluation process. Section 3.1 briefly discusses the types of source characterization information that are necessary before control technology options can be considered. Section 3.2 provides guidance on selecting candidate technologies and determining whether they are appropriate for inclusion in the evaluation process. Section 3.3 provides general information on the control technologies available for process effluent stream treatment; Section 3.4 addresses the waste-disposal needs that must be considered in evaluating any candidate control technology. Figure 3.1 shows how technology identification and selection fit into the general BATREC evaluation process.

3.1 SOURCE CHARACTERIZATION INFORMATION

Before candidate technologies are selected, information on all liquid effluent streams should be collected, including identification of constituents and their concentrations. Detailed analysis of the individual mass loading and flow of the process effluent stream is necessary. The proportions of radiological pollutants occurring as suspended solids and as dissolved solids in each liquid process effluent stream must be known for appropriate removal technologies to be selected. Priority pollutants, which include the 129 toxic substances specified by the EPA, should be treated by BAT before being discharged to surface waters. However, the presence of conventional nonradiological pollutants, including total organic carbon, pH, oil/grease, and suspended solids, can affect operation of treatment systems.

Although this manual focuses on technologies directed toward radiological pollutants, the technologies that will be used to handle the nonradiological component of the effluent must also be considered in selecting the overall best technology as the BATREC for the process. Knowing the volume of the process effluent stream is

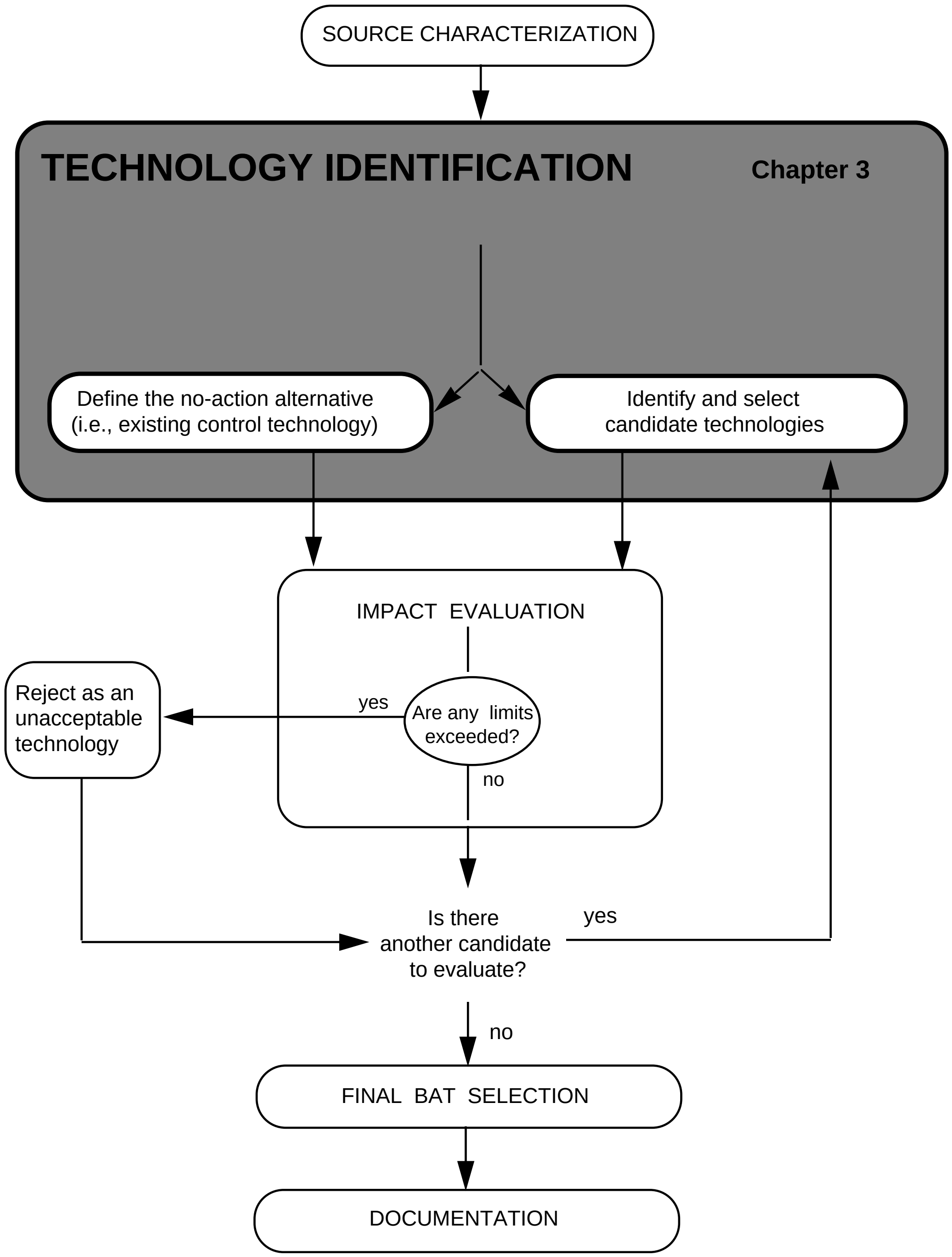

FIGURE 3.1. Control Technology Identification/Selection Process

important for determining the size of the treatment system. Some waste streams can be combined for centralized treatment. However, where different liquid wastes are combined prior to discharge, a number of technologies may have to be combined in a treatment train. Flow equalization canaffect the operability and efficiency of treatment systems. Table 3.1 provides an example of the kinds of water quality data needed before a technology can be selected.

TABLE 3.1. Example Water Quality Data

General Criteria	Cations	Trace Metals	Anions	Organics	Spectra and Radionuclides
Flow[a]	Aluminum	Lead	Sulfate	Acid/Base	Gamma
pH	Sodium	Calcium	Chloride	Neutral extractable organics	spectrum
Total suspended solids	Silicon	Chromium	Nitrate		Tritium
	Calcium	Barium	Fluoride		^{129}I
Silt index[b]	Magnesium	Mercury			^{90}Sr
Total dis-solved solids	Potassium	Silver		Volatile organics	^{137}Cs
Alkalinity					^{106}Ru
Temperature					^{99}Tc
Oil/grease					^{238}U
Total organic carbon					TRU[c]
Gross alpha					
Gross beta					

(a) Includes daily average and observed minimum and maximum flows.
(b) Functional test that is often specified for membrane technologies.
(c) Transuranics.

3.2 TECHNOLOGY SELECTION

This section discusses the methods used in the technology selection process. It provides guidance on how to identify candidate technologies for inclusion in the overall process of BATREC selection.

What types of control technology systems should be considered in the BATREC selection process is highly dependent on the information gathered during source characterization. Experience with comparable process effluent streams is incorporated in reviewing relevant effluent guidelines, existing full-scale treatment systems, and similar treatment trends and treatability studies.

Information on full-scale treatment systems operating on similar waste streams is used to select candidate technologies. If existing technologies cannot be transferred, then treatability studies are used to broaden the range of technology considered. If even these comparisons do not provide defensible candidate technologies, candidate technologies may be identified from examination of generic treatment systems. In some cases, the selection of BATREC may involve a combination of technology transfer, treatability studies, and consideration of generic treatment systems.

3.2.1 Selection Based on Technology Transfer Considerations

Selecting candidate technologies by means of technology transfer involves identifying treatment systems used on process effluent streams that are similar to the stream of interest. If the streams are essentially identical, it is likely that similar control technologies will achieve similar control efficiencies. Thus the data describing control technology performance should be based on the removal of pollutants that are identical or chemically similar. The performance data should also pertain to the treatability of liquid wastes containing approximately the same pollutant concentrations. Compositional differences, variability in pollutant concentrations, and differences in waste discharge volumes should be noted. If composition, concentrations, or flow differ significantly, technology transfer may not be appropriate.

Candidate treatment systems are most likely to be found at facilities that generate process streams as a result of similar processes. Therefore, treatment systems at DOE facilities nationwide should be reviewed to identify any controlled streams that are sufficiently similar to support use of the technology transfer method.

Technologies used at other types of nuclear facilities, EPA effluent guidance documents, treatability manuals, and vendor information should also be reviewed to determine potentially applicable treatment technologies. Two standards that provide technical guidance in selecting technologies are 40 CFR Part 423 (Steam Electric Power Generating) and 40 CFR Part 440 (Ore Mining and Dressing). These standards address conventional and priority pollutants only. Radiological pollutants are typically placed in the nonconventional category by EPA. Therefore, when reviewing EPA and other guidance documents and treatability manuals, it should be kept in mind that the radiological pollutants present in DOE process streams can preclude use of the technologies used by similar industries on streams not involving radiological pollutants. See Chapter 8 (Technology Bibliography) for a list of references offering further information.

3.2.2 Selection Based on Treatability Study Considerations

The treatability study method for selecting candidate technologies uses information from treatability studies to broaden the range of applicability. This method for selecting candidate technologies should be used when the treatment technology is well established on similar process streams, but when technology transfer does not provide defensible candidates for BAT determination. For effectively assessing the treatability of liquid wastes, treatability data should document the removal of pollutants that are identical, or at least chemically similar. Treatability studies have been conducted on a number of industrial process streams, and treatability studies conducted by other DOE facilities, the nuclear power industry, and the steam electric industry should be examined. Detailed information is needed for comparing treatment system influent characteristics and projected removal performance. Bench-scale tests can confirm the removal efficiencies reported from candidate treatment systems for particular pollutants.

However, larger-scale tests may also be needed to eliminate uncertainties due to scale-up factors.

3.2.3 Selection Based on Generic Treatment Systems

The generic treatment system approach to selecting candidate technologies provides a method that can be used to select control alternatives when relevant data on controls for similar process streams are not available. This approach examines alternative treatment systems in which additional control steps are implemented as required by site-specific conditions. A progressive approach is taken in determining the level of treatment required, until the desired level of reduction in liquid effluent concentrations is achieved. A typical progression of control steps would examine source controls, pre-treatment, suspended solids removal, and finally one or more stages of dissolved solids removal, as shown in Figure 3.2. However, treatment steps may be considered in any order, or any combination of treatment steps may be used to achieve the desired level of control.

Applicable technologies for source control, suspended solids removal, and dissolved solids removal are discussed in Section 3.3, with emphasis on the removal of radionuclides. Pretreatment may involve such steps as flow equalization, pH adjustment, or temperature control. A flow diagram including applicable technologies for a generic treatment system is shown in Figure 3.3.

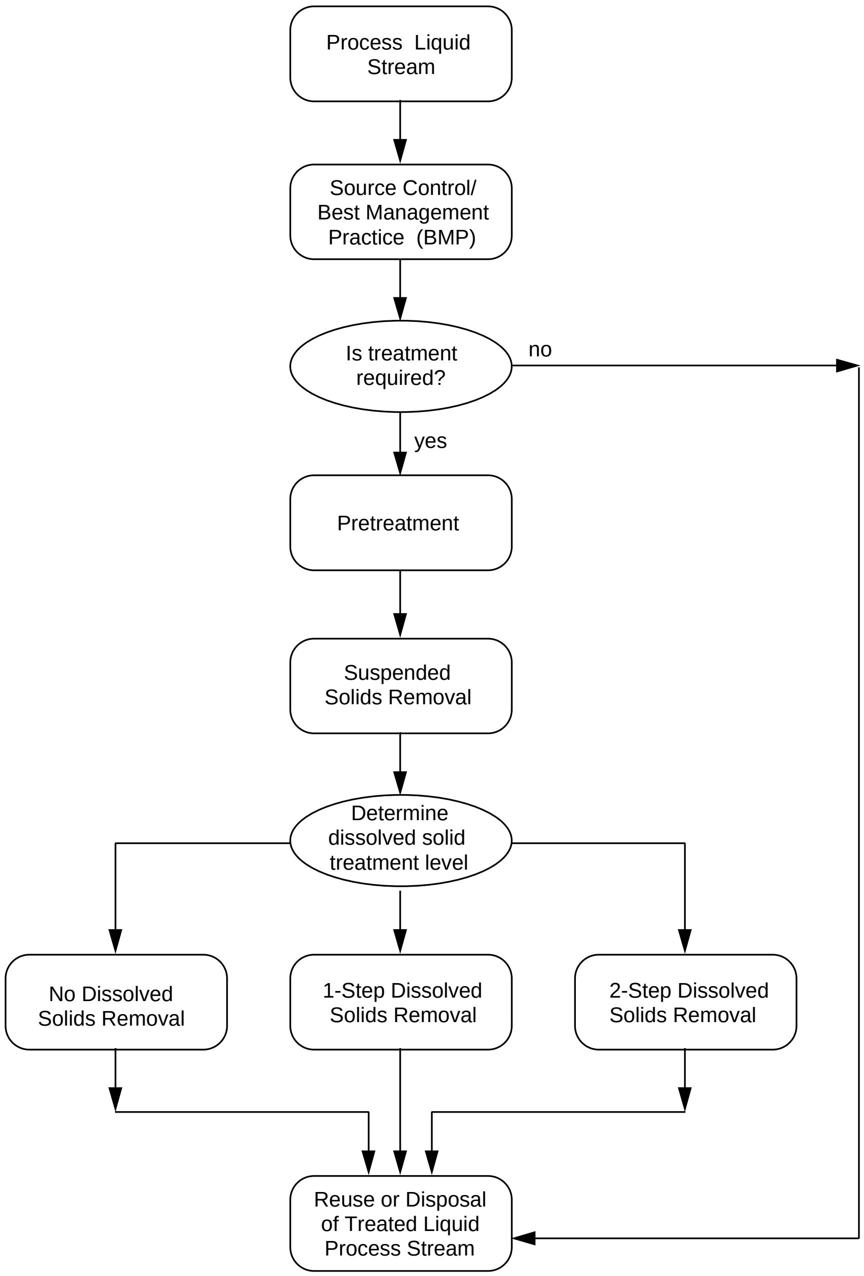

FIGURE 3.2. Selecting Candidate Technologies Using the Generic Treatment System Approach

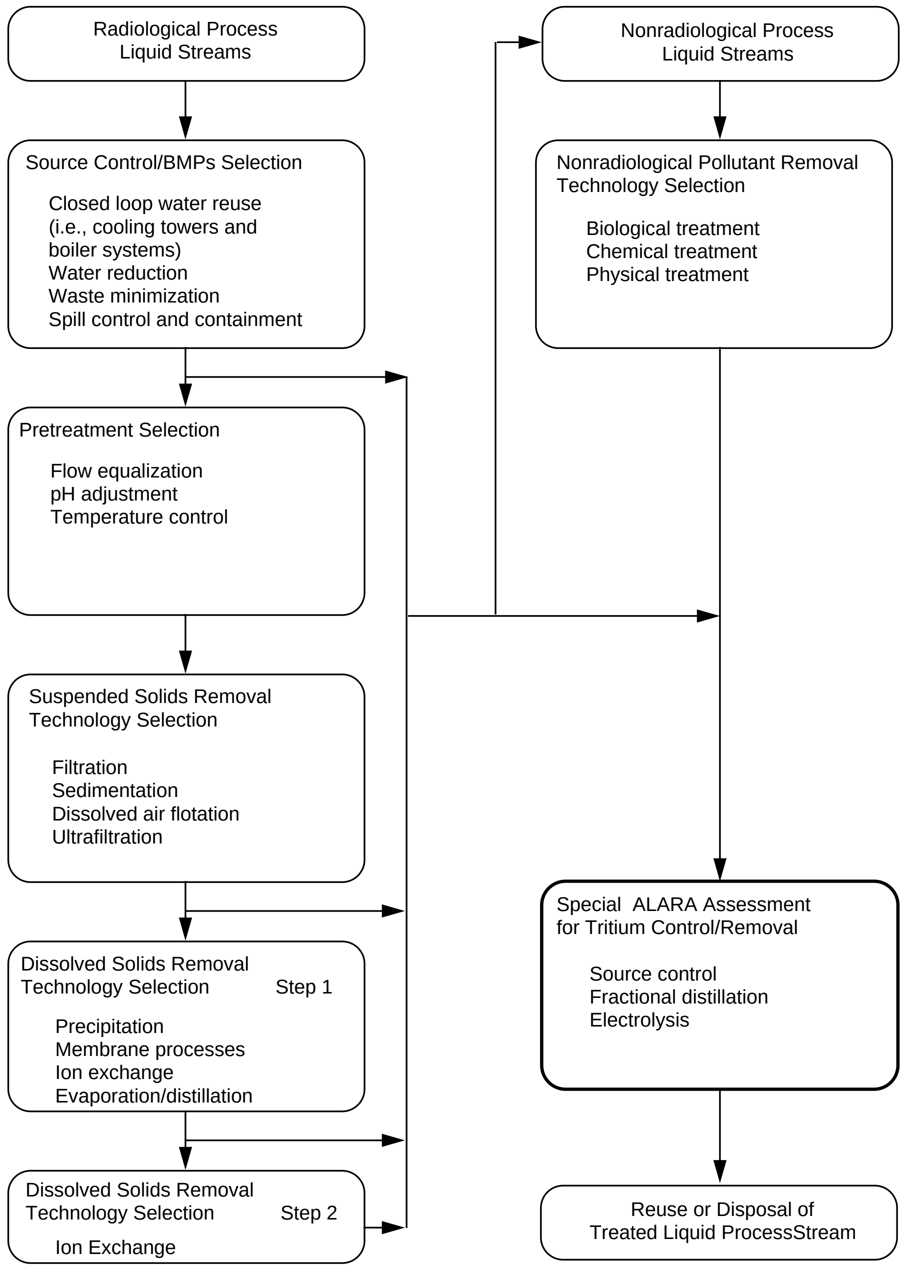

FIGURE 3.3. Applicable Technologies to be Considered in a Generic Treatment System

3.2.4 Selection of Candidate Technologies

An initial coarse screening of the identified treatment systems should be performed to identify which technologies will be strong contenders for BAT. Criteria that should be met include acceptable levels of treated effluent quality and process safety. It is also desirable that the candidates meet the criteria of least cost, reliability, efficiency and flexibility of operation, ease of maintenance, minimum impact on worker exposure, minimum impact on operations, minimum technology development, and minimum generation of secondary waste. Bench-scale testing of proposed treatment technologies can be used to evaluate alternatives. An assessment of the performance of generic treatment systems and of approximate (order-of-magnitude) costs is useful to reduce the number of treatment alternatives to be considered. More detailed evaluation of the strongest BAT contenders is performed as part of the impact evaluation (Chapter 4).

3.3 TECHNOLOGIES FOR PROCESS STREAM CONTROLS

Technologies currently employed for process stream treatment fit into the following general categories: source controls (process design and control), suspended solids removal, and dissolved solids removal. Source controls include in-plant modifications (e.g., water reuse), improved process control, spill control and containment, and other waste-minimization techniques. Applicable technologies for suspended solids treatment include filtration, sedimentation, centrifugation, and flotation. Technologies for dissolved solids removal include chemical precipitation, ion exchange, reverse osmosis, electrodialysis, hyperfiltration, and evaporation/distillation. These technologies are briefly discussed in the following sections, with emphasis on their applicability to radioactive contaminants, to provide information to be used in identifying and selecting appropriate control technologies.

3.3.1 Source Controls (Process Design and Control)

Source controls and process improvements, including improved equipment, are important means of controlling pollutant discharges. Source controls reduce chemical and radiological pollutant loads on the process streams and may provide better operational controls for preventing spills. Process design and control practices are actions or procedures used to prevent or minimize the potential release of pollutants to the environment. These practices include spill prevention, containment, mitigation, and cleanup techniques for potential discharges of pollutants of concern.

Source-control technologies include segregation of contaminated streams from uncontaminated streams, control and containment of chemical spills, and techniques for maintaining waste volume. Leakage detection and corrective action programs are important waste-containment measures. Administrative means for waste minimization include process control, restriction of materials brought into radiological controlled areas, and worker education about proper waste management.

In-plant modifications that provide source control include recycling (reuse of water in a closed loop), cascade waste-water reuse, and reduction of water use. Closed-loop recycling means using the effluent discharged at one point as influent for the same use. This process may increase concentrations of suspended and dissolved solids. Closed-loop water systems require close examination of water chemistry as well as improved operating and maintenance practices for successful operation. Cascade water reuse takes the effluent from one stream and uses it as influent at another water use point. Water use reduction techniques include water flow restriction devices and meters to prevent unnecessary water use.

3.3.2 Technologies for Suspended Solids Removal

For purposes of this report, technologies for suspended solids removal are defined as those that are effective for solids with a particle size greater than about 0.5 micron. Examples of technologies for removing suspended solids are shown in Figure 3.4. Filtration alone may be sufficient to reduce radionuclides to concentration levels acceptable for discharge. It is often necessary to remove nonradiological pollutants first, to prevent interference with or damage to radiological pollutant removal equipment.

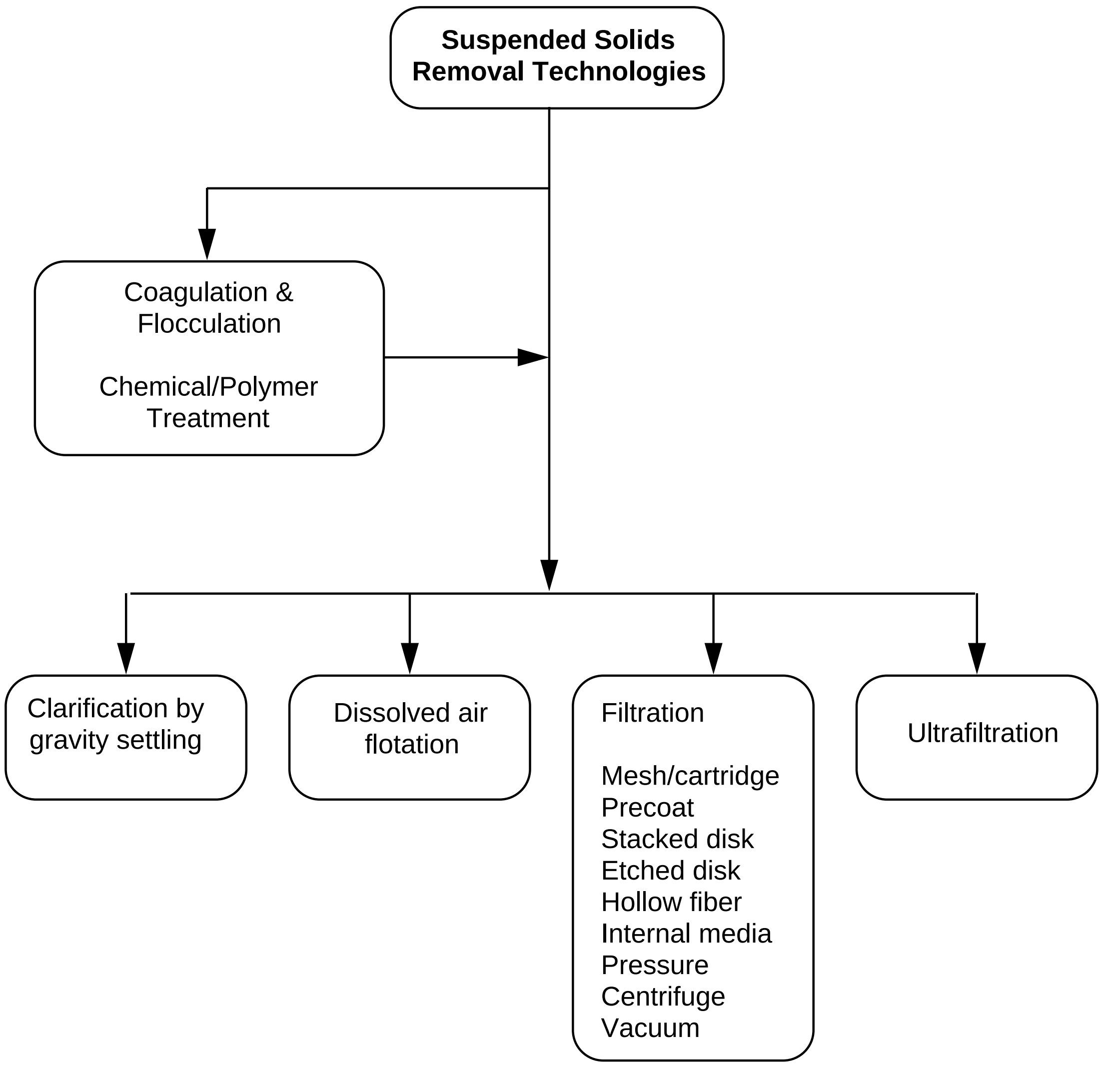

FIGURE 3.4. Examples of Technologies for Suspended Solids Removal Applicable to Treatment of Liquid Low-Level Radioactive Waste

Filtration

Filtration is a well-developed liquid/solid separation process currently applied to full-scale treatment of many industrial waste waters and sludges. Filtration is a physical process in which particles suspended in a fluid are separated by forcing the fluid through a porous medium. As the fluid passes through the medium, the suspended particles are trapped on the surface or within the body of the medium. Filter media are generally permeable barriers of various materials, such as filter cloth, sand, or diatomaceous earth. The pressure differential used to move the fluid through the medium can be induced by gravity, positive pressure, or vacuum. As a waste-water treatment process, filtration usually follows some form of flocculation or sedimentation process.

Cake, depth, and surface filtration are the more common filtration processes. Cake filtration involves separating solids from the aqueous phase by passing the liquid through a porous filter medium, such as a cloth filter. The process creates a thick cake of material on the cloth. When the operating pressure of the system increases significantly as a result of cake buildup, the medium must be cleaned, backwashed, or replaced. The concentrated waste is then disposed of. In depth filtration, a bed of porous material serves as the filtration medium. A process stream passes through the filter, where the solid particles become trapped within pore spaces. When the differential pressure rises to a specified control level, the filter must be replaced or backwashed so that it returns to its original porosity. In surface filtration, the liquid is strained as in cake filtration, but the filter becomes clogged at a much higher rate.

Filter types include cartridge, precoated, stacked disk, etched disk, and hollow-fiber filters. Stacked disk filters appear to be a more efficient removal technology than precoated filters. Progress is being made to improve filter precoats and body feeds. The addition of polyelectrolytes and polymers can greatly improve the performance of precoated filters by increasing their removal efficiencies.

Filtration can be used to remove both radioactive and nonradioactive suspended solids. The technology can remove radionuclides that have lower solubilities, that tend to absorb to suspended particles, or that can be coprecipitated with other cations.

Multimedia filter beds typically have not been used for radioactive process streams because the resulting large volumes of backwash water must be treated as secondary waste.

Precipitation, Flocculation, and Sedimentation

These processes are discussed together because they are commonly used as consecutive treatments. Precipitation is a physical process involving a chemical reaction in which dissolved substances are converted to small or colloidal insoluble solids. Flocculation transforms small suspended particles into larger suspended particles that can more easily be removed from solution. Sedimentation removes the suspended particles from the liquid by gravity settling. To be feasible, a precipitation process requires that the process stream have a fairly uniform composition and concentration of contaminants. Hydroxide system precipitation can be used to remove a significant number of soluble metal ions, including many heavy metals. Precipitation reactions are not typically used for radionuclide removal because of the variable composition of the process streams and the difficulties in handling the waste-water sludges.

Centrifugation

This mechanical means of separating suspended solids has been used for solids removal following a precipitation reaction to concentrate radionuclides. Centrifugation is a process in which the components of a fluid mixture are separated mechanically by rapidly rotating the mass of fluid within a rigid vessel. Centrifugal forces cause particles that are denser than the fluid to migrate to the periphery of the rotating vessel. Types and configurations of centrifuges are tubular, disk, conveyor bowl, batch, conical basket, and pusher centrifuges. Centrifugation is not normally considered as an option for new systems for streams with high solid concentrations because its performance is poor compared to that of filtration processes.

Flotation

Flotation is a physicochemical method carried out in a wet environment to concentrate fine particles. The flotation process involves chemical treatment of a slurry to create conditions favorable for the attachment of selected particles to air bubbles formed therein. The air bubbles carry the selected particles to the surface of the slurry and form a stabilized froth that is skimmed off.

3.3.3 Technologies for Dissolved Solids Removal

Technologies for removing dissolved solids include carbon adsorption, ion exchange, membrane separation processes (reverse osmosis, electrodialysis, hyper-filtration), and evaporation/distillation.

The treatment technologies applied to process streams with high concentrations of dissolved solids differ from those applied to streams with low concentrations of dissolved solids. Examples of technologies for removing total dissolved solids are shown in Figure 3.5. The treatment of liquid streams with high concentrations of dis-solved solids involves the removal of the dissolved solids or concentrated contaminants with a concentrator before the process stream is passed through a demineralizer, which is suitable for streams with low total dissolved solids. A concentrator, such as a reverse osmosis unit, is expensive, but the cost benefits realized through the demineralizer system, such as longer ion exchange resin life and volume reduction, can outweigh the expense.

Carbon Adsorption

This process removes compounds from a liquid by accumulating them on the sur-face of activated carbon. Attractive forces that predominate at the carbon surface are the basis for the contaminant removal. The porous carbon provides a surface area of

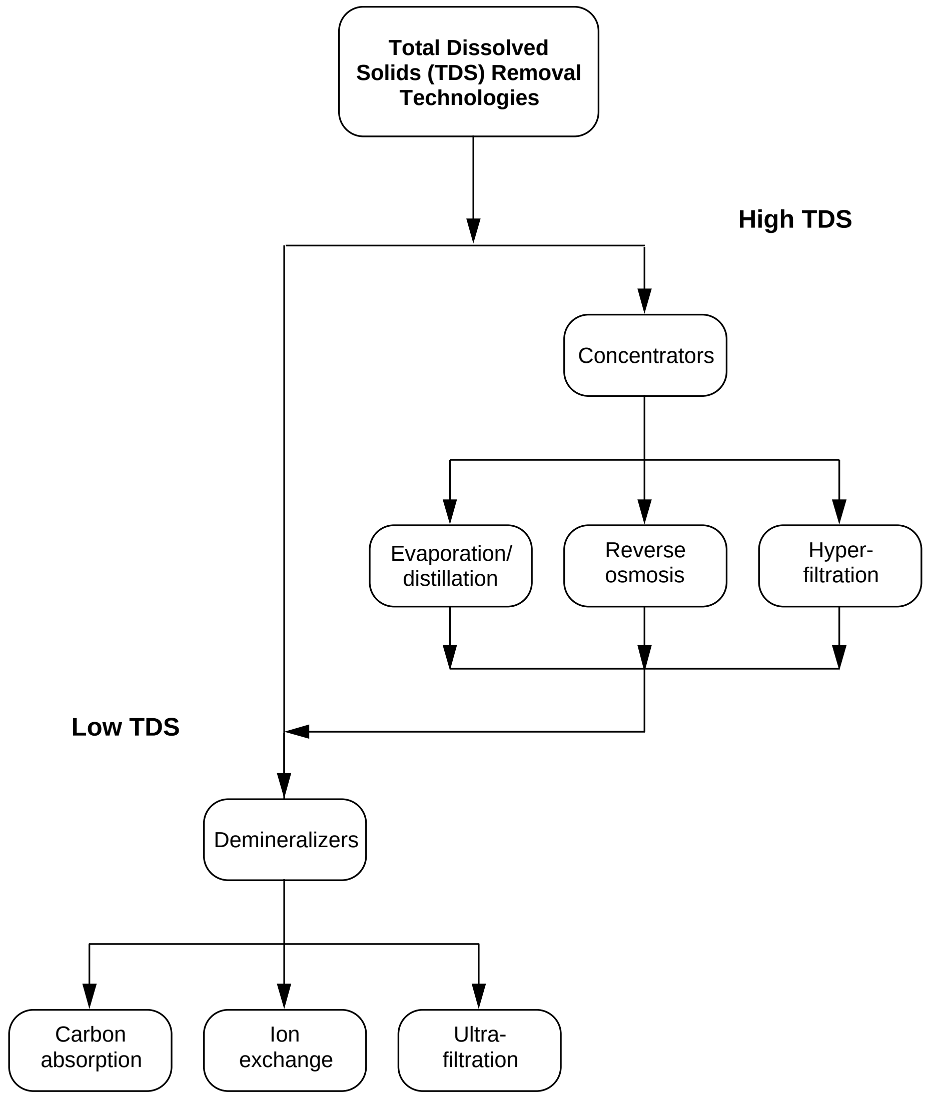

FIGURE 3.5. Examples of Technologies for Dissolved Solids Removal Applicable to Treatment of Liquid Low-Level Radioactive Waste

500 to 1500 m^2/g of adsorbent. Carbon absorption is generally used for removing organics; however, it is also capable of removing some inorganics. Larger amounts of organics can be removed using multistage reactors. Adsorption can be either a batch or a continuous process. The continuous processes most commonly used are down-flow or up-flow fixed beds, although fluidized beds are used occasionally.

Activated carbon can be thermally regenerated at temperatures of 800° to 950°C by oxidation with steam, CO, or O_2. Swing adsorbers are used to allow regeneration of one bed without interruption of the liquid flow. Such contaminants as cobalt and cesium can be removed successfully by carbon adsorption. In addition, materials that have relatively low solubility in water or have large molecules exhibit good adsorption rates [e.g., polychlorinated biphenyls (PCBs)].

Ion Exchange

The resins used for ion exchange are solid matrices with bound ions of one charge and loosely held ions of the opposite charge. Exchange continues until all of the loosely held ions have been displaced. The loaded resins can be either disposed of or chemically regenerated with an excess solution of the original ion. The removed ions will be at much higher concentrations in the regenerant wastes than in the influent, and so the wastes must be treated further or solidified for disposal. Fixed beds are the usual mode for ion exchange; however, ion exchange may also be applied in a batch mode (equilibrium stage operations). Operations can be cyclical, with in-place regeneration of the resin. A system with replacement modules might also be desirable.

The sorption efficiencies of ion exchange resins are continually being improved. In many applications, a pollutant ion will be present in small amounts with large amounts of a relatively innocuous ion of the same or higher valence state. Therefore, ion-selective resins are being developed for removal of specific radionuclides and other pollutants. Ion-selective resins offer the potential to greatly reduce the costs of liquid radioactive waste treatment. Ion exchange is applicable for such contaminants as cobalt, strontium, cesium, plutonium, and uranium. Ion exchange can also be used for removal of soluble metallic elements, inorganic anions, and carboxylic and sulfonic acids.

Membrane Separation Technologies

These technologies, including dialysis, electrodialysis, reverse osmosis, and ultrafiltration, require equipment that has 1) a barrier that preferentially transfers certain components of a fluid mixture through a membrane and 2) a driving force to cause the transfer to occur. Table 3.2 lists the processes, the functions of the membrane, and the types of driving force used in each. Membranes are typically manufactured from cellulose or synthetic polymer compounds. These materials generally have good transfer rates, suitable mechanical strength and durability, resistance to chemical degradation, and low cost.

TABLE 3.2. Membrane Separation Processes and Principal Driving Forces

Process	Function of Membranes	Principal Driving Force
Reverse osmosis	Transports water selectively	Pressure
Ultrafiltration	Discriminates on the basis of molecular size, shape, and flexibility	Pressure
Electrodialysis	Transports ions selectively	Electrical potential
Dialysis	Transports solutes selectively	Concentration
Gel permeation chromatography	Retards penetration by high-molecular-weight solute	Concentration
Liquid permeation	Transports liquids selectively	Concentration

Electrodialysis is used to transfer an ionic species from one stream of liquid through a semipermeable membrane into another stream of liquid under the influence of an applied electrical potential. The process depends on special synthetic membranes that are permeable to a single type of ion. Reverse osmosis has applicability for metal ions, low-molecular-weight organic contaminants, strontium, cobalt, and cesium. Ultrafiltration has applicability for high-molecular-weight inorganic and organic contaminants, uranium, and plutonium.

Hyperfiltration is able to remove smaller particles than ultrafiltration. Like reverse osmosis, hyperfiltration is a membrane process, but its design is radically different. A hyperfiltration unit consists of a porous stainless steel tube that has a membrane applied to its interior surface. Feed water is pumped through the interior of the tube, forcing a clean permeate through the pipe wall while the concentrate remains inside.

Evaporation and Distillation

These processes involve heating the process stream to produce a vapor phase. In evaporation, the vapor is usually a single component; if it is a mixture, no attempt is made to separate the vapor into fractions. In distillation, separation is a primary goal.

Evaporation processes can be classified as indirect, direct contact, or natural, depending on the heating medium. Most industrial evaporators employ indirect, tubular heat-transfer surfaces. Evaporation methods are more effective for heavier contaminants, such as cesium, uranium, and plutonium. Fractional distillation is effective for tritium removal.

3.4 WASTE DISPOSAL NEEDS ASSOCIATED WITH EFFLUENT CONTROLS

Although technology applications that reduce the volumes and hazards associated with process streams should be included in an evaluation of BATREC, and changes in process technology that eliminate a process stream or treatment options that destroy the hazardous component are preferable, for many DOE facilities, such BATREC choices may not be available. Thus, selection and implementation of a particular BATREC may result in the production of a concentrated waste requiring disposal. The examination of each candidate control technology is not complete until the waste disposal needs resulting from use of that technology are assessed.

For many concentrated wastes, containerized, near-surface burial may be the most practicable disposal technology. Depending on applicable regulations and potential post-closure hazards, a number of design requirements would have to be met, including ground-water monitoring, leachate collection, and elimination of liquids from waste containers, for near-surface burial to be an acceptable method of disposal.

Evaluations of BATREC must consider the costs, impacts, and feasibility of providing for such disposal (plus storage and transportation as appropriate). These attributes can be identified by means of a two-step process involving determination of the waste classification and identification of the disposal facility or technology. The following discussion of this process is only a summary. It is recommended that the investigator or evaluation team consult individuals with expertise in current waste disposal regulations.

The regulatory agency authorities and requirements associated with disposal of DOE wastes are determined according to waste classification, as are DOE's requirements.[a] In addition to those already mentioned, other requirements for near-surface disposal include barriers to water infiltration [e.g., Resource Conservation and Recovery Act (RCRA) barriers] and structural stability of the waste form or container (to minimize trench subsidence).

Although definitions for radioactive waste classification vary from state to state, the following classes are generally applicable:

- Low-Level Radioactive Waste (LLW) includes any waste stream that is moderately contaminated with radionuclides, such that near-surface disposal is not precluded as a disposal option. Low-level radioactive waste is defined in the Low-Level Radioactive Waste Policy Act of 1980, as amended, as radioactive material that

(a) DOE's requirements are provided to field offices and contractors by means of DOE Orders (e.g., DOE 5820.2A, Radioactive Waste Management, September 26, 1988).

(a) is not high-level radioactive waste, spent nuclear fuel, or by-product material [as defined in section 11e(2) of the Atomic Energy Act of 1954], and that

(b) is classified as LLW by the U.S. Nuclear Regulatory Commission (NRC), consistent with existing law and in accordance with (a).

Department of Energy is responsible for regulating its LLW disposal operations, which must be carried out in accordance with general standards of the EPA (Environmental Standards for the Management, Storage, and Land Disposal of Low-Level Radioactive Waste and Naturally Occurring and Accelerator-Produced Radioactive Waste, which will be promulgated at 40 CFR Part 193).

- High-Level Radioactive Waste (HLW) includes any waste stream that is sufficiently contaminated to require deep geologic disposal. Pursuant to the Nuclear Waste Policy Act of 1982, as amended, this waste class includes

  (a) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and

  (b) other highly radioactive material that the NRC, consistent with existing law, determines by rule to require permanent isolation.

  Regulation of repository disposal is provided by NRC (10 CFR Part 60, Disposal of High-Level Radioactive Wastes in Geological Repositories), in accordance with EPA's general standards (40 CFR Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes).

- Transuranic Waste (TRU Waste) includes any waste stream that is moderately contaminated with transuranic elements at concentrations greater than 100 nCi/g. Such waste generally is required to be stored for subsequent disposal, possibly in the Waste Isolation Pilot Plant in New Mexico.

  Transuranic waste storage and disposal are regulated by DOE, in accordance with EPA's general standards (40 CFR Part 191).

- Mixed Waste (MW) includes any radioactive waste stream that is also contaminated with hazardous wastes (i.e., nonradioactive hazardous chemical constituents) as defined in

EPA regulations (pursuant to the Resource Conservation and Recovery Act) or State regulations (pursuant to applicable State law). Although near-surface burial in permitted facilities is generally an acceptable disposal mechanism (when other treatment or destruction is not feasible and the waste is in solid form), certain hazardous wastes may not be disposed of at these facilities. The EPA (40 CFR Parts 260-280, On Hazardous Waste Management) and/or the applicable State agency (per its regulation) regulate the disposal of the hazardous waste component of mixed-waste streams.

Although this manual principally deals with selection of BATREC for radioactively contaminated process streams, processing modifications or treatment technologies considered as part of the BATREC evaluation could generate hazardous waste streams (as defined by EPA or State regulations) that are not contaminated with radioactive constituents. Such a condition would require consideration of the handling of the hazardous waste when selecting BATREC for the process.

Waste handling and disposal needs are briefly discussed in this manual to draw the investigator's attention to the need for considering the costs, impacts, and feasibility of handling and disposal of the waste when deciding on the BATREC.

4.0 EVALUATING THE POTENTIAL IMPACT OF SELECTED TECHNOLOGIES

Evaluating the potential impacts of a candidate control technology is a major portion of the BATREC evaluation process. As Figure 4.1 shows, the impact evaluation is the most detailed step of the general BATREC evaluation process. It is the only step that explicitly calls for a decision on the suitability of various candidate technologies before the final selection process. If the candidate technology can pass the preliminary impact evaluation (Section 4.1), evaluation of additional environmental (Section 4.3), operational (Section 4.4), energy and resource (Section 4.5), and economic (Section 4.6) impacts is necessary. The results of these impact evaluations are recorded in a series of matrices like those shown in Appendix B and provide the basis for completing the final technology selection matrix described in Chapter 5.

4.1 PRELIMINARY IMPACT EVALUATION

A candidate control technology may be eliminated from further consideration (and further impact evaluation) during a preliminary round of impact evaluation. Like the coarse screening process for candidate control technologies described in Chapter 3, this preliminary evaluation serves to eliminate those technologies that are readily identifiable as being inadequate. A candidate control technology is eliminated if it is determined that liquid effluent streams from that technology cannot meet the derived concentration guides of DOE 5400.5, or if any applicable regulatory limits cannot be met by implementing the technology. Any candidate technology that is not eliminated during this two-part preliminary evaluation must undergo more detailed evaluation in specific areas of potential impact.

4.1.1 Comparison with Derived Concentration Guides (DCGs)

The DCGs are reference values for conducting radiological environmental protection programs at operational DOE facilities and sites. They are presented for each of three exposure modes - ingestion of water, submersion in air, and inhalation.

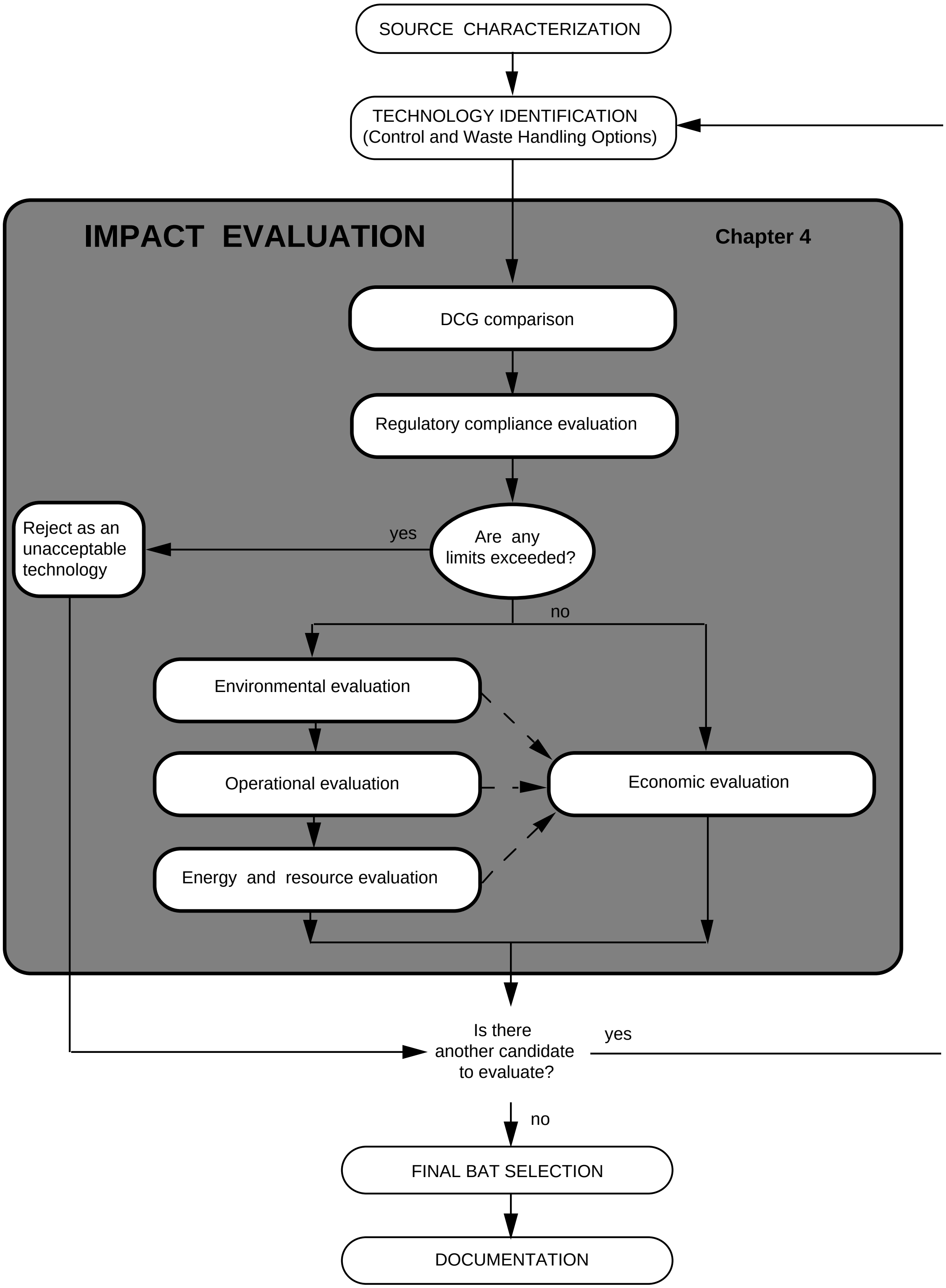

FIGURE 4.1. Evaluating Potential Impacts in the BAT Evaluation Process

The DCGs are applied assuming continuous exposure to a single one of the potential exposure modes, with a resultant dose of 100 mrem committed effective dose equivalent. The intent is that the DCGs serve as screening concentrations for reviewing routine operations to determine whether further investigation is needed. Thus, the DCGs can be used as a baseline for comparing the relative effluent concentrations between candidate technologies. The DCG values for radionuclides are listed in DOE 5400.5, Chapter III.

The preliminary evaluation uses the DCGs for ingested water as initial screening levels for determining acceptability of a control technology. All constituent radionuclides of the liquid effluent stream must be considered in this evaluation. For discharges to surface waters, the Directives state that further treatment is not normally required if discharge concentrations are less than the DCG reference values at the point of discharge to a surface waterway or soil column. The discharge concentrations to surface water or soil columns are calculated as the annual arithmetic average of constituent radionuclide concentrations (i.e., average for the most recent calendar year) for comparison with DCG screening values. For discharges to sanitary sewerage systems, further treatment is not normally required when discharge concentrations are less than five times the DCG reference values at the point of discharge. These discharge concentrations are calculated as the monthly arithmetic average of constituent radionuclide concentrations. For discharges containing more than one radionuclide, the fractional DCG values for all of the radionuclides present should be summed for both annual and monthly calculations. For determining concentrations of contaminants in a process stream, this manual assumes that unplanned releases of contaminants are included with routine releases. However, field office managers may decide not to include documented unplanned releases in the BAT evaluation process.

4.1.2 Regulatory Compliance Analysis

Each candidate technology should be evaluated for compliance with all applicable regulations and requirements. Any candidate that fails to meet regulatory requirements must be rejected. The analysis should consider compliance with regulatory requirements for both radiological and nonradiological contaminants. The analysis for radiological contaminants should be based on dose modeling (over all exposure pathways) and take into consideration public and occupational exposures, including those associated with transportation and waste disposal. This analysis should include the requirements of DOE 5400.5 [including its supportive regulatory guide (DOE 1991)] and other legally applicable requirements for all affected media and waste forms (e.g., DOE 5820.2A; 40 CFR Parts 61, 125, 141, 191, 192, and 260-280; and 10 CFR Parts 60 and 72), and 10 CFR Part 834 and any applicable implementation guides. Analytical methods and dose modeling should be conducted in accordance with the Directives and other applicable procedural requirements. The analysis for nonradiological contaminants should consider the effect of new or increased concentrations of nonradiological constituents in the liquid effluent stream.

If not enough information is available to adequately evaluate a candidate technology during the preliminary evaluation, the technology may be considered for detailed evaluation. During the detailed evaluation, special precautions should be taken to gather information and perform an analysis (including dose modeling considering all pathways) to make sure that use of the technology results in full compliance with all applicable requirements.

4.2 DETAILED EVALUATIONS OF POTENTIAL IMPACTS

Detailed evaluations are begun for candidate technologies that have not been rejected as unacceptable in the preliminary evaluation. The objective of these detailed evaluations is to determine which of the candidate technologies is the optimum one for the site-specific application being considered. Specifically, the Directives require that, at a minimum, the following factors be considered:

- the age of equipment and facilities involved
- the process employed
- the engineering aspects of the applications of various types of control techniques

- process changes
- the cost of achieving effluent reduction
- non-water-quality environmental impacts (including energy requirements)
- safety considerations
- public policy considerations.

These factors are included in the four areas of detailed impact evaluation described in Sections 4.3 through 4.6: environmental, operational, energy and resource, and economic. The factors listed above and in the sections that follow are not the only ones that may be considered in the evaluation process. Each site or facility is responsible for determining what factors should be considered in its own site-specific BATREC analyses and for determining the extent of the evaluation.

An intermediate result of evaluating candidate technology impacts is the identification of specific impact issues for which all candidate technologies will be evaluated in making the final BATREC selection. These issues are one of the bases of the technology issues matrix used in Chapter 5 to determine the final BATREC selection. The identification of issues is an iterative process, beginning with the existing control technology. As additional control technologies are identified and evaluated, additional impact issues may also be identified. Each previously identified candidate technology must then be reevaluated for each of the newly identified issue categories.

For those issues that are not rejected as insignificant, a comparative analysis should be conducted. In evaluating existing facilities, the existing control technology (no-action alternative) should be considered as the baseline, and candidate technologies should be compared with it. The criteria in Table 4.1, combined with best professional judgment, should be used to assign "value factors" to each issue category for each candidate technology, after the estimate or issue has been thoroughly examined as to technical feasibility, sensitivity, parties involved, and level of concern. Since a candidate technology may be either better or worse than the existing no-action alternative for a specific issue, the no-action alternative is assigned a value (5) in the center of the range (0-10) of value factors. The analysis should focus on factors that will help in evaluating the relative impacts of the alternatives, that is, on those factors that will assist in discriminating among the candidate technologies.

TABLE 4.1. General Criteria for Establishing Value Factors for Evaluating Candidate Control Technologies

Value Factor (VF)	Criteria
0	Inferior (i.e., the candidate technology is not appropriate for this issue)
1-2	Substantially deficient, definite negative effect (i.e., the candidate technology is significantly worse for this issue than the existing technology)
3-4	Slightly deficient, slight negative effect (i.e., the candidate technology is somewhat worse for this issue than the existing technology)
5	No change (i.e., the candidate technology does offer any change from the existing, baseline technology)
6-7	Minimal improvement, slight positive effect (i.e., the candidate technology improves on this issue only slightly)
8-9	Substantial improvement, definite positive effect (i.e., the candidate technology improves on the issue quite well)
10	Excellent improvement, significant positive effect (i.e., the candidate technology improves on the issue extremely well, even if it does not totally resolve the issue)

All evaluations should be as objective as is practicable. The process of BATREC selection requires the use of best professional judgment at each step, so that the BATREC evaluation can be tailored to fit site-specific conditions. Every effort should be made to be as consistent as possible when making the best professional judgments. In addition, efforts should be made to be consistent in the way best professional judgment is applied to different facilities at the DOE site and at different sites in the DOE system.

In all cases, documentation of each step in the evaluation should provide sufficient detail for independent review of the scope, methodology, and conclusions. The documentation should indicate how each issue was considered and, if appropriate, should briefly describe the reasons for not performing a detailed analysis. For example, further analysis of impacts on land use may be eliminated if none of the alternatives would alter current land use.

With adequate justification and documentation, the detailed evaluations may be performed addressing only significant radionuclides. Significant radionuclides are those radionuclides deemed to be significant contributors to dose (e.g., those radionuclides that are estimated to contribute at least 99% of the calculated dose to members of the public). The definition of significant radionuclides is applicable after the candidate technology has been applied; that is, it includes only those radionuclides that remain in liquid effluent discharges after treatment. This allows any minor radionuclides identified in the preliminary DCG comparison to be eliminated from further consideration.

When completed, the evaluations of issues should be summarized in a format that permits ready comparison among the candidate technologies. The summary should compare all of the alternative technologies and the no-action alternative for each impact issues, using the value factors described above. An example of a summary table is shown in Figure 4.2. This summary information is fundamental to the final BATREC selection described in Chapter 5.

4.3 ENVIRONMENTAL ISSUES

Potential environmental impacts of the candidate technologies must be considered in evaluating the alternatives. The analysis should focus on aspects of the environment that may be affected by the liquid effluent discharge, but it should also examine other types of environmental impacts. Because the purpose of this analysis is

Issue Identified for Evaluation	No-Action Alternative VFs (VF=5)	Option 1 VFs	Option 2 VFs	Option 3 VFs
Significant Nuclides				
Reference DCGs				
Example Environmental Issues				
Comparison to DCGs	5			
Regulatory Compliance	5			
Accumulated Quantity	5			
Dose Contribution	5			
Example Operational Issues				
Public Policy	5			
Safety	5			
Process Changes	5			
Engineering Aspects	5			
Example Energy and Resource Issues				
Energy Use	5			
Land Use	5			
Scarce Commodity Use	5			
	5			
Example Economic Issues (uses economic Figure-of-Merit for evaluation)				
Capital Investment				
Interim Capital Cost				
Operating Cost				
Decommissioning Cost				

FIGURE 4.2. Example for Summarizing the Comparison of Impacts among the No-Action Alternative and Candidate Control Technology Options

to help select the BATREC, the analysis should seek to discriminate among the alternative technologies. Consequently, those environmental issues that are expected to differ among the technologies should be emphasized.

Best professional judgment should be applied in planning the evaluation of environmental impact, using guidance provided in Section 4.2.

Principal factors to be considered in the environmental analysis are differences among candidate technologies in impacts on ground water, surface water, soils, aquatic or marine ecosystems, and threatened and endangered species or candidate species in these ecosystems. Ambient air quality and terrestrial ecosystems should also be considered. The evaluation should include the generation and ultimate disposal of all types of waste and should not be limited to consideration of impacts of the effluent discharge alone. The impact on the environment near the operating facility should be emphasized. However, consideration may also have to be given to the environment of the waste disposal site and to the environment associated with any transport of wastes.

Examples of environmental issues that should be included in the evaluation of candidate technologies are listed below. The detailed environmental evaluation includes evaluation of discharge concentrations relative to DCGs and regulatory compliance analysis performed as part of the preliminary evaluation described in Section 4.1.

Environmental Issues

- Concentration of Significant Radionuclides at Discharge - The concentration of each significant radionuclide in the treated liquid stream should be considered. These concentrations were determined and compared to the reference DCG as part of the preliminary evaluation.

- Accumulated Activity - The known or estimated total activity of each significant radionuclide accumulated in soils, sediments, and sludges should be listed. Evaluation of the activity accumulated provides for consideration of widespread, low-level contamination and possible long-term build-up in soils, sediments, and sludges. The accumulation of each radionuclide should be projected over the estimated lifetime of the facility. The accumulated quantities should include accumulation in soils (for soil column discharges that meet discharge limits to surface water or that may have contaminants that tend to build up in the soil), sediments (for discharges to surface waters), and sludges (for discharges to sewerage systems).

- Total Annual Discharge of Contaminants - The total quantity or activity of pollutants discharged annually in liquid effluent should be considered. This may be an important decision factor in cases in which both radiological and nonradiological contaminants are discharged.

- Dose Contribution - The results of any radiological dose calculations should be considered, including those for potential dose to members of the public and dose to native aquatic organisms.

- Waste Generation and Disposal - Types, forms, and quantities of waste generated and associated ultimate disposal issues, including waste transportation, should be addressed.

- Other Environmental Issues - Any other outstanding issues related to environmental impact should be addressed, in addition to those directly associated with concentrations of radionuclides in the effluent stream, accumulated quantities of radionuclides, and radiological dose. Among the issues that could be listed are those involving release of different nonradiological process or treatment chemicals to the liquid effluent stream. Such issues as socioeconomic and public policy impacts may be considered insofar as they relate directly to environmental issues. However, such issues as land use and use of resources should be considered under energy and resource impacts (Section 4.6).

4.4 OPERATIONAL ISSUES

Operational issues are those other than environmental and regulatory ones that affect the daily operations of the process facility and associated liquid effluent treatment systems. Of the eight factors specifically mentioned in Section 4.2 for consideration in BATREC selection, six fall within the category of operational impacts. These factors are the age of equipment and facilities involved, the process employed, engineering aspects of the application of various types of control techniques, process changes, safety considerations, and public policy considerations. Other issues that may also be of concern are the availability and ease of maintenance of the equipment, changes in throughput, alteration of process flow streams, operational safety, occupational exposure, and impacts on program mission.

Operational issues for the near term can be divided into two general categories: 1) issues that determine the cost of operating the technology and 2) issues that determine how well the technology fulfills its functional requirements. Other operational issues are relevant for the long term. These include the ability of the technology to permit reassurance to the public about concerns with the facility, to adapt to expected changes in future functional requirements, such as expanded or reduced processing needs (i.e., mission changes) while still satisfying the overall objectives of the facility, to incorporate personnel safety considerations, and to allow for upgrading to include future improvements in the technology.

This section is intended to assist the reader in considering the important operational issues relevant to the technology being evaluated. It is expected that these issues will also affect economic feasibility, energy and resource issues, and other areas.

4.4.1 Cost and Performance

The following near-term issues related to cost and performance should be considered when evaluating process stream control technologies:

- Existing Facility Constraints - Each candidate technology for treating process streams at facilities should be reviewed to determine facility constraints that would negatively impact or perhaps preclude implementation. For example, existing facility constraints may include limited space, inability to reconfigure buildings, and incompatibility between existing technology and the candidate treatment technologies.

- Throughput Capability - For each process stream, the throughput capability of the technology should be quantified, and the technology's ability to meet functional design requirements should be assessed. This assessment should take into account the reliability, availability, and maintainability of the system.

- Equipment Maintenance Needs and Available Support - An approximate schedule for preventive maintenance and repair for the technology should be planned. The purpose of this effort is to assist in identifying 1) the maintenance cost for the technology and 2) the maintenance support required in terms of personnel, spare components, and maintenance contracts. This information should include information about servicing of filtration systems, and so on, to serve as input into the routine occupational dose assessment.

- Expected Equipment Availability and Reliability - In many cases, the technology being evaluated will be part of a larger system. Therefore, each candidate technology should be characterized in terms of its expected availability and reliability. This will help to ensure that the availability and reliability of the entire system is not significantly reduced, if and when the technology is implemented.

- Resources Required to Operate - Requirements for operating personnel should be reviewed and quantified. This information supports the economic analysis discussed in Section 4.6.

- Human Factors and Training Considerations - The role of human factors in the operation and maintenance of candidate technologies should be reviewed. This review should include analysis of the tasks required to be performed by operators and maintenance staff and consideration of whether the technologies are designed to minimize both human error and the results of such errors if they occur (i.e., considerations of operational safety). The results of this analysis should be incorporated into the evaluations of availability, reliability, safety, and throughput capability. The human factors review will also support an analysis of training requirements by assessing the difficulty of operations and maintenance tasks. Both initial and continuing training requirements should be determined, including the number of workers in various categories who must be trained, the amount of training time required, the necessary qualifications of instructors, and the availability of training programs and material.

4.4.2 Long-Term Technology Effectiveness

The following factors regarding the long-term effectiveness of the technology should be reviewed:

- Response to Public Policy Issues Associated with the Facility - Public policy issues are associated with the public perception of the facility for which the effluent control systems are being applied. Concerns of the public may be over either identified or perceived contamination control problems. In either case, the issues are real and should be addressed.

  The reviewer should identify and list each significant public policy issue (if any exist) associated with the facility. Candidate technologies and the no-action alternative can be compared relative to how well each technology satisfies individual public policy issues.

- Flexibility of Technology to Adapt to Changing Mission - The term "changing mission" refers to changes in facility operations that could cause changes in the composition of the process stream, throughput, and other areas that could in turn affect the technology being evaluated. Potential mission changes (if any) should be reviewed, and the ability of the treatment technology to fulfill these potential missions should be considered. This effort could be accomplished by devising scenarios for expected future system functional requirements and evaluating each technology for each scenario. In addition, each candidate technology should be examined to see whether it would alter the facility in such a way as to adversely affect the current mission of the facility. If so, the situation should be examined to determine whether such alteration is acceptable.

- Ability of Technology to Satisfy Personnel Safety Considerations - The operational aspects of each candidate technology and the no-action alternative should be examined to determine whether there will be any associated operational safety problems. Any resulting safety issues should be listed in the issues matrix so that they can be considered when selecting the BAT for the facility.

- Flexibility of Technology to Accommodate Advances in Technology - Information regarding technology trends and expected developments should be reviewed, and the ability of each candidate technology to incorporate expected improvements should be considered. This information could not only reflect the effectiveness of selected candidate technologies but also preclude implementation of a technology doomed to premature obsolescence.

Operational impact issues other than those concerning public policy and safety should also be addressed so that they can be considered when selecting the BAT for a facility.

4.5 ENERGY AND RESOURCE ISSUES

Energy consumption and use of limited or scarce resources are impacts that must be considered as part of the BAT impact analysis process.

4.5.1 Energy Usage

As an attribute affecting BAT evaluation, energy usage may influence technology selection in two ways. The first is in energy costs. Cost estimates (see Section 4.6) should include the costs of energy associated with operating different technologies. Thus those options that have high operating costs because of their increased energy requirements are identified.

The second way in which energy usage should be considered in BATREC evaluations concerns energy conservation, particularly with respect to strategic fuels (e.g., coal, natural gas, and oil).[a] For example, technology options that make extensive use of strategic fuels should be separately identified (in addition to being indicated by the cost parameter). Although a candidate that makes such use of strategic fuels may still be the technology of choice, it is important that the decision-maker consider this point explicitly. If candidates are otherwise equivalent, the technology that makes less use of strategic fuel or that has lower energy requirements would be preferable.

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a DOE's requirements with respect to energy conservation are contained within DOE 6430.1A, Design Criteria for DOE Facilities, Chapter 13, "Energy Conservation."

Any energy-conservation issues related to a specific candidate technology, including the no-action alternative, should be evaluated so that they can be considered when selecting the BAT for the facility.

4.5.2 Resource Usage

As was the case for energy usage, the cost of the resources that would be used should be considered in evaluating candidate technologies. This cost should be included as part of the economic impact analysis (Section 4.6).

Resource commitments, including irreversible commitments of resources (except for those considered under energy usage) should be evaluated. These include direct or indirect resource commitments, such as use of precious metals in effluent removal technology, or use of scarce commodities or services that may impact other operations onsite or in surrounding communities. Other potential resource impacts that may be considered are land use and land planning issues, and possible socioeconomic effects of uses of specific resources. Positive effects, such as recovery and recycling of materials or chemicals, should also be considered.

4.6 ECONOMIC FEASIBILITY ISSUES

The economic feasibility of the candidate technologies is another area to be considered in the evaluations for BATREC. Unlike the other categories of potential impacts, economic merits are evaluated using economic "figures-of-merit." Economic figures-of-merit are constructed from projections of the cash flows associated with constructing and operating a control system, and they help determine the economic feasibility of the control technology under consideration. Calculational details of this method are given in Appendix A.

The method requires that the candidate technologies be characterized in sufficient detail to allow capital and operating costs to be determined accurately enough to reveal real differences among the competing technologies. The performance analysis must also be detailed enough that the required inputs can be generated with a reasonable level of accuracy. This method requires the consideration of general project information (process annual production rate and radionuclide removal rate), general economic assumptions (real escalation rates for capital equipment and operating costs), and estimates of project costs.

The basis of the economic analysis is the calculation of annual cash flows for four categories of costs: initial (construction and start-up) capital costs, subsequent interim (annual) capital costs, operation and maintenance costs, and decommissioning costs. A final calculation, for net present value, is a combination of all previous cash flow calculations. Four different economic figures-of-merit may be calculated from this information and used for the economic analysis portion of technology comparison. These are the net present value, the annualized cost, the levelized life-cycle cost of radionuclide removal, and the levelized life-cycle cost per unit of throughput.

A check list for capital costs is provided in Section 4.6.1; Section 4.6.2 has a similar check list for annual operation and maintenance costs, and Section 4.6.3 includes a check list for decommissioning costs. These check lists are not exhaustive but rather are intended to help the user gather the necessary cost information. Information and equations to assist in calculating the annual cash flows and the figures-of-merit are described in detail in Appendix A.

4.6.1 Determination of Capital Costs

Initial capital costs are any costs that occur only at the beginning of the project, during construction and facility start-up. Interim capital costs may occur at any time during the life of the facility. They are typically associated with major modifications or process improvements, and they occur infrequently. The Department of Energy requires that a "betterments" provision be met for improvements or modifications to be classified as capital expense: 1) the total cost of modification must be at least 20% of the initial cost and 2) the modification must extend the useful life of the facility.

In the following list for identifying capital costs, capital cost headings are followed by examples in each category

- Facilities
  - Buildings containing process equipment
  - Support facilities (e.g., test, maintenance, inspection)
  - Storage facilities for containment and treatment of waste
  - Facilities for packaging waste for transport and disposal

- Equipment
  - Filtration system
  - Reverse osmosis system
  - Ion exchange units
  - Pretreatment units (e.g., pH adjustment, temperature control)
  - Concentrator (e.g., membranes, evaporation/distillation)
  - Heat exchangers
  - Storage tanks
  - Surge tanks
  - Monitoring and sampling equipment

- Original Complement
  - Low-cost items required to initially outfit the facility for use by occupants; life of the items must be greater than the current accounting period (i.e., fiscal year) and their aggregate cost must exceed $100,000

- Other Capital Costs
  - Engineering
  - Design
  - Design-support activities (e.g., permit preparation and regulatory compliance evaluation)
  - Initial set-up and testing
  - Document preparation (in some circumstances).

4.6.2 Determination of Operation and Maintenance (O&M) Costs

Operation and maintenance costs are regularly occurring costs that can be estimated on an annual basis. Such costs are generally for labor and materials; however, other annual costs such as increased downtime are also included. Changes in O&M labor costs should be carefully considered. Increased labor costs can generally be attributed to one of three factors: 1) increases in the number of operating or maintenance hours required by the technology, 2) increases in labor rates for operators or maintenance personnel (reflecting a need for more skilled personnel), or 3) a decrease in the labor hours available from each worker because of increases in exposure.

Major O&M cost headings are followed by examples of the costs that fit in each category:

- Routine Operations
  - Operating procedures
  - Waste storage and handling
  - Waste disposal and transportation
  - Dose monitoring
  - Monitoring and sampling BAT system
  - Inspection and testing

- Maintenance
  - Additional facilities
  - Increased requirements for current facilities as a result of modification
  - Equipment for BATREC
  - Test, inspection, monitoring, and sampling equipment
  - Utility systems

- Utilities (cost changes due to increased requirements--per unit and demand charges)
  - Electrical
  - Other energy
  - Water

- Supplies

  - Filters
  - Chemicals
  - Spare parts
  - Other materials

- Downtime

  - Unscheduled facility outages due to BAT system
  - Increased scheduled downtime

- Other O&M Costs

  - Hiring for BAT facility (e.g., recruitment, security clearance)
  - Training (new hires and refresher training)
  - Document preparation (e.g., updating procedures, training manuals)
  - Annual administrative, regulatory, and other reporting requirements.

4.6.3 Determination of Decommissioning Costs

At the end of the useful life of the facility, the facility and control process equipment must be decommissioned and disposed of. These costs consist primarily of labor to decontaminate the facility and disposal costs. Any potential revenue from recycle and recovery activities should be weighed against decommissioning costs.

Major decommissioning cost headings are followed by examples of the costs that fit in each category:

- Decontamination

  - System for decontamination (hand cleaning, water jet, sandblasting)
  - Wastes generated during decontamination (liquid, solid)
  - Need for onsite treatment of wastes

- Disposal

  - Disposal site costs
  - Nature of material to be disposed of (e.g., radionuclides present, activity levels)
  - Classification of waste (low-level, TRU, mixed)
  - Transportation costs (e.g., need for shielded casks)
  - Storage costs for wastes with no disposal options.

4.6.4 Figures-of-Merit

The figures-of-merit for the existing, no-action alternative and for each candidate technology should be entered into the cost-effect table described in Chapter 5. The reviewer has the choice of using the net present value, the real annualized cost, the levelized life-cycle cost of radionuclide removal, or the levelized life-cycle cost per unit of throughput; however, the same figure-of-merit must be used consistently so that the costs of the candidate technologies and the no-action alternative are comparable.

5.0 SELECTION OF BATREC

A number of factors are involved in selecting a technology that constitutes the BATREC, and many of these factors are site- and facility-dependent. A selection system for determining BATREC must utilize the best professional judgment of those individuals performing the evaluation. While relying on best professional judgment, the process for final BATREC selection also provides a structured approach that encourages objective evaluation and accountability. Using information gathered in the general BATREC evaluation process, criteria are established and assigned relative levels of importance (through the use of weighting and value factors) according to site- or facility-specific considerations and professional judgment. This process is case-specific rather than generic, since each candidate technology is evaluated relative to the existing control technology for each of the issues considered. Final BATREC selection may then proceed impartially with examination of the costs and effects of each of the candidate technologies.

Final BATREC selection accounts for three steps in the general BATREC evaluation process, as shown in Figure 5.1. The first step is to assemble a matrix of technology issues and involves impartially examining the issues related to environmental, operational, and energy impacts. The second step is to assemble the economic figures-of-merit and compile the issues related to economic impacts. The third step is to perform a cost-effect analysis by compiling all of the information on technology issues (step 1) and economic feasibility issues (step 2) into a cost-effect table. The cost-effect ratio of each candidate technology is examined, and the candidate that represents the BATREC is selected.

It may be desirable to make this three-step process an iterative one, first screening out the least acceptable candidate technologies and then focusing on two or three reasonable and closely competitive candidate technologies. The details of the three steps in the selection process are discussed in the subsections that follow.

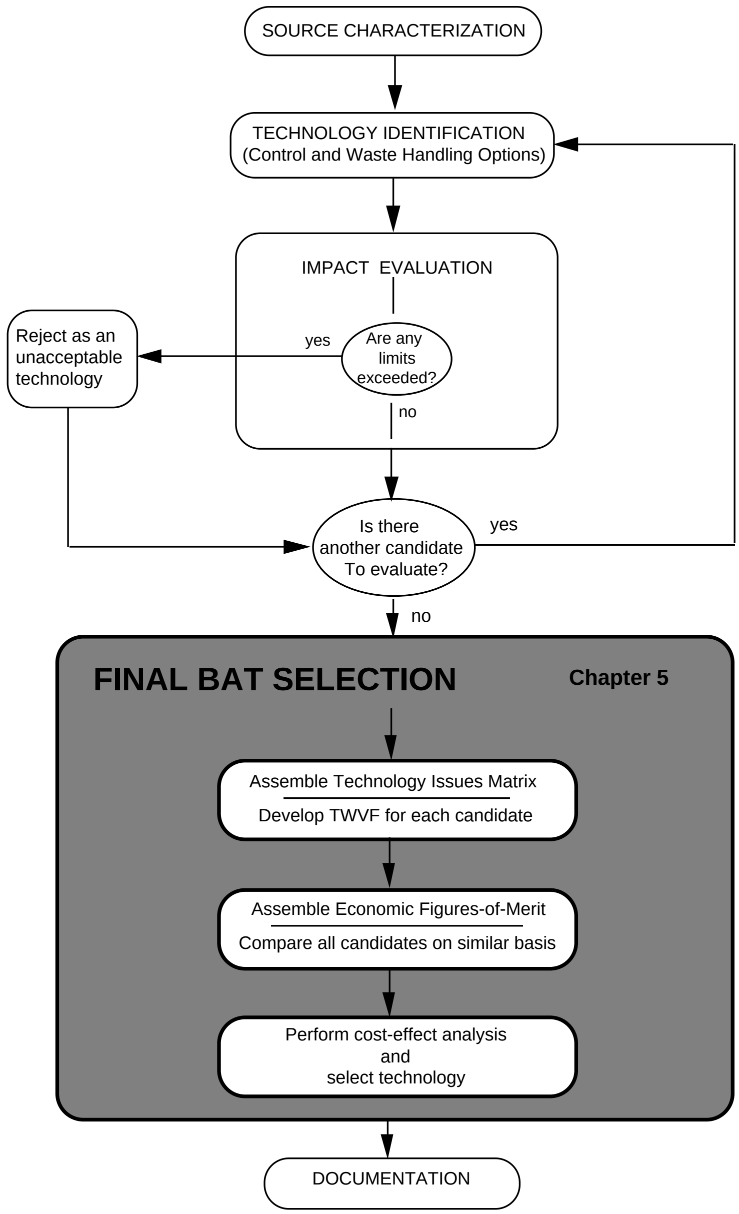

FIGURE 5.1. Final Selection Process for BAT

5.1 STEP 1: ASSEMBLE A TECHNOLOGY ISSUES MATRIX

The first step in the BATREC selection process is to assemble a technology issues matrix. This matrix provides a means for comparing and evaluating different candidate technologies on a similar basis using the same criteria. Two types of information are needed for the matrix. The first information needed is gathered from the evaluations of environmental, operational, and energy and resource issues performed for each candidate technology, as described in Chapter 4. The issues identified during the evaluation process and the value factors (VF) determined for each candidate technology for each of those issues are the foundation of the matrix. It may also be useful to include information that is addressed in impact evaluations and that is common or applicable to all the technology options. This includes such information as the significant radionuclides and the applicable DCGs for these radionuclides.

The next information needed is a determination of the relative importance of each of the technology issues. A weighting factor (WF) is assigned to each issue based on that issue's relative importance compared to all other issues. The weighting factors should be kept consistent for all candidate technologies being considered for that facility. In general, they will also probably be fairly constant for all the facilities at a particular site. However, there may be reasons for them to vary between facilities at a site. The weighting factors must be established at least on the level of individual sites because the regulatory climate, local policy, and other considerations are site-specific.

Some constraints are placed on the assignment of weighting factors. The values of the weighting factors should be such that, when all are added together, they total 100, a convenience to allow the relative contribution of each issue to be easily set. Issues in the environmental impacts category must have a weighting factor total of at least 50 (i.e., environmental impacts are weighted to be at least 50% of all of the issues being considered). Within the environmental impacts category, the results of any initial calculations of radiological dose may be considered but should be lightly weighted (i.e., a weighting factor no greater than 5). An example of the assignment of weighting factors is provided in Table 5.1.

TABLE 5.1. Example Issues and Weighting Factors[a] for the Technology Issues Matrix

Issues Identified During Impact Evaluations	Weighting Factor (WF)
Environmental Issues (must total at least 50)	
Effluent discharge concentrations	20
Accumulated quantity	25
Dose contribution	5
Other environmental issues	10
Operational Issues	
Safety	10
Public policy	10
Other operational issues	5
Energy and Resources	
Resource issues	10
Energy issues	5
Total of Weighting Factors	100

(a) This is only an example of weighting factor assignments. The actual weighting factors used in the evaluation for a facility should be established on a site- or facility-specific basis.

As shown in Table 5.1, the weighting factors will differ significantly depending on which issues must be emphasized for the facility. Assigning the weighting factors is purposely delayed until the issues have been examined and assigned value factors for each candidate technology, so that the reviewer will have the best feel for which issues are more important. However, once the weighting factors are established, the same factors must be used for all of the candidate technologies to ensure that comparisons among them will be meaningful. Figure 5.2 shows a simplified example of a technology issues matrix with relationships of candidate technologies, issues, value factors, and weighting factors. More complete examples are shown in Appendix B.

Technology Issues Matrix		Existing No-Action Alternative		Option 1		Option 2		Option 3	
Significant nuclides		Pu-239 Sr-90							
	WF	VF	WVF	VF	WVF	VF	WVF	VF	WVF
Environmental Issues									
Comparison to DCGs	20	5	100	7	140	8	160	6	120
Regulatory compliance	5	5	25	7	35	8	40	5	25
Accumulated quantity	20	5	100	8	160	8	160	5	100
Dose contribution	5	5	25	7	35	8	40	5	25
Other environmental issues	5	5	25	3	15	8	40	4	20
Operational Issues									
Public policy	10	5	50	7	50	6	60	6	60
safety	10	5	50	4	20	5	50	6	60
Engineering aspects	5	5	25	4	20	6	30	7	35
Process changes and capacity	10	5	50	5	50	4	40	7	70
Energy and Resource Issues									
Energy use	5	5	25	5	25	6	30	4	20
Resource use	5	5	25	5	25	5	25	4	20
Total Weighted Value Factor (TWVF) for each option = ∑(WVF)		500		575		675		555	
VF: value factor, see Table 4.1 WVF: weighted value factor = WF x VF WF: weight factor, see Table 5.1 TWVF: sum of issue WVFs for an option									

FIGURE 5.2. Sample Technology Issues Matrix for Comparisons Between Control Technology Options

Once all value factors and weighting factors have been established and entered in the matrix, the total weighted value factor (TWVF) is calculated for each candidate technology. Examining each candidate technology individually, the value factor is multiplied by the weighting factor (a weighted value factor) for each issue. The weighted value factors for each issue are summed to produce the TWVF for that candidate technology. The equation for the TWVF is as follows:

$$TWVF_{candidate_x} = \sum_{i=1}^{n} VF_i \times WF_i$$

where x is the candidate technology under consideration and n is the total number of issues considered for each candidate.

Once the TWVFs for each of the candidate technologies have been calculated and entered on the matrix, the selection process moves to Step 2.

5.2 STEP 2: ASSEMBLE THE ECONOMIC FIGURES-OF-MERIT

The second step in the evaluation process is to organize the information associated with the cost and economic impact of each candidate technology. This information is taken from the economic impact analysis calculations discussed in Section 4.6. Figures-of-merit should be developed for each candidate technology (including the no-action alternative). The figures-of-merit for all candidate technologies should be on the same basis. That is, the same method should be used for each technology evaluation, whether the calculation is of net present value, real annualized cost, levelized life-cycle cost of radionuclide removal, or levelized life-cycle cost per unit of throughput. (These terms are defined in Appendix A, pages A.7 - A.9). The levelized life-cycle cost of radionuclide removal is the preferred method. When information for the economic figures-of-merit has been compiled for all candidate technologies, the selection process moves to Step 3.

5.3 STEP 3: FINAL COST-EFFECT ANALYSIS AND CANDIDATE SELECTION

In the final step of the selection process, the information from the first two steps is assembled and examined together, and the candidate technology that is considered to be the BATREC for the facility is selected. This step begins with compiling the TWVF results and economic figures-of-merit for each candidate technology into a single table. The candidate technologies should be listed in descending order by TWVF; that is, the technology option with the highest TWVF should be entered first. Figure 5.3 is an example cost-effect table.

When the cost-effect table is completed, each of the candidate technologies should be considered carefully, starting with the one that has the highest TWVF value (i.e., the one with the greatest positive effect). The TWVF, which contains the evaluation of environmental, operational, and energy-related issues, is the primary factor to be considered in the final BAT selection. The economic figure-of-merit (i.e., the cost or economic feasibility of the technology) should be a secondary factor in the decision-making process.

Establishing cost in evaluating BATREC, as described in this manual, is for comparative purposes. It may be difficult to establish realistic cost data, because a host of variables associated with each facility affect the cost of controlling liquid effluents.

At this point, any circumstantial limiting factors would be considered, using best professional judgment in evaluating them and weighing the positive effects against limitations. If the candidate with the highest TWVF is not chosen as the BATREC, the reasoning and justifications for rejecting it should be explained fully in the documentation.

Upon completion of this final examination of the candidates, one technology is chosen as the BATREC. To document the decision, extract all of the information pertinent to the chosen BATREC. This information should then be assembled into a brief statement describing the BATREC. Documentation requirements for the BATREC selection process are described in Chapter 6.0.

Candidate Technology	TWVF (Effect)	Figure-of-Merit (Cost)	Overall BAT Ranking
Option ___	Highest TWVF Value	$	
Option ___	Next Highest TWVF	$	
•	•	•	
•	•	•	
•	•	•	
Option ___	Lowest TWVF Value	$	

FIGURE 5.3. Example Cost-Effect Table for Final BAT Selection

6.0 DOCUMENTATION OF BATREC EVALUATION

Each step in the BATREC evaluation process must be documented. Such documentation ensures that all of the conditions, assumptions, and results of the evaluation are recorded so that the BAT evaluation can be adequately defended if necessary. In addition, the documentation would be extremely useful to BATREC evaluations on similar facilities at the site or at other sites within the DOE system.

The format and general elements to be included in documenting a BATREC evaluation are as follows:

Executive Summary

- Brief Description of Facility/Process
- Brief Description of Evaluation Process
- Brief Description of Result of Evaluation

1.0 Introduction

- Background
- Facility Description and Mission
- Discussion of Process Streams
- Discussion of Contaminants to be Controlled
- Discussion of Existing Liquid Effluent Treatment Systems
- Purpose of Evaluation

2.0 Selection of Candidate Technologies

- Discussion of Existing Conditions (No-Action Alternative)
- Discussion of Candidate Technologies Considered
- Selection of List of Candidate Technologies
- Rationale for Inclusion or Exclusion of Technologies on Candidate List

3.0 Analysis of Environmental Issues (for Each Candidate Technology)

- Contaminants and Concentrations in Discharge Streams
- Comparison with Derived Concentration Guide (DCG) Values
- Regulatory Compliance
- Environmental Issues Evaluated and Results of the Evaluation of Each Issue

4.0 Analysis of Operational Issues (for Each Candidate Technology)

- Operational Considerations Linked to Cost and Performance
- Operational Considerations Linked to Long-Term Technology Effectiveness

5.0 Analysis of Energy and Resource Issues (for Each Candidate Technology)

- Energy Use and Conservation Issues
- Resource Use and Conservation Issues

6.0 Analysis of Economic Feasibility (for Each Candidate Technology)

- Determination of Capital Costs
- Determination of Operating and Maintenance (O&M) Costs
- Determination of Decommissioning Costs
- Levelized Cost Methodology
    - Levelized Cost Assumptions
    - Project Costs and Cash Flow Calculations

- Project Economic Analysis

- Figure-of-Merit Calculations

7.0 Selection of BATREC

- Step 1: Technology Issues Matrix

- Assumptions and Significant Judgement Decisions

- Rationale for Value Factors as Assigned per Candidate Technology

- Rationale for Weighting Factors as Assigned per Matrix Issue Category

- Step 2: Economic Figures-of-Merit

- Rationale for Selection of Figures-of-Merit in the Final BATREC Selection Process

- Step 3: Final Cost-Effect Analysis and Candidate Selection

- Statement of BATREC for the Facility

- Discussion of Waste Treatment Needs/Changes Associated with Selected BATREC and Plan for Management of the Resulting Waste Streams

- Rationale Documenting the BATREC Decision

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APPENDIX A

HOW TO CALCULATE ANNUAL CASH FLOWS AND ECONOMIC FIGURES-OF-MERIT

APPENDIX A

HOW TO CALCULATE ANNUAL CASH FLOWS AND ECONOMIC FIGURES-OF-MERIT

This appendix describes how to calculate the information needed to perform the economic impact analyses for the BATREC selection process. Calculation of annual cash flow is fundamental to the economic impact analysis and is discussed in Section A.1. Annual cash flow information is used in Section A.2 to determine the economic figures-of-merit. Figures-of-merit are calculated for each candidate control technology to allow levelized comparison of candidate technology project economics. These figures-of-merit are then incorporated into the cost-effect table (Section 5.3) for final BAT selection.

A.1 COST METHODOLOGY

Annual cash flows for a proposed candidate control technology are calculated using a levelized cost methodology. Cash flow data are subsequently used to analyze the project's economic cost.

A.1.1 Levelized Cost Assumptions

The levelized cost methodology contains a number of assumptions about project cost and economics. These assumptions, designated key (unchangeable) and changeable assumptions, are discussed below.

Key Assumptions

Key assumptions are those that are intrinsic to the methodology and for which modification would be undesirable because it could render the results not comparable to those of other analyses. The following are the principal assumptions used in the levelized cost methodology.

- All cash flows are expressed in real (reference-year) dollars.
- All cash flows are assumed to occur at the end of the year.
- The base year for discounting cash flows is year 0 (the last year of construction). All cash flows occurring in year 0 are not discounted (i.e., the present value equals the cash flow), with cash flows occurring in all other years being discounted appropriately.
- The reference year is typically the current year (the year in which the analysis is being done). The reference year will have a negative value unless the construction is expected to be completed during the year in which the analysis is performed (and thus the reference year is 0). For example, if an analysis is being done in 1992 for a BATREC system that will be completely installed by 1995, the reference year is -3 (negative 3).

Changeable Assumptions

All other assumptions can be easily modified. For example, the cash flow equations presented below assume uniform real escalation relative to a reference year. A more complicated pattern of escalation can be modeled by determining each individual year's estimated real cash flow explicitly. Changeable assumptions of the methodology are

- Capital costs during construction are assumed to be split equally among the construction years. Where uniform construction pay-out is not valid, the cash flows can be determined explicitly [in real (reference-year) dollars] in each year, or an approach based on the percentage of "overnight" cash flow can be used.
- Interim capital costs are assumed to take place within a single year.
- All operating expenses will commence in year 1 and continue for the life of the project.

A.1.2 Cost Considerations

The analytical methods for calculating cash flows and present values that are used to determine economic figures-of-merit are discussed below. A number of project cash flows must be analyzed, including those for initial (construction or start-up) capital costs, interim capital costs, operating and maintenance costs, and decommissioning costs.

To maintain a frame of reference and ensure that the results from evaluations of different candidate technologies are comparable, all costs must be in terms of the same year-dollars. This does not present a problem if a new cost estimate is being prepared; however, if portions of the estimate come from older estimates, costs must be adjusted to the reference year. The method described here uses a "real dollar" method. "Real dollars" are dollars of equivalent purchasing power; general inflation is not included. "Nominal dollars" include inflation and must be adjusted to the reference year (typically the current year). Converting historical costs (nominal dollars) to reference-year dollars is easily accomplished using the following equation and the data provided in Table A.1:

$$CF_d = CF_a \left(\frac{IPD_d}{IPD_a} \right) \tag{A.1}$$

where CF_d = cash flow in reference-year dollars
CF_a = cash flow in nominal year dollars
IPD_d = implicit price deflator for reference-year dollars, Gross National Product (GNP)
IPD_a = implicit price deflator for nominal year dollars, GNP

Cash flows in future years can be estimated using real escalation rates, or by explicitly determining various cash flows. To use real escalation rates, the cash flows for the reference year are specified and then the cash flows for future years are calculated based on real annual escalation rates. To explicitly determine cash flows, the user specifies each cash flow, in real terms, for each year in which it occurred; this option is most useful for modeling fluctuating cash flows.

TABLE A.1. GNP Implicit Price Deflator (IPD)

Year	IDP	Year	IDP
1976	52.3	1986	96.9
1977	55.9	1987	100.0
1978	60.3	1988	103.8
1979	65.6	1989	108.6
1980	71.7	1990	113.3
1981	78.9	1991	117.6
1982	83.9	1992	120.9
1983	87.1	1993	123.5
1984	91.1	1994	126.1
1985	94.4		

The methodology provided here can be used in either a total cost approach (all costs considered) or a differential cost approach (only differential costs included). A differential cost approach considers only the cash flows associated with a process that has changed because new equipment or procedures have been incorporated. The cost of investing in a BAT project would normally be calculated by means of a differential cost approach.

Initial Capital Costs

Capital costs include all costs incurred over the construction period. This includes equipment (including installation cost), spare parts, and initial supplies (e.g., filters, chemicals). Although most BAT systems could probably be installed in one year or less, any real cost escalation during construction is accounted for in the methodology.

Interim Capital Costs

Some BAT systems will have additional capital costs during operations, when equipment must be replaced during the project. Interim capital costs must be expressed in terms of the reference year's price level; the methodology accounts for real price escalation between the reference year and the year that the replacement occurs.

Operation and Maintenance Costs

Operation and maintenance expenses, such as those for electricity, fuel, maintenance labor, and maintenance materials, must be included in the economic evaluation. Operation and maintenance costs are expressed in the reference-year dollars, and real escalation rates applicable to each cost are used to calculate the real-dollar O&M cash flows in each year of the project's operating life. As an alternative to assuming uniform real escalation of O&M costs, each year's O&M expense may also be determined explicitly.

Decommissioning Costs

Decommissioning costs represent the net cost associated with removing the BAT system after its useful life. Because much of the equipment will have to be decontaminated before it can be either used again onsite or sold, the cost of removing the BAT equipment will typically be higher than its salvage value. The decommissioning cost is the cost of removing and decontaminating equipment, and related expenses, minus any earnings from the transfer or sale of any salvaged equipment. Care should be taken in determining what portions of the plant are made available for release to the public after decommissioning, because of the possibility of public radiation exposure. Decommissioning is assumed to occur in the year after the last year of plant operation. The costs are specified by the user as a fraction of the initial capital investment. Decommissioning costs are assumed to change at the same real rate as used for calculating the initial capital investment in the BAT equipment that will eventually be decommissioned.

A.1.3 Cash Flow Calculations

Specific equations for calculating the cash flows for initial capital investment, interim capital investment, operation and maintenance costs, decommissioning costs, and total cash flow are presented below. Variables for describing the total interim capital investment costs and the total operation and maintenance costs are also included, although no specific equation is presented.

Initial Capital Investment (CI)

During the construction period, the real dollar cash flow for capital investment in year i (CI_i) is based on the "overnight" construction cost (CI) and the rate of real price escalation. The overnight construction cost is an estimate of what the construction cost would be if the BAT could be constructed instantaneously; thus, this cost does not include any real price escalation or consider the time value of money during construction. Assuming uniform construction payout, the cash flow for capital investment in each year is

$$CI_i = \frac{CI}{CT}\left[(1 + CI_g)^{(i - CI_p)}\right] \qquad (A.2)$$

where CI_i = real dollar cash flow in year i
CI = total "overnight" cost estimate in reference-year dollars
CT = construction time
CI_g = real escalation rate for CI
CI_p = reference year.

If more detailed information about the actual cash flows during the construction period is known, then the real dollar cash flows can be stated explicitly. If, as is commonly the case, the percentage of the overnight construction cost to be expended each year is known, the real dollar cash flow for capital investment in year i (CI_i) is

$$CI_i = CI\ CIP_i\left[(1 + CI_g)^{(i - CI_p)}\right] \qquad (A.3)$$

where CIP_i is the percentage of total "overnight" cost spent in year i.

Interim Capital Investment (ICI)

Interim capital investments are assumed to occur in a single year (rather than being spread out over several years). If the assumed real price escalation of the various interim capital investments is the same for all investments in a given year, the costs can be summed and the total escalated. During the year that an interim capital investment occurs, the real dollar cash flow for interim capital replacements is

$$ICI_i = ICI\left[(1 + ICI_g)^{(i - ICI_p)}\right] \qquad (A.4)$$

where ICI_i = real dollar cash flow in year i for an interim capital replacement
ICI = total cost estimated in reference-year dollars
ICI_g = real escalation rate for ICI
ICI_p = reference year.

Equation (A.4) is used to determine the real dollar cash flow for each year. If the price is assumed to escalate differently for separate interim capital investments, then Equation (A.4) should be used separately for each investment.

Total Interim Capital Investment (ICIT)

Total interim capital investment in year i ($ICIT_i$) is equal to the summation of all individual interim capital investments in year I:

$$ICIT_i = \sum^{n} ICI_i \qquad (A.5)$$

Operation and Maintenance Costs (O&M)

Operation and maintenance costs (including fuel or electricity, filters, maintenance labor, and other annual expenses) begin in year 1 and occur throughout the plant's operating lifetime. Operation and maintenance cash flows for each item should be calculated separately because real escalation rates for the individual O&M cash flows frequently differ. For example, as equipment gets older, it typically requires more maintenance; therefore, the O&M cost can be expected to rise in real terms. For DOE estimates of real energy price escalation rates, refer to Lippiatt and Ruegg (1987).

The O&M cash flow in year i is calculated as

$$O\&M_i = O\&M\left[(1 + O\&M_g)^{(i - O\&M_p)}\right] \quad (A.6)$$

where

$O\&M_i$ = real dollar cash flow in year i
$O\&M$ = annual O&M cost estimate in reference-year dollars
$O\&M_g$ = real escalation rate for O&M
$O\&M_p$ = reference year.

Total Operating and Maintenance Costs (O&MT)

Total O&M costs in year i ($O\&MT_i$) are equal to the summation of all individual O&M cash flows in year i.

$$O\&MT_i = \sum^{n} O\&M_i \quad (A.7)$$

Decommissioning Costs (DCI)

Decommissioning occurs in the year following the last year of plant operation. Decommissioning costs are associated with all initial capital investments for BATREC equipment and facilities. The decommissioning cash flow is calculated as

$$DCI_i = CI\ dcf\left[(1 + CI_g)^{(L - 1 - CI_p)}\right] \quad (A.8)$$

where DCIi = the real dollar decommissioning cost for CI
CI = total "overnight" cost estimate in reference-year dollars
dcf = decommissioning cost fraction
CI_g = real escalation rate for CI
L = plant operating life
CI_p = reference year.

Total Cash Flow (TCF)

The total cash flow in year i (TCF_i) is calculated as

$$TCF_i = -DCI_i - CI_i - ICIT_i - O\&MT_i \qquad (A.9)$$

A.1.4 Present Value Calculations

The present value (PV) is the final cash flow calculation, one that combines all previous cash flow calculations and is the final value used in determining the economic figure-of-merit for a given candidate control technology. The present value calculation uses the total cash flow calculated for each year of projected use of the technology [Equation (A.7)] and a discount rate to adjust for the before-tax average rate of return on private investments after inflation. Office of Management and Budget Circular No. A-94 (Shultz 1972) states that a discount rate of 10% should be used in evaluating decisions concerning the initiation, renewal, or expansion of all programs and projects. This value of 10% is intended to represent an estimate of the before-tax average rate of return on private investments after inflation.

The present value of the total cash flow in year i is calculated as

$$TCF_{pvi} = \frac{TCF_i}{(1+k)^i} \qquad (A.10)$$

where TCF_{pvi} is the present value of TCF_i and k is the discount rate.

A.2 FIGURE-OF-MERIT CALCULATIONS

The levelized cost methodology provides for project economic analysis by specifying equations for calculating several different economic figures-of-merit. These calculations are included because of the differing areas of interest of potential system users and because different figures-of-merit highlight different aspects of a project's economic worth. The preferred economic figure-of-merit is found is Section A.2.3, the levelized life-cycle cost of radionuclide removal.

The figures-of-merit discussed below are in essence a hierarchy of economic analysis methods. The baseline method is the calculation of net present value (NPV), which is based on the cash flow calculations discussed in Section A.1 of this appendix. The second method, real annualized cost (AC), uses the NPV as well as including a capital recovery factor. Both levelized life-cycle cost methods, the one for radionuclide removal (LCCRR) and the one for effluent throughput (LCCT), use the real annualized cost adjusted for per unit reductions in radionuclide concentration or total throughput, respectively.

A.2.1 Net Present Value

The net present value (NPV) of the project represents how much the use of the candidate technology will cost in reference year-dollars after accounting for the time value of money. The net present value of the project is equal to

$$NPC \text{ (in dollars)} = \sum_{i} TCF_{pci} \tag{A.11}$$

where TCF_{pvi} is the present value of total cash flow calculated in Equation (A.8).

A.2.2 Real Annualized Cost

The annualized cost (AC) is defined as the cost per year for operating the BAT system, accounting for the time value of money. Expressed in reference-year dollars, the real annualized cost is a constant cash flow in real dollars that, over the lifetime of the project, would result in a present value equal to the present value of all project cash flows. When the AC is used in comparing candidate control technologies, the technologies must be designed to provide equivalent levels of service for the comparison to be meaningful. The real annualized cost is calculated as

$$AC\ (\text{in dollars}) = NPV\ CRF \qquad (A.12)$$

The capital recovery factor (CRF) in Equation (A.10) is calculated as

$$CRF = \frac{k}{1 - (1 + k)^{-L}} \qquad (A.13)$$

where k is the discount rate and L is the project's operating life.

A.2.3 Levelized Life-Cycle Cost of Radionuclide Removal

The levelized life-cycle cost of radionuclide removal (LCCRR) is the preferred alternative for calculating the economic figure-of-merit. It is the real annualized cost divided by the annual estimated reduction in total activity (in curies or becquerels) of radionuclides released in liquid effluents. This analysis should consider the quantity or activity of the key or significant radionuclides removed annually, i.e., those radionuclides which make up 99% of the total activity released. The LCCRR is expressed in reference-year dollars per unit reduction of activity released and is defined as

$$LCCRR\ (\text{in dollars/curie}) = \frac{AC}{RR} \qquad (A.14)$$

where RR is the radionuclide radioactivity removed annually (in curies or becquerels) from liquid effluent streams released to the environment.

A.2.4 Levelized Life-Cycle Cost per Unit of Throughput

The levelized life-cycle cost per unit of throughput (LCCT) is the real annualized cost divided by the amount of liquid effluent that goes through the BAT system annually. This value represents the cost per unit of throughput (e.g., liters, gallons, tons) to treat the process stream. It is expressed in reference-year dollars per unit of throughput. The real levelized life-cycle cost per unit of throughput (LCCT) is

$$\text{LCCT (in dollars/gallon)} = \frac{AC}{AT} \qquad \text{(A.15)}$$

where AT is the annual throughput for the system (in gallons, tons, etc.).

If the installation of a BAT system will decrease throughput capability, the LCCT will be adversely affected only if the facility would need to operate above its new maximum capacity. For example, if the facility has a maximum capacity of 100 units/day and currently operates at 50 units/day, a new BAT system that reduces the maximum capacity to 90 units/day would not affect LCCT; however, it would affect flexibility. Conversely, if the reduced throughput capability would affect the plant's ability to fulfill its mission, the cost of the reduced capability should be included in the analysis, and the technology could be eliminated from consideration on account of its operational impacts.

APPENDIX B

SAMPLE TECHNOLOGY ISSUES MATRIX FOR DETERMINING TWVFs

SUMMARY OF ALL TECHNOLOGY ISSUES IN CONTROL TECHNOLOGY COMPARISONS	No-Action Alternative	Option 1	Option 2	Option 3
Significant Nuclides				
Reference DCGs				
Regulatory Compliance				
ISSUE CATEGORIES	**WEIGHTED VALUE FACTORS (WVF)**			
Environmental				
Operational				
Resource and energy				
Total Weighted Value Factor (TWVF) for Each Issue = $\sum$(WVF)				

FIGURE B.1. Summary Technology Issues Matrix for Comparisons Between Control Technology Options

ENVIRONMENTAL ISSUES		No-Action Alternative	Option 1	Option 2	Option 3
Significant Nuclides					
ISSUES	**WF**	**VF**	**VF**	**VF**	**VF**
Comparison to DCGs		5			
Regulatory Compliance		5			
Accumulated Quantity		5			
Dose Contribution		5			
Total Release Quantity		5			
Effluent Temperature		5			
Chemical Constituents		5			
Suspended and Dissolved Solids		5			
Endangered Species Impact		5			
Type and Quantity of Waste Generated		5			
Ultimate Waste Disposal Options		5			
Weighted Value Factor for Environmental Issues = $\sum(WF \times VF)$					

FIGURE B.2. Sample Environmental Issues Matrix for Comparisons Between Control Technology Options

OPERATIONAL ISSUES		No-Action Alternative	Option 1	Option 2	Option 3
Significant Nuclides or Other Considerations					
ISSUES	**WF**	**VF**	**VF**	**VF**	**VF**
Occupational Safety		5			
Occupational Radiation Exposure		5			
Process Changes		5			
Process Throughput Capability		5			
Adaptability of Current Facility		5			
Equipment Reliability		5			
Maintenance Requirements		5			
Flexibility to Mission Changes		5			
Existing Public Policy Issues		5			
Public Concern on a Specific Issue		5			
Scope of Increased Training Requirements		5			
Weighted Value Factor for Operational Issues = $\sum$(WFxVF)					

FIGURE B.3. Sample Operational Issues Matrix for Comparisons Between Control Technology Options

ENERGY AND RESOURCE ISSUES		No-Action Alternative	Option 1	Option 2	Option 3
Significant Nuclides or Other Considerations					
ISSUES	**WF**	**VF**	**VF**	**VF**	**VF**
Energy Use and Conservation		5			
Land Use		5			
Use of Scarce Commodities		5			
Impact on Nearby Communities		5			
Recycling and Recovery Options		5			
		5			
		5			
		5			
		5			
		5			
		5			
Weighted Value Factor for Energy & Resource Issues = ∑(WFxVF)					

FIGURE B.4. Sample Energy and Resource Issues Matrix for Comparisons Between Control Technology Options

SIGNIFICANT NUCLIDES OR OTHER CONSIDERATIONS		No-Action Alternative	Option 1	Option 2	Option 3
ISSUES	**WF**	**VF**	**VF**	**VF**	**VF**
		5			
		5			
		5			
		5			
		5			
		5			
		5			
		5			
		5			
		5			
		5			
Weighted Value Factor for Issues = ∑(WFxVF)					

FIGURE B.5. Blank Issues Matrix for Comparisons Between Control Technology Options

APPENDIX C

EXAMPLE CASES FOR DETERMINING BATREC

BEST AVAILABLE TECHNOLOGY FOR RADIOACTIVE EFFLUENT CONTROL ANALYSIS FOR THE LAUNDRY AND RESPIRATOR-CLEANING FACILITY AT THE SPACE REACTOR TEST STATION

This appendix contains an example BATREC analysis that is based on an actual analysis performed at a DOE facility. The original analysis was conducted before the Interim Final Report of DOE/EH-263T was issued in June 1992 and so is deficient in some areas where it does not strictly follow the manual guidance. Parts of the original analysis have been clarified and expanded to provide additional illustration of the use of the BAT Guidance where adequate information was available. Names of the site and facilities have been changed throughout the example.

Throughout the text, comment boxes have been provided to point out areas where more extensive analysis and documentation should have been provided, and to indicate approaches that readers should consider following in other BATREC analyses.

In general, the following BATREC analysis represents a "bare-bones" analysis, which should provide more description and documentation of the evaluative process. Users are referred to Chapter 6.0 of the guidance manual for the format and general elements to be included in documenting a BATREC evaluation.

EXECUTIVE SUMMARY

Comment: As shown here, a concise summary of the liquid discharge situation, the need for BAT analysis, the evaluation process, and the results is recommended.

The Laundry and Respirator-Cleaning Facility (LRCF) at the Space Reactor Test Station is located in the Station West Area (SWA). The facility uses industrial laundry equipment to clean contaminated protective clothing and respirators, as well as other types of uncontaminated, company-provided clothing. Approximately 3000 gallons of laundry waste water are discharged daily (750,000 gal/yr) to the SWA subsurface drainage field. The SWA subsurface drainage field also receives waste water from the SWA Sewage Treatment Plant (STP). The LRCF is estimated to contribute approximately 80% of the radionuclides discharged annually to the drainage field.

The concentrations of radionuclides (^{137}Cs, ^{90}Sr, ^{60}Co, and ^{3}H) in liquid discharges from the LRCF are below the Derived Concentration Guides (DCGs) established in DOE 5400.5, both individually and using the sum-of-ratios rule for combined radionuclide concentrations. However, the U.S. Department of Energy (DOE) requires that any radiological liquid discharges to a soil column must be evaluated using a Best Available Technology for Radioactive Effluent Control (BATREC) analysis to determine if other potential treatment technologies can more effectively reduce the discharge radionuclide concentrations. The LRCF, as the major radionuclide contributor to the drainage field, was selected as the focus of the BATREC analysis. In addition, a new STP has been proposed for the SWA.

The BATREC analysis for the LRCF identified a no-action alternative and six potential treatment options for reducing the concentrations of radionuclides in liquid process streams. The six options consisted of various combinations of filtration, recycle, ion exchange, reverse osmosis, forced evaporation, and confined discharge.

The BATREC for treating liquid process streams in the LRCF was determined to be represented by Option 3. This treatment option involves a system of filtration (a 1-micron-particle-efficient unit) and discharge to a lined pond for natural evaporation of the water. The system treats the LRCF liquid process stream and isolates the liquid discharge from all other SWA sanitary waste water. Under this option there would be no soil column discharge from the LRCF. Additional waste minimization actions are possible for the laundry process. These actions would result in a higher concentration of radionuclides in the liquid discharge; however, the water would remain isolated from the soil and surface water environments and the amount of waste water released would be minimized.

C.1 INTRODUCTION

The Laundry and Respirator-Cleaning Facility (LRCF) is located at the Space Reactor Test Station, which is operated for the U.S. Department of Energy (DOE). The facility is located in the Station West Area (SWA), and uses industrial laundry and washing equipment to clean contaminated protective clothing and respirators, as well as other types of uncontaminated, company-provided clothing.

Contamination from clothing and respirators is removed in the cleaning process and is suspended in the wash water discharged from the LRCF. There are three separate laundry and respirator-cleaning processes in the LRCF, as diagrammed in Figure C.1. Liquid streams from potentially contaminated laundry ("hot" laundry) and respirators ("hot" respirators) are kept separate from the uncontaminated ("cold") laundry streams. Liquid discharges from the wash and rinse cycles of the "hot" laundry-cleaning process and from the soak tank and dishwasher of the respirator-cleaning process are discharged to a sump in the LRCF. From there water is pumped to the SWA subsurface drainage field. Other discharges to the "hot" sump are

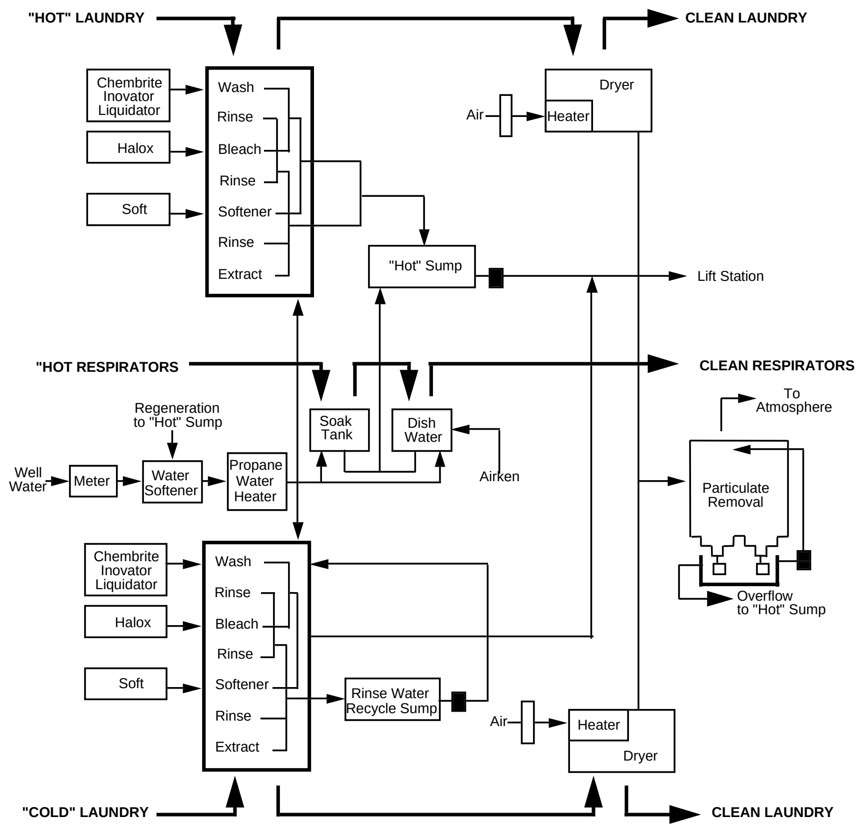

FIGURE C.1. Laundry and Respirator-Cleaning Processes in the LRCF regeneration liquids from the water softener used to condition well water used for laundry make-up water, and any liquid overflow liquids from the "hot" and "cold" dryers. Wash and rinse water from the "cold" laundry-cleaning process is also discharged to the SWA subsurface drainage field, but does not go through the "hot" sump.

Approximately 3000 gallons of laundry waste water are discharged each day the laundry operates (750,000 gal/yr) to the SWA subsurface drainage field. The sub-surface drainage field also receives waste water from the SWA Sewage Treatment Plant (STP). There are currently no radionuclide treatment systems used on the liquid discharges from the LRCF.

Four different radionuclides — ^{137}Cs, ^{60}Co, ^{90}Sr, and ^{3}H — have been detected in the liquid effluent of the LRCF. The concentrations of each of these radionuclides are well below the applicable Derived Concentration Guides (DCGs) of DOE 5400.5 (DOE 1990), as shown in Table C.1 for 1989 average values. Using the most restrictive DCGs, the percent of DCG for each radionuclide ranges from 5.7% for ^{60}Co to 2.1% for ^{137}Cs. Using the sum-of-ratios method (DOE 5400.5, page III-3) to consider the concentrations of all four radionuclides detected, the ratio is 0.13, or 13% of applicable DCGs. Although these radionuclide concentrations are below applicable standards, there is potential for radionuclides to accumulate in the soil under certain circumstances.

containing process-derived radionuclides, which are discharged to a soil column for an indefinite period, regardless of concentration. The Nonradiological and water quality parameters have also been measured for the LRCF liquid effluent. Averages for 1988, 1989, and the two-year combined averages calculated two different ways are also shown in Table C.2. Results are shown compared with the State Drinking Water Standards (1985), which are applicable to injected fluids. All yearly and two-year average values exceed the State Drinking Water Standards for pH, total dissolved solids (TDS), total organic content (TOC), nitrate (NO_3), cadmium (Cd), and selenium (Se). In addition, values for arsenic (As) and lead (Pb) were exceeded both during 1989 and by using one of the two methods of two-year averaging.

DOE directives require an analysis of the BATREC to treat liquid waste streams containing process-dervied radionuclides, which are discharged to a soil column for an indefinite period, regardless of concentration.

TABLE C.1. 1989 Radionuclide Concentrations in LRCF Effluent

Nuclide	1989 Average (μCi/mL)	SWA Well 1 (μCi/mL)	SWA Well 2 (μCi/mL)	DCG (μCi/mL)
^{137}Cs	6.3 x 10^{-8}			3.0 x 10^{-6}
^{60}Co	1.2 x 10^{-7}			5.0 x 10^{-6}
^{90}Sr	5.7 x 10^{-8}			1.0 x 10^{-6}
^{3}H	5.1 x 10^{-5}	2.5 x 10^{-5}	1.7 x 10^{-5}	2.0 x 10^{-3}

TABLE C.2. Water Quality Parameters and Nonradiological Constituents of LRCF Effluent in 1988 and 1989

Parameter	1989 Average	Average 1[a]	Average 2[b]	Limit[c]
Cond. (μS)	996	937	937	--
pH	8.8	9.0	9.0	6.5-8.5
TDS (mg/L)	660	630	630	500
TOC (mg/L)	130	110	110	10
Cl (mg/L)	91	88	88	250
F (mg/L)	0.8	16	1.4	1.4-2.4
NO_3 (mg/L)	14	12	12	10
PO_4 (mg/L)	2.7	2.1	1.9	--
SO_4 (mg/L)	76	79	79	250
Ag (μg/L)	0	0	0	50
As (μg/L)	220	220	27	50
Ba (μg/L)	70	63	32	1000
Cd (μg/L)	13	16	12	10
Cr (μg/L)	29	33	29	50
Cu (μg/L)	81	78	72	1000
Hg (μg/L)	0.3	0.3	0.2	2
Ni (μg/L)	27	30	18	--
Pb (μg/L)	280	150	39	50
Se (μg/L)	250	280	70	10
Tl (μg/L)	133	133	17	--
Zn (μg/L)	340	310	310	5000

(a) Average 1 is the average of those values shown and does not include the values not detected.
(b) Average 2 is the average of all values, including those not detected (assumed to be zero).
(c) The limits are derived from State Drinking Water Standards (1985) applicable to injected fluids. The units are the same as those shown in Column 1.

The BATREC analysis helps determine if other potential treatment technologies can more effectively reduce the discharge radionuclide concentrations than the treatment technology currently in use.

This appendix describes the BATREC analysis for the LRCF that examined a no-action alternative and six potential treatment options for reducing the concentrations of particulate radionuclides in liquid process streams. The six candidate treatment technologies consisted of various combinations of filtration, recycle, ion exchange, reverse osmosis, forced evaporation, and confined discharge. Environmental, operational, and energy and resource issues were identified for analysis relative to each of the treatment options. The economic feasibility of each option was also considered. The evaluation of these treatment systems and related issues and the process of selecting the BATREC are described in the following sections.

C.2 SELECTION OF CANDIDATE TECHNOLOGIES

The radionuclide source term of the LRCF liquid waste streams was characterized in Section C.1. DOE recognizes that there is no BATREC for control of low concentrations of tritium, and tritium is exempted from the BATREC requirements.[(1)] This analysis, therefore, concentrated on treatment technologies that would remove the three other radionuclides in the process streams, ^{137}Cs, ^{60}Co, and ^{90}Sr, which are typically present as particulates.

The nonradiological and water quality characteristics of the liquid process were also identified in Section C.1. None of these characteristics or constituents were determined to have a particularly adverse effect on any of the treatment systems considered for radionuclide removal from the liquid process streams.

Four different treatment technologies — filtration, ion exchange, reverse osmosis, and forced evaporation — were combined with recycling, confined discharge, and unconfined discharge and considered as six different treatment systems options. The no-action alternative was also evaluated. No other treatment technologies or systems were considered in the BATREC analysis. All of the treatment options evaluated used existing and commercially available technology. Because the liquid process streams

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(1) Pelletier, R. F. 1992. Implementation Guidance for DOE 5400.5, Section II.3 ("Management and Control of Radioactive Materials in Liquid Discharges and Phaseout of Soil Columns"), attachment to DOE memorandum dated June 17, 1992 from Raymond F. Pelletier to Distribution, "Guidance regarding water protection elements of DOE 5400.5", and

Pelletier, R. F. 1995. Interpretation of Tritium Control Exception of DOE 5400.5, Radiation Protection of the Public and the Environment. Exceptions for Liquid Waste Control Requirements Section 3.E(2) - Tritium Control.

result from a widely used and understood process, no treatability studies or pilot testing was necessary.

Comment: More extensive descriptions of candidate technologies should be provided than are included below. The rationale for selecting each candidate technology should also be provided.

Comment: Diagrams and simple graphics of the candidate technologies, such as those below, are excellent aids in understanding the various processes.

C.2.1 Option 1: Existing Treatment System (No-action Alternative)

The first option was the "no-action alternative," which was to continue the current practice of discharging liquid effluents to the SWA subsurface drainage field. There is no treatment of these liquid process streams. The only evaluations performed for this option were 1) waste water characterization and 2) examination of the potential accumulation of radionuclides in the percolation pond soil. This option is diagrammed in Figure C.2.

C.2.2 Option 2: Filtration and Discharge to a Percolation Pond

The second option considered was the addition of a filtration unit that filters very fine particles. It would remove 95% of particulates 1 micrometer (μm) and larger from the waste water before releasing the water to the percolation pond. Of primary concern for the filtration technology are the ^{60}Co particulates, which are about 0.2 μm in diameter. The vendor of one commercially available particle-filtration unit noted that ^{60}Co might not be filtered out. However, with a cake build-up on the filtration media a

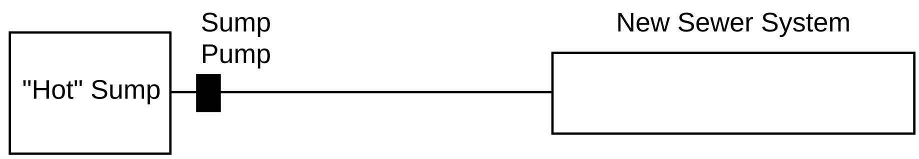

FIGURE C.2. Option 1, The Existing Treatment System
(No-Action Alternative)

certain amount of filtration of these smaller particles could occur. In evaluating the filtration unit it was assumed that 50% of the particulate contaminates measuring less than 1 μm would be filtered out of the liquid effluent stream. The bulk of the cost of this option would be for the equipment. The principal advantage of this option was the reduction in accumulation of the radionuclides in the soil of the percolation pond. A diagram of this option is shown in Figure C.3.

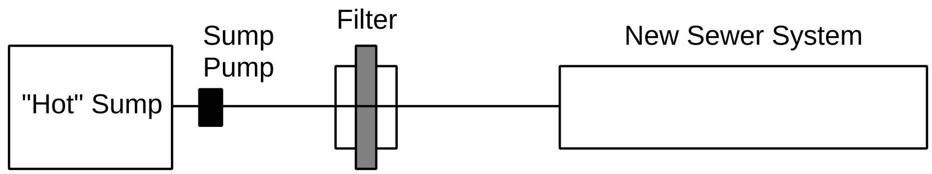

FIGURE C.3. Option 2, Filtration and Discharge to a Percolation Pond

C.2.3 Option 3: Filtration and Discharge to a Lined Evaporation Pond

Option 3 considered the addition of a filtration unit that filters very fine particles (identical to that described for Option 2), with discharge to a lined evaporation pond similar to ponds installed elsewhere in the SWA. The cost of this option was similar to Option 2 but included the additional cost of the lined evaporation pond. The major considerations were the accumulation of radionuclides in the pond; the administrative controls to prevent release of the radionuclides beyond the pond boundaries; the possible requirement for periodic collection, treatment, and disposal of accumulated sediments in the pond; and the possible reuse of the filtered water for wash or rinse water. This option is diagrammed in Figure C.4.

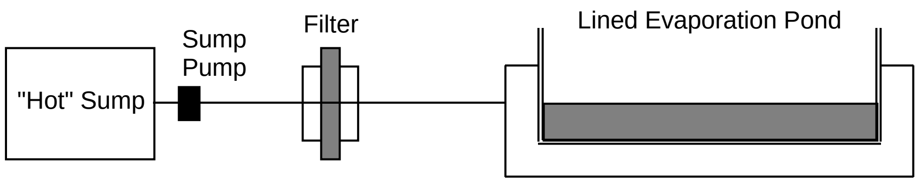

FIGURE C.4. Option 3, Filtration and Discharge to a Lined Evaporation Pond

C.2.4 Option 4: Ion Exchange and Water Recycle

The fourth option considered was the addition of an ion exchange unit. This option would reuse the wash and rinse water in the laundry because 1) water run through the ion-exchange process would be purer than service water and 2) reuse would maximize the length of time before regeneration of the ion exchange resin was necessary. The major considerations in evaluating this option were water quality, the quantity of waste generated, the operation of the process (continuous or periodic processing of waste water), and waste treatment and disposal methods.

Costs included the addition of a building to house the ion-exchange equipment. Wastes generated from the process would be both solid and liquid. Solid waste would be disposed of in the Station Radioactive Waste Storage Area (SRWSA) with only transportation cost. The disposal of liquid waste would be to another onsite station facility for evaporation (cost of $1.15/gal based on 1500 gal). Future upgrades to the facility were also considered. The upgrades included the addition of evaporation units to reduce the liquid waste to a dry salt cake, so that the only waste out of the facility is solid waste for disposal at the SRWSA. Option 4 is diagrammed in Figure C.5.

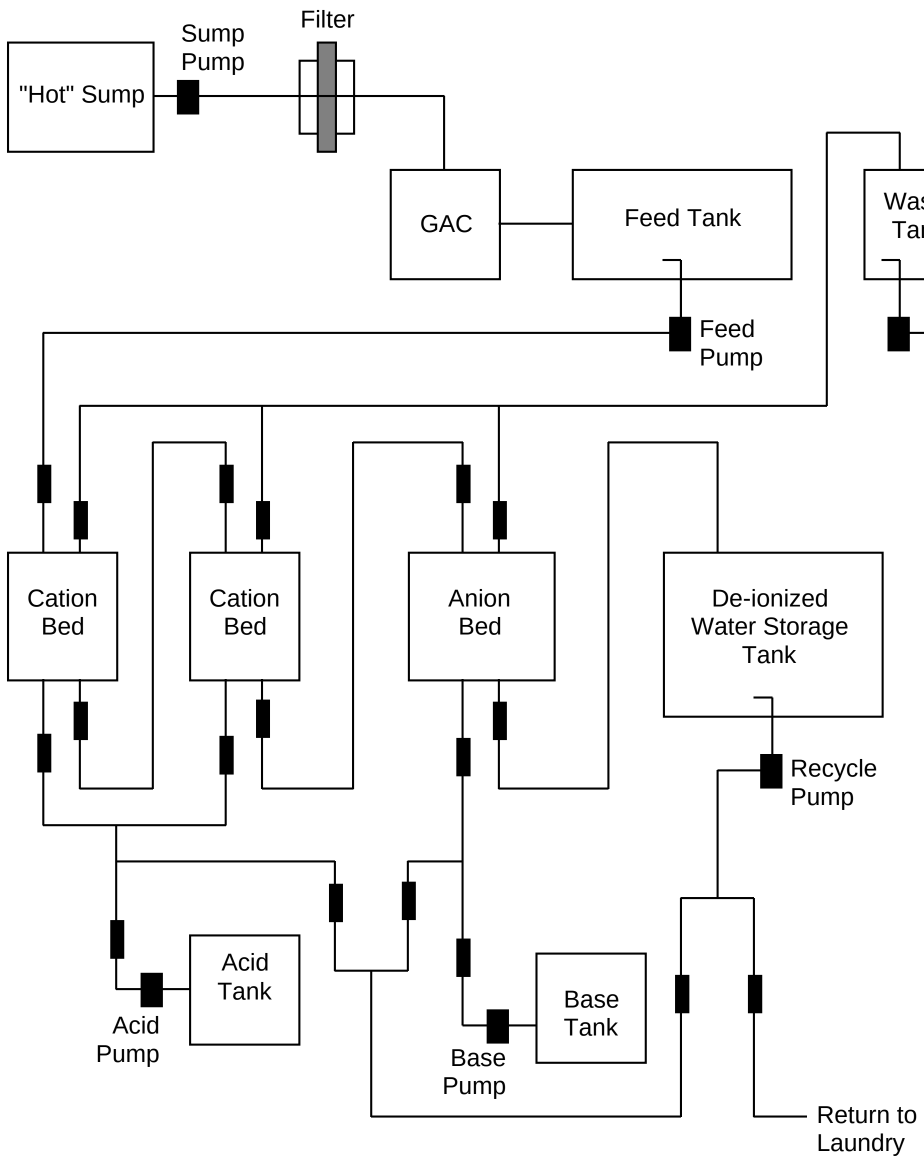

FIGURE C.5. Option 4, Ion Exchange and Water Recycle

C.2.5 Option 5: Ultrafiltration, Dual Reverse Osmosis, and Water Recycle

The fifth option considered was the addition of an ultrafiltration unit, a spiral-wound reverse osmosis unit, and a tubular reverse osmosis unit. This treatment system would provide high-quality water that would be reused in the laundry. If better water quality were required for recycling to the laundry, additional treatment such as ion exchange or reverse osmosis could be added. These additional treatment subsystems were not considered during this analysis. The evaluation of this option was similar to that for Option 4. This option is diagrammed in Figure C.6.

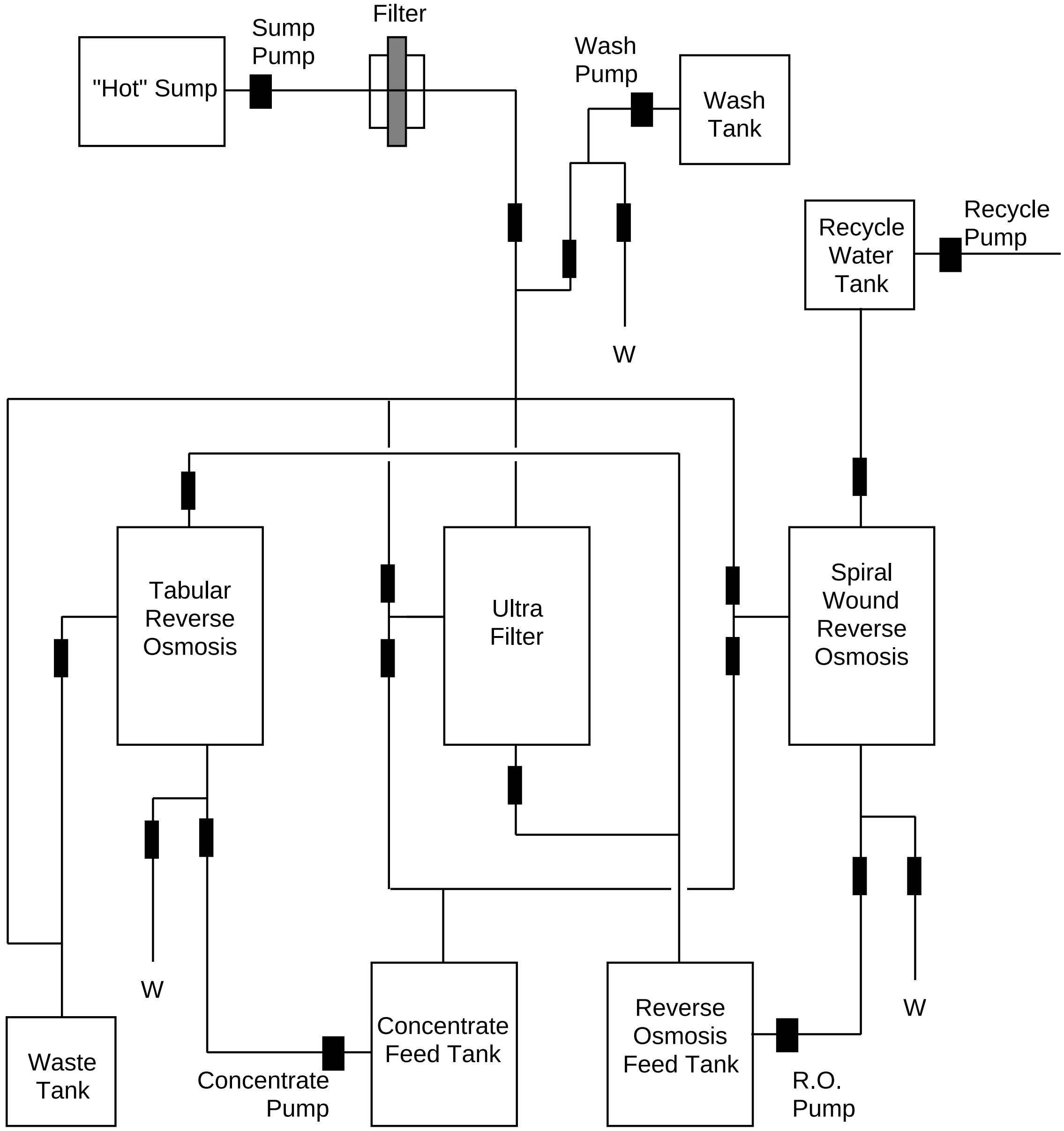

FIGURE C.6. Option 5, Ultrafiltration, Dual Reverse Osmosis, and Water Recycle

C.2.6 Option 6: Reverse Osmosis, Evaporation, and Water Recycle

The sixth option considered was the addition of a spiral-wound reverse osmosis unit and an evaporation unit. Option 6 creates less waste for disposal and uses less energy and water, respectively, than reverse osmosis or evaporation options alone. The analysis for this option was similar to thosefor Options 4, 5, 6, and 7, which treat process water and recycle it back to the laundry. The evaporator concentrates the waste stream from the reverse osmosis unit by a factor of 10, which is equivalent to removing 90% of the water. Although not considered here, a possible future upgrade to the process is the addition of a more efficient evaporator that removes almost all of the water and leaves a semi-dry salt cake for disposal as solid waste. Option 6 is diagrammed in Figure C.7.

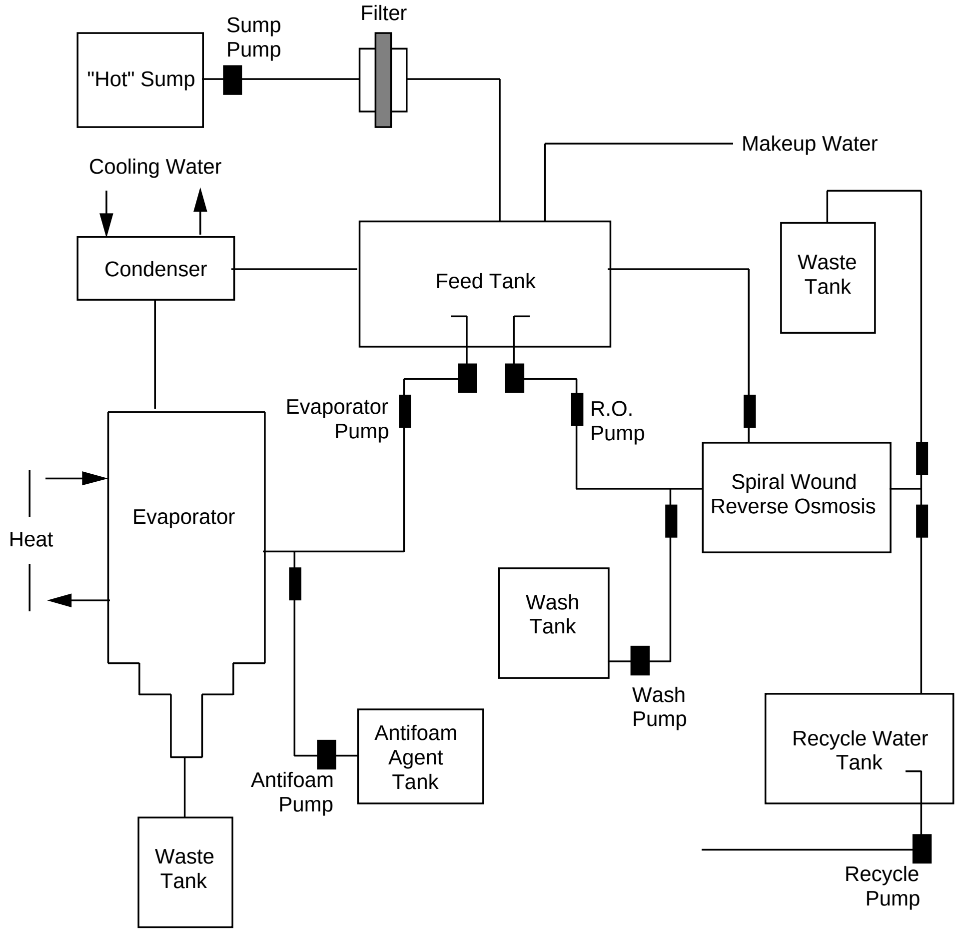

FIGURE C.7. Option 6, Reverse Osmosis, Evaporation, and Water Recycle

C.2.7 Option 7: Evaporation and Water Recycle

The seventh option considered was the addition of an evaporation unit. Evaporation is a typical method of reducing radioactive liquid waste, but is very energy intensive. This analysis was similar to those for Options 4, 5, 6, and 7, which treat process water and recycle it back to the laundry. A possible future upgrade is the addition of an evaporator unit that would produce a semi-dry solid waste. The evaporator considered in this evaluation removed only 90% of the water. Option 7 is diagrammed in Figure C.8.

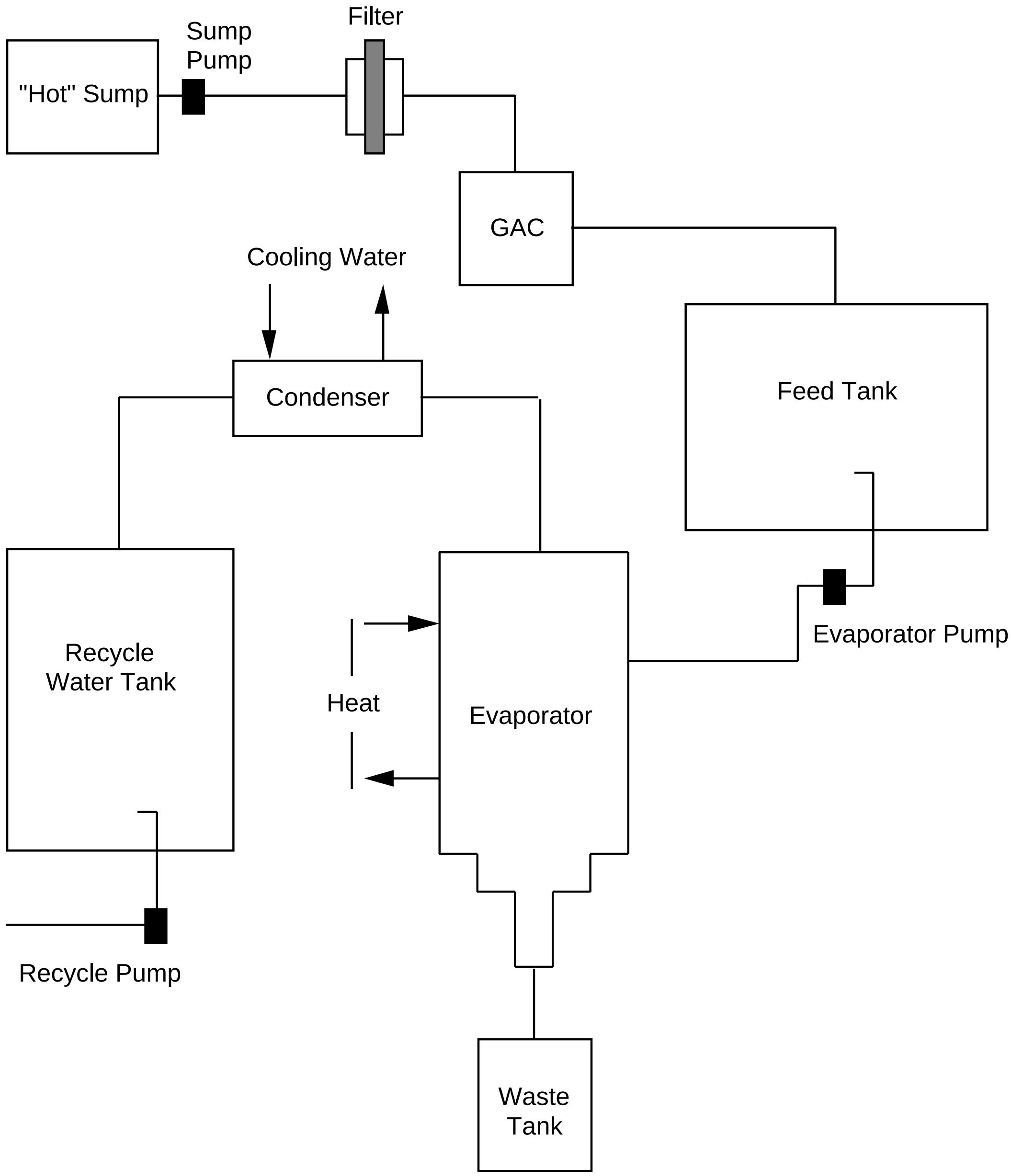

FIGURE C.8. Option 7, Evaporation and Water Recycle

C.3 ANALYSIS OF ENVIRONMENTAL ISSUES

Comment: Additional information should be provided in this area, including documentation of the preliminary evaluation of comparison to DCG values (section 4.1.1) and a regulatory compliance evaluation (section 4.1.2). Information should also be provided on how the environmental issues included in this section were identified.

Four environmental issues related to radiological liquid discharges from facilities were identified for evaluation of the effect of using the candidate treatment technologies to address the issues. The four issues were 1) the concentration of radionuclides at discharge (compared with the DCGs); 2) the build-up and accumulation of radionuclides in soil receiving the discharge; 3) the generation of solid and liquid wastes; and 4) other environmental issues specific to each particular option considered.

Environmental issues were given 57% of the weighting applied to all issues, thereby meeting the DOE/EH-263T requirement for at least 50%. The highest weighted individual issue was other environmental issues, at 21%, followed by waste minimization at 19%, accumulated quantity in soil at 12%, and concentration at discharge (comparison with DCGs) at 5%.

The highest ranked candidate treatment system for the environmental issues category was Option 4, with a weighted value factor (WVF) of 513. It was followed closely by Option 3 (497), Option 6 (490), and Option 5 (475). The evaluation of environmental issues for the candidate treatment systems are summarized in Table C.3.

C.3.1 Radionuclide Concentrations at Discharge

The effect of the various treatment options on the radionuclide concentrations at discharge from the LRCF is shown in Table C.4. For each option, the table presents the concentrations of the process stream in the laundry, the liquid effluent concentration after treatment, the net reduction factor from the in-process stream to the effluent stream, and the effluent stream fraction of the applicable DCG.

The fraction of DCG is the best indicator of how well the treatment option reduces the radionuclide concentration. The treatment options that recycle laundry water (Options 4, 5, 6, and 7) actually increase the in-process stream concentration, so the treatment option with the largest net reduction factor is not necessarily the option with the lowest effluent concentration.

The lowest effluent concentrations for ^{137}Cs, ^{60}Co, and ^{90}Sr are achieved using treatment Options 5, 6, and 7. Option 4 is the next most effective, and Options 2 and 3 are the least effective in reducing effluent concentrations. None of the treatment options are effective at removing ^{3}H.

Comment: There are unexplained differences in water concentrations between Table C.1, which displays 1989 average radionuclide effluent concentrations and Table C.4, which displays baseline laundry process water concentration. The process concentrations in Table C.4 are significantly lower than the 1989 measured concentrations presented in Table C.1.

In Option 1 (the no-action alternative), the process concentrations would be expected to be similar to the effluent concentrations unless factors not mentioned are involved. Likewise, Option 1 effluent concentrations would be expected to be identical to those in Table C.1 unless unidentified measures have been taken.

Tritium concentration information is omitted from Table C.4 and should be presented for completeness.

TABLE C.3. Environmental Issues Matrix for the Laundry and Respirator-Cleaning Facility (LRCF)

Environmental Issues		No-Action Alternative (Option 1)	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Significant Nuclides (in liquid effluent stream after treatment)		^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{60}Co,^{90}Sr ^{137}Cs, ^{3}H	^{60}Co,^{90}Sr ^{137}Cs, ^{3}H	^{3}H	^{3}H	^{3}H	^{3}H
ISSUES	WF	VF	VF	VF	VF	VF	VF	VF
Comparison with DCGs (concentration at discharge)	5	5	8	8	10	10	10	10
Accumulated Quantity in Soil	12	5	8	10	10	10	10	10
Waste Minimization	19	5	7	10	7	5	8	7
Other Environmental Issues	21	5	5	7	10	10	8	5
Weighted Value Factor for Environmental Issues ∑(WFxVF)	(WVF)	285	374	497	513	475	490	408

TABLE C.4. Radionuclide Discharge Concentrations and Reduction Fraction of DCGs for LRCF Treatment Options

		^{137}Cs	^{60}Co	^{90}Sr	^{3}H
DCG (μCi/mL)		3×10^{-6}	5×10^{-6}	1×10^{-6}	2×10^{-3}
Well Make-Up Water Concentration (μCi/mL)		0	0	0	2×10^{-5} 0.01
Laundry Process Water Concentration (μCi/mL)		7.3×10^{-10}	1.1×10^{-10}	4.1×10^{-10}	
	Effluent Conc.	7.3×10^{-10}	1.1×10^{-10}	4.1×10^{-10}	
Option 1 (No-Action)					
	Net Reduction	0	0	0	
	Fraction of DCG	2×10^{-4}	2×10^{-5}	4×10^{-4}	
	Laundry Conc.	7.3×10^{-10}	1.1×10^{-10}	4.1×10^{-10}	
	Effluent Conc.	3.6×10^{-10}	8.4×10^{-11}	2.0×10^{-10}	
Option 2					
	Net Reduction	2	1.25	2	
	Fraction of DCG	1×10^{-4}	2×10^{-5}	2×10^{-4}	
	Laundry Conc.	7.3×10^{-10}	1.1×10^{-10}	4.1×10^{-10}	
	Effluent Conc.	3.6×10^{-10}	8.4×10^{-11}	2.0×10^{-10}	
Option 3					
	Net Reduction	2	1.25	2	
	Fraction of DCG	1×10^{-4}	2×10^{-5}	2×10^{-4}	
	Process Conc.	1.7×10^{-8}	2.4×10^{-9}	9.4×10^{-9}	
	Effluent Conc.	6.1×10^{-12}	3.0×10^{-11}	3.4×10^{-12}	
Option 4					
	Net Reduction	2800	80	2800	
	Fraction of DCG	2×10^{-6}	6×10^{-6}	3×10^{-6}	
	Process Conc.	2.9×10^{-8}	4.2×10^{-9}	1.6×10^{-8}	
	Effluent Conc.	1.5×10^{-12}	1.1×10^{-12}	8.1×10^{-13}	
Option 5					
	Net Reduction	20000	3800	20000	
	Fraction of DCG	5×10^{-7}	2×10^{-7}	8×10^{-7}	
	Process Conc.	2.9×10^{-8}	4.2×10^{-9}	1.6×10^{-8}	
	Effluent Conc.	1.5×10^{-12}	1.1×10^{-12}	8.1×10^{-13}	
Option 6			3800	20000	
	Net Reduction	20000	2×10^{-7}	8×10^{-7}	
	Fraction of DCG	5×10^{-7}			

	Process Conc.	2.9×10^{-8}	4.2×10^{-9}	1.6×10^{-8}
	Effluent Conc.	1.5×10^{-12}	1.1×10^{-12}	8.1×10^{-13}
Option 7				20000
	Net Reduction	20000	3800	8×10^{-7}
	Fraction of DCG	5×10^{-7}	2×10^{-7}	

C.3.2 Build-Up and Accumulation of Radionuclides in a Percolation Pond

Comment: This is a good example of a site-specific environmental issue, although more discussion and documentation of the evaluation of this issue would be appropriate.

As mentioned previously, the LRCF is the major source of radionuclides released to the percolation ponds and subsurface drainage fields. For example, the total release of ^{90}Sr to the percolation ponds from all of SWA during 1989 was reported to be 2.05×10^{-4} Ci. The ^{90}Sr activity discharged from the LRCF was estimated to be 1.61×10^{-4} Ci, or approximately 78% of the total ^{90}Sr activity discharged. Liquid discharges from the LRCF contain low concentrations of ^{137}Cs, ^{60}Co, and ^{3}H in addition to ^{90}Sr. Although these concentrations currently comprise small fractions of the DCGs, as the LRCF continues to operate and release liquid effluents, the levels of these radionuclides in the soil are expected to build up and accumulate. Table C.5 shows the estimated monthly activity that was released to percolation ponds' sediments and soils during 1989.

The build-up and accumulation of radionuclides in percolation pond soils was evaluated considering the radioactive half-life of each radionuclide present. Table C.6 indicates that build-up to limits listed in Environmental Concentration Guides for Soil can occur in 2 years, if all the radionuclides are concentrated in only the first one-foot depth of soil and if the waste water is discharged to only one of the three currently used percolation ponds.

C.3.3 Waste Generation and Minimization

For each of the candidate treatment systems considered, there is the environmental issue of waste generation and minimization. The waste may be either radionuclide-bearing liquids or solids. Table C.7 summarizes the type and amount of expected wastes from each treatment system option.

TABLE C.5. Estimated Monthly Radionuclide Activity Discharged from the LRCF During 1989 (Ci) [a]

Month (1989)	Number of Days	^{137}Cs	^{60}Co	^{90}Sr	^{3}H	Monthly Total	Monthly Total w/o ^{3}H
January	21	1.0×10^{-5}	5.1×10^{-6}	7.2×10^{-6}	1.0×10^{-2}	1.1×10^{-2}	2.8×10^{-5}
February	19	1.3×10^{-5}	1.4×10^{-5}	4.6×10^{-6}	1.1×10^{-2}	1.1×10^{-2}	2.1×10^{-5}
March	23	1.9×10^{-5}	4.1×10^{-5}	8.4×10^{-6}	1.4×10^{-2}	1.4×10^{-2}	6.8×10^{-5}
April	20	1.5×10^{-5}	1.1×10^{-4}	9.5×10^{-6}	1.2×10^{-2}	1.2×10^{-2}	1.4×10^{-4}
May	22	2.1×10^{-5}	5.3×10^{-5}	7.6×10^{-6}	1.2×10^{-2}	1.2×10^{-2}	8.2×10^{-5}
June	22	2.4×10^{-5}	2.2×10^{-5}	9.5×10^{-6}	1.2×10^{-2}	1.2×10^{-2}	5.5×10^{-5}
July	20	1.4×10^{-5}	1.2×10^{-5}	7.6×10^{-6}	1.2×10^{-2}	1.3×10^{-2}	3.2×10^{-5}
August	23	2.3×10^{-5}	2.3×10^{-5}	9.5×10^{-6}	1.3×10^{-2}	1.3×10^{-2}	4.2×10^{-5}
September	20	1.5×10^{-5}	1.5×10^{-5}	6.1×10^{-5}	1.2×10^{-2}	1.2×10^{-2}	1.1×10^{-4}
October	22	9.5×10^{-6}	9.5×10^{-6}	2.6×10^{-5}	1.1×10^{-2}	1.1×10^{-2}	5.2×10^{-5}
November	19	1.3×10^{-5}	1.3×10^{-5}	1.6×10^{-6}	1.1×10^{-2}	1.1×10^{-2}	2.3×10^{-5}
December	19	1.9×10^{-5}	1.9×10^{-5}	1.9×10^{-6}	1.1×10^{-2}	1.1×10^{-2}	3.0×10^{-5}
Total (yr)	250	1.8×10	3.4×10^{-4}	1.6×10^{-4} -4	1.4×10^{-1}	1.5×10^{-1}	6.8×10^{-4}

(a) Assume daily flow is 3000 gallons.

TABLE C.6. Estimated Build-Up of Contamination in the Percolation Pond

Year	Activity (Ci)	^{137}Cs Concen. (μCi/g)	% of Guide	Activity (Ci)	^{60}Co Concen. (μCi/g)	% of Guide	Activity (Ci)	^{90}Sr Concen. (μCi/g)	% of Guide
0	1.8×10^{-4}	4.2×10^{-7}	7	3.4×10^{-4}	7.9×10^{-7}	79	1.6×10^{-4}	3.7×10^{-7}	6
1	3.6×10^{-4}	8.4×10^{-7}	14	6.4×10^{-4}	1.9×10^{-6}	148	3.2×10^{-4}	7.4×10^{-7}	12
2	5.3×10^{-4}	1.2×10^{-6}	21	9.0×10^{-4}	2.1×10^{-6}	208	4.7×10^{-4}	1.1×10^{-6}	18
3	7.0×10^{-4}	1.6×10^{-6}	27	1.1×10^{-3}	2.6×10^{-6}	261	6.2×10^{-4}	1.4×10^{-6}	24
4	8.7×10^{-4}	2.0×10^{-6}	34	1.3×10^{-3}	3.1×10^{-6}	307	7.7×10^{-4}	1.8×10^{-6}	30
5	1.0×10^{-3}	2.4×10^{-6}	40	1.5×10^{-3}	3.5×10^{-6}	348	9.1×10^{-4}	2.1×10^{-6}	35
6	1.2×10^{-3}	2.8×10^{-6}	46	1.7×10^{-3}	3.8×10^{-6}	384	1.1×10^{-3}	2.4×10^{-6}	41
7	1.4×10^{-3}	3.1×10^{-6}	52	1.8×10^{-3}	4.2×10^{-6}	415	1.2×10^{-3}	2.7×10^{-6}	46
8	1.5×10^{-3}	3.5×10^{-6}	58	1.2×10^{-3}	4.4×10^{-6}	442	1.3×10^{-3}	3.1×10^{-6}	51
9	1.6×10^{-3}	3.8×10^{-6}	64	2.0×10^{-3}	4.7×10^{-6}	466	1.4×10^{-3}	3.4×10^{-6}	56
10	1.8×10^{-3}	4.2×10^{-6}	69	2.1×10^{-3}	4.9×10^{-6}	487	1.6×10^{-3}	3.6×10^{-6}	61
11	1.9×10^{-3}	4.9×10^{-6}	75	2.2×10^{-3}	5.1×10^{-6}	506	1.7×10^{-3}	4.0×10^{-3}	65
12	2.1×10^{-3}	4.8×10^{-6}	80	2.3×10^{-3}	5.2×10^{-6}	522	1.8×10^{-3}	4.2×10^{-6}	70
13	2.2×10^{-3}	5.1×10^{-6}	85	2.3×10^{-3}	5.4×10^{-6}	536	1.9×10^{-3}	4.5×10^{-6}	75
14	2.3×10^{-3}	5.4×10^{-6}	90	2.4×10^{-3}	5.5×10^{-6}	549	2.0×10^{-3}	4.7×10^{-6}	79
15	2.5×10^{-3}	5.7×10^{-6}	95	2.4×10^{-3}	5.6×10^{-6}	560	2.2×10^{-3}	5.0×10^{-6}	83
16	2.6×10^{-3}	6.0×10^{-6}	100	2.5×10^{-3}	5.7×10^{-6}	569	2.3×10^{-3}	5.3×10^{-6}	88
17	2.7×10^{-3}	6.3×10^{-6}	105	2.5×10^{-3}	5.8×10^{-6}	577	2.4×10^{-3}	5.5×10^{-6}	92
18	2.8×10^{-3}	6.6×10^{-6}	110	2.5×10^{-3}	5.9×10^{-6}	585	2.5×10^{-3}	5.6×10^{-6}	96
19	3.0×10^{-3}	6.9×10^{-6}	114	2.6×10^{-3}	5.9×10^{-6}	591	2.6×10^{-3}	6.0×10^{-6}	99
20	3.1×10^{-3}	7.1×10^{-6}	119	2.6×10^{-3}	6.0×10^{-6}	597	2.7×10^{-3}	6.2×10^{-6}	103

TABLE C.7. Waste Generated by Each of the Treatment System Options

Candidate Treatment Technology Options	Solid Waste		Liquid Waste	
	Total Cubic Feet	Constituent Type and Volume	gal (K)	Type
Option 1 No-Action Alternative	0		780	Current waste
Option 2 Filtration and Discharge to Percolation Pond	66	66 Filter	780	Filtered waste
Option 3 Filtration and Discharge to Lined Evaporation Pond	66	66 Filter	780	Filtered waste
Option 4 Ion Exchange and Recycle	595	159 Filter 250 Resin	58.1	Regeneration waste
Option 5 Ultrafiltration, Dual Reverse Osmosis, and Recycle	246	66 Filter 180 Media	130	Cleaning sol.; concen. waste
Option 6 Reverse Osmosis, Evaporation, and Recycle	149	66 Filter 83 Media	37.2	Cleaning sol.; concen. waste; descale sol.
Option 7 Evaporation and Recycle	252	66 Filter 186 GAC[a]	94.8	Descale sol.; concen. waste

(a) GAC = granulated activated charcoal

C.3.4 Other Environmental Issues

Other environmental issues were specific to each of the particular candidates examined. These issues included water quality, nonradiological constituents of the liquid streams, potential land clean-up liability, effect on wildlife, soil, transport of waste, air quality permitting, chemicals used in treatment processes, and resource commitments. Tables C.8 and C.9 show water quality and nonradiological constituents of the process streams for the various options.

C.3.5 Candidate Treatment Systems

Important environmental issues for each of the candidate treatment systems are discussed in the following subsections.

TABLE C.8. Water Quality Parameters and Nonradiological Constituents Before Treatment (ppm)

Parameters	Well	Laundry	Option 4	Option 5	Option 6	Option 7
Sodium	17	50	35,000	250	500	460
Calcium	64	64	1,480	360	660	630
Magnesium	22	22	500	120	220	210
Potassium	3	3	70	20	30	30
Copper	0.01	0.07	2	0.4	0.7	0.7
	0.04					
Zinc	0.05	0.3	7.2	1.5	3.1	2.8
Cadmium	0	0.05	1.2	0.3	0.5	0.5
Nickel	0.002	0.02	0.4	0.1	0.2	0.2
Lead	0.01	0.04	0.9	0.2	0.4	0.4
Silver		0.01	0.2	0.1	0.1	0.1
	90					
Chloride	150	90	950	500	900	870
Bicarbonate	37	150	3,480	860	1,550	1,500
Sulfate	3	79	1,830	410	800	740
Nitrate	0.1	12	280	60	120	110
Silicate		30	690	140	300	270
	0.01					
Chromate	0	0.03	0.7	0.2	0.3	0.3
Cyanide	0.01	0	0	0	0	0
Iron	0	0.01	0.2	0.06	0.1	0.1
Manganese	0.005	0.02	0.4	0.07	0.2	0.1
Arsenic		0.03	0.6	0.1	0.3	0.3
	0.005					
Selenium	0.1	0.07	1.6	0.3	0.7	0.6
Barium	0.002	0.12	3	0.7	1.2	1.2
Mercury	0.2	0.002	0.05	0.01	0.02	0.02
Fluoride	0.1	1.4	30	6.6	14	12
NO_2		0.1	2.3	0.6	1	1
	1					
Carbonate	0.005	1	22	5.4	9.7	9.4
Tin	0	0.005	0.12	0.03	0.05	0.05
PO_4	250	50	1,150	240	500	450
Hardness	0	250	5,800	1,430	2,570	2,480
TSS		300	6,920	1,420	3,000	134
	0					
TOC	310	107	2,460	500	1,070	4.7
TOS	130	630	14,500	3,280	6,380	5,920
Alkalinity		130	2,880	710	1,280	1,240

TABLE C.9. Water Quality Parameters and Nonradiological Constituents After Treatment (ppm)

Parameters	Options 1, 2, and 3	Option 4	Option 5	Option 6	Option 7
Sodium	50	0.3	0.3	10	0.5
Calcium	64	0.3	0.4	13	0.7
Magnesium	22	0.1	0.1	4.3	0.2
Potassium	3	0.02	0.02	0.6	0.03
Copper	0.07	0	0	0.01	0
Zinc	0.3	0	0	0.06	0
Cadmium	0.05	0	0	0.01	0
Nickel	0.02	0	0	0	0
Lead	0.04	0.0002	0.0002	0.008	0.0004
Silver	0.01	0.00005	0.00006	0.002	0.0001
Chloride	90	0.4	0.6	17	1
Bicarbonate	150	0.8	0.9	20	1.7
Sulfate	79	0.4	0.5	15	0.8
Nitrate	12	0.06	0.07	2.4	0.1
Silicate	30	0.2	0.2	6	0.3
Chromate	0.03	0	0	0.006	0.0003
Cyanide	0	0	0	0	0
Iron	0.01	0.00005	0.00006	0.002	0.0001
Manganese	0.02	0.0008	0.00008	0.003	0.0002
Arsenic	0.03	0.0001	0.0001	0.005	0.0003
Selenium	0.07	0.0004	0.0004	0.01	0.001
Barium	0.1	0.0006	0.0007	0.02	0.001
Mercury	0.002	0.00001	0.00001	0.00001	0.00002
Fluoride	1.4	0.007	0.007	0.3	0.01
NO_2	0.1	0.0005	0.0006	0.02	0.001
Carbonate	1	0.005	0.006	0.2	0.01
Tin	0.005	0.00005	0.00003	0.001	0.0007
PO_4	50	0.3	0.3	9.6	0.5
Hardness	250	1.3	1.6	49	2.8
TSS	15	1.5	1.5	58	0.15
TOC	110	0.5	0.5	20	0.005
TDS	630	3.2	3.6	123	6.6
Alkalinity	130	0.6	0.8	25	1.4

Option 1: Existing Treatment System (No-Action Alternative)

The "no-action alternative" results in liquid effluents being sent to the percolation pond where the contaminants can accumulate in the soil or migrate down through the soil. The accumulation was calculated and is shown in Table C.5. The assumption for these calculations is that the contaminants accumulate in the first foot of soil and are homogeneously mixed in one percolation pond area. The percolation pond does not guarantee containment of the contaminants and this option has the highest probability of contamination spread.

Option 2: Filtration and Discharge to a Percolation Pond

This treatment option added a filtration unit, limiting accumulation of radionuclides in the soil to one-half of the no-action alternative, because the filter efficiency is assumed to be 50% for radionuclides in the suspended solids. Radionuclides still accumulate, but not as fast; it would require twice as many years to accumulate to values equal to those in Option 1.

Option 3: Filtration and Discharge to a Lined Evaporation Pond

Option 3 also includes a filtration unit but discharges to a lined evaporation pond, which keeps the radionuclides in the pond separated from the soil. However, the possibility of airborne contamination still exists, in particular for tritium released with water vapor. Particulate radionuclides may be released via resuspension of dried solids on the liner of the pond.

Option 4: Ion Exchange and Water Recycle

The principal concern with the ion exchange option is waste generation. This option generates both solid and liquid wastes. The quantity of resin waste is calculated assuming an average replacement of the resin beds every 1.5 years. Regeneration of the resin would be every 10 days or 2 weeks and would result in 58,100 gallons of waste water. The regeneration waste consists of about 3 to 5% (by weight) salts with

95% of the salt being sodium chloride if HCL and NaOH is used in regeneration. These liquid wastes are held in above-ground tanks until final disposal elsewhere onsite where they are evaporated prior to calcination.

Option 5: Ultrafiltration, Dual Reverse Osmosis, and Water Recycle

The reverse osmosis option generates solid and liquid wastes. The reverse osmosis medium is changed every 3 years and the amount of waste medium generation is a yearly average of the third-year disposal amount. Two types of waste comprise the liquid waste: concentrated waste and cleaning waste. The composition of the concentrated waste is given Table C.8. The cleaning waste will be an acidic solution or detergent to dissolve the particulate matter or ion entrapped in the membrane. These wastes are also held in an above-ground tank prior to their disposal onsite by calcination.

Option 6: Reverse Osmosis, Evaporation, and Water Recycle

The waste produced by the reverse osmosis/evaporator option is similar to the waste produced by both the reverse osmosis and evaporator options. This option does not use granular activated carbon (GAC). The water quality from each process is compared in Table C.9. The liquid waste is held in an above-ground tank prior to its disposal onsite by calcination.

Option 7: Evaporation and Water Recycle

The evaporation option produces both solid and liquid wastes. The GAC is removed yearly by a vendor who will recharge the column and dispose of the depleted carbon. The liquid waste, whose composition is shown in Table C.8, is the concentrate from the bottom of the evaporator. The other liquid waste is a descaling solution that is acidic and is used yearly to remove scale build-up in the evaporator. This waste is held in an above-ground tank prior to disposal onsite by calcination.

C.4 ANALYSIS OF OPERATIONAL ISSUES

Operational issues for the LRCF were also evaluated within three general categories: public policy, safety, and general operational issues. Public policy issues included the perception of potential for eventual leaching of radionuclides into groundwater, air pollution, effects on wildlife, and perception of the potential for generation of mixed waste. Safety issues included filter changeouts and handling, use of hazardous chemicals, and high voltage sources. Specific operational issues for each treatment option are discussed in the following subsections.

The operational issues category received 37% of the total weighting associated with all issues. Within the operational issues category, general operational issues received 17%, while safety and public policy issues each received 10%.

Comment: Issues of safety and public policy now have a more important part in operational issues than when considered in this BATREC analysis. DOE Field Offices may wish to consider including public input in the BAT selection process.

Option 2 (filtration and percolation pond discharge) was the highest ranked treatment system in the operational issues category. Option 2 received 205 points, followed closely by Option 3 (filtration and lined evaporation pond discharge) at 201 points. A summary of the operational issues evaluation is provided in Table C.10.

TABLE C.10. Operational Issues Matrix for Laundry and Respirator-Cleaning Facility (LRCF)

Operational Issues		No-Action Alternative (Option 1)	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Significant Nuclides (in liquid effluent stream after treatment)		^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{60}Co,^{90}Sr ^{137}Cs, ^{3}H	^{60}Co,^{90}Sr ^{137}Cs, ^{3}H	^{3}H	^{3}H	^{3}H	^{3}H
ISSUES	WF	VF	VF	VF	VF	VF	VF	VF
Safety Issues	10	5	5	5	3	3	1	1
Public Policy	10	5	7	10	10	10	10	10
Other Operational Issues	17	5	5	3	1	1	1	1
Weighted Value Factor for Operational Issues ∑(WFxVF)	(WVF)	185	205	201	147	147	127	127

C.4.1 Option 1: Existing Treatment System (No-action Alternative)

The only operational issues identified for the no-action alternative were those of public policy. There is potential for eventual leaching of radionuclides from the discharge area and public concern about the effects of this leaching; there is also the perception of the potential for generation of mixed waste.

C.4.2 Option 2: Filtration and Discharge to a Percolation Pond

The operational issues identified for Option 2 were those associated with the filter, including operation of the filter unit (differential pressure monitoring) and filter changeout (safety, removal when the differential pressure increase or decreases to specified values). Public policy issues included the potential for leaching, effects on wildlife, air pollution, and generation of mixed waste.

C.4.3 Option 3: Filtration and Discharge to a Lined Evaporation Pond

Some of the operational issues identified for Option 3, associated with filter unit operation and filter changeout, were similar to those for Option 2. Other operational issues for Option 3 included clean-out of the lined evaporation pond, possible need for agitation of water, possibly recirculating water to reduce volume, and reusing hot water. Public policy issues included effects on wildlife, air pollution, leak detection, and potential for generation of mixed waste.

C.4.4 Option 4: Ion Exchange and Water Recycle

The main operational issues identified for Option 4 were monitoring the water to be recycled to determine time for regeneration of the resin (estimated every 2 weeks), regenerating the resin with 10% HCl solution and 1 molar NaOH, and operating the process continuously to preserve proper polishing of the water. Other issues considered were maintenance of a separate building for the ion exchange system, change-out of filter and carbon bed resin, system down-time for resin regeneration, the need for additional trained personnel, system reliability, potential increase in waste and waste handling, and cost. A safety issue was the use of hazardous chemicals, and a public policy issue was the possible generation of mixed waste.

C.4.5 Option 5: Ultrafiltration, Dual Reverse Osmosis, and Water Recycle

The major operational issues for Option 5 were monitoring the differential pressure across the reverse osmosis unit to determine the extent of fouling, periodically washing the membrane surface to remove particulates entrapped in the pores of the membrane media, and monitoring product water quality for recycling back to the laundry. Other issues considered were similar to those for Option 4, such as maintenance of a separate building for the filtration/osmosis system, change-out of filter and osmosis membrane, the need for additional trained personnel, system reliability, and potential increase in waste and waste handling. A safety issue was the use of hazardous chemicals, and a public policy issue was the possible generation of mixed waste.

C.4.6 Option 6: Reverse Osmosis, Evaporation, and Water Recycle

Option 6 issues incorporate those from Option 5 (reverse osmosis) and Option 7 (evaporator), because both processes are incorporated in this treatment system. Issues were monitoring the differential pressure across the reverse osmosis unit to determine the extent of fouling, periodically washing the membrane surface to remove particulates entrapped in the pores of the membrane media, maintenance of a separate building for the reverse osmosis system, change-out of the reverse osmosis membrane, the need for additional trained personnel, system reliability, potential increase in waste and waste handling, temperature of the evaporator, descaling with acidic solution, and monitoring the condensate quality for recycle into the laundry. Safety issues were the use of hazardous chemicals and high voltage, and a public policy issue was the possible generation of mixed waste.

C.4.7 Option 7: Evaporation and Water Recycle

Option 7 operational issues were all related to the evaporator and included temperature of the evaporator, descaling with acidic solution, and monitoring of the condensate quality for recycle into the laundry. Safety issues were the use of hazardous chemicals and high voltage, and a public policy issue was the possible generation of mixed waste.

C.5 ANALYSIS OF ENERGY AND RESOURCE ISSUES

The category of energy and resource use evaluated in determining the LRCF BATREC addressed the combined issue of electricity use, fuel use, and water use. The energy and resource category received only 6% of the total weighting associated with all three technical categories. The energy and water requirements for each treatment/process option evaluated are compared in Table C.11.

Compared with the no-action option, there was no additional electricity or fuel use for Options 2 and 3, the filtering and discharge options. There was slightly increased electrical power usage for treatment options that recycle the laundry process stream (Options 4, 5, 6, and 7). In these options electricity is used only for pumping liquid through the various process units. The additional usage and cost was similar for all four options, with additional annual cost ranging from $1 to 3K. No fuel was used for Options 1, 2, 3, 4 or 5, but fuel was used extensively for Options 6 and 7, chiefly as the power source to drive the evaporation processes.

Water usage for each of the treatment options was based on 260 operating days per year, and varied from approximately 4,000 to 37,000 gallons per operating day. Table C.11 shows total water usage and broken down by cooling water, and hot and cold water streams. Cold water use is the same for all

TABLE C.11. Estimates for Annual Utility Cost and Daily Water Consumption

Options	Additional Annual Utility Cost ($K)			Total Water Usage (1000s gal/day)			
	Electric	Fuel	Total	Cooling	Hot	Cold	Total
Option 1 No-Action Alternative	--	--	--	8	3.0	3.8	6.8
Option 2 Filtration and Discharge to Percolation Pond	0	0	0	0	3.0	3.8	6.8
Option 3 Filtration and Discharge to Lined Evaporation Pond	0	0	0	0	3.0	3.8	6.8
Option 4 Ion Exchange and Water Recycle	3.0	0	3.0	0	0.1	3.8	3.9
Option 5 Ultrafiltration, Dual Reverse Osmosis, and Water Recycle	2.2	0	2.2	0	0.6	3.8	4.4
Option 6 Reverse Osmosis, Evaporation, and Water Recycle	1.5	25	26.5	8.5	0.2	3.8	12.5
Option 7 Evaporation and Water Recycle	1	97	98	32.7	0.7	3.8	37.2

seven options. Significant reduction in hot water use were noted for Options 4, 5, 6, and 7, which use ion exchange, reverse osmosis, and/or evaporation. Options 4 and 5 result in less overall use of water because of recycling. Options 6 and 7 also recycle water, but are the only options that use cooling water. Copious amounts of cooling water are needed to condense water vapors to liquid in the evaporation process. The condensate can then be cooled to temperatures needed for the laundry. Service water may be added to the hot water to cool the water to secondary temperatures.

The weighted value factors for energy and resource issues are shown in Table C.12. None of the possible treatment options were rated better than the no-action alternative for this category, although two options were rated the same as the no-action alternative. Energy use (electricity, fuel) was deemed more important than water usage. Consequently, options using no additional energy (Options 2 and 3) were ranked higher than those that used more energy but less water (Options 4 and 5). Options that had both high energy use and high water use were ranked the lowest (Options 6 and 7).

C.6 ANALYSIS OF ECONOMIC FEASIBILITY

The costs associated with any new facility construction (capital costs), normal operation and maintenance, waste disposal, and decommissioning or clean-up are shown in Table C.13.

Estimated yearly operating costs for a 20-year facility lifetime are shown in Table C.14, and a break-down of the first year operating costs are shown in Table C.15.

The economic figures-of-merit (FOM) are summarized in Table C.16. Three different FOM were determined for this BAT analysis: the levelized life-cycle cost of radionuclide removal (LCCRR), which is the preferred alternative for calculating the FOM (DOE/EH-263T, Appendix A). The real annualized cost (AC) and the net present value (NPV) were also calculated as the FOM, using guidance provided in DOE/EH-263T. The capital recovery factor (CRF) used was 0.12; it was calculated using the DOE guidance and used to determine the AC.

TABLE C.12. Energy and Resource Issues Matrix for the Laundry and Respirator-Cleaning Facility (LRCF)

Energy and Resource Issues		No-Action Alternative (Option 1)	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Significant Nuclides (in liquid effluent stream after treatment)		^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{3}H	^{3}H	^{3}H	^{3}H
ISSUES	WF	VF	VF	VF	VF	VF	VF	VF
Energy Issues	6	5	5	5	3	3	2	1
Weighted Value Factor for Energy and Resource Issues $\sum(WF \times VF)$	(WVF)	30	30	30	18	18	12	6

TABLE C.13. Life-Cycle Costs for LRCF Treatment Options

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Net Present Value (NPV)	$350 K	$1.2 M	$1.9 M	$4.5 M	$4.2 M	$2.6 M	$5.4 M
NPV (Operations)	$0	$200 K	$240 K	$3.3 M	$3.8 M	$2.3 M	$4.9 M
Annual Cost (AC)	$42 K	$140 K	$230 K	$530 K	$500 K	$310 K	$630 K
Ci Removed (RR)	0	7.3 x 10	1.5 x 10^{-1}	1.5 x 10^{-1}	1.5 x 10^{-1}	1.5 $^{-2}$x 10^{-1}	1.5 x 10^{-1}
LCCRR (AC/RR)	∞	$1.9 M	$1.5 M	$3.5 M	$3.3 M	$2.1 M	$4.2 M
Cost/Pound	$0.14	$0.47	$0.75	$1.76	$1.66	$1.03	$2.11
Op. Cost/Pound	$0.00	$0.04	$0.04	$0.61	$0.69	$0.42	$0.89
Capital Costs	$0	$5 K	$950 K	$610 K	$250 K	$190 K	$280 K
Clean-Up Costs	$520 K	$520 K	$170 K	$4.1 M	$1.7 M	$1.2 M	$1.9 M

TABLE C.14. Estimated Yearly Operating Costs for LRCF Treatment Options

Year of Operation	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
1	$0	$10,900	$13,200	$182,850	$207,350	$125,350	$267,200
2	$0	$11,990	$14,520	$201,135	$228,085	$137,885	$293,920
3	$0	$13,199	$15,972	$221,249	$250,894	$151,674	$323,312
4	$0	$14,508	$17,569	$243,373	$275,983	$166,841	$355,643
5	$0	$15,959	$19,326	$267,711	$303,581	$183,525	$391,208
6	$0	$17,555	$21,259	$294,482	$333,939	$201,877	$430,328
7	$0	$19,310	$23,385	$323,333	$367,333	$222,065	$473,361
8	$0	$21,241	$25,723	$356,323	$404,066	$244,272	$520,697
9	$0	$23,365	$28,295	$391,955	$444,473	$268,699	$572,767
10	$0	$25,702	$31,125	$431,151	$488,920	$295,569	$630,044

TABLE C.15. Breakdown of First Year Annual Operating Costs for the LRCF Treatment Options

Expenses	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Labor	0	1,100	3,300	21,000	28,000	17,500	24,000
Electricity	0	0	0	3,300	2,500	1,300	1,800
Fuel	0	0	0	0	0	97,000	25,000
Filters	0	8,800	8,800	21,200	8,800	8,800	8,800
Chemicals	0	0	0	3,100	22,000	2,000	13,400
Resins	0	0	0	35,000	0	0	0
GAC	0	0	0	28,000	0	28,000	0
RO Media	0	0	0	0	13,000	0	6,000
Waste Disposal	0	300	300	69,000	131,000	110,000	43,000
Equipment Repairs	0	500	500	1,000	750	1,250	1,000
Preventive Maintenance	0	100	200	250	300	350	350
Training	0	100	100	1,000	1,000	1,000	2,000
Total First Year Operating Cost	0	10,900	13,200	182,850	207,350	267,200	125,350

TABLE C.16. Economic Figures-of-Merit for LRCF Treatment Options

Treatment Option	Economic Figures-of-Merit (rank)[a]		
	LCCRR	AC	NPV
1	∞	$42 K **(1)**	$350 K **(1)**
2	$1.9 M (2)	$140 K (2)	$1.2 M (2)
3	$1.5 M **(1)**	$230 K (3)	$1.9 M (3)
4	$3.5 M (5)	$530 K (6)	$4.5 M (6)
5	$3.3 M (4)	$500 K (5)	$4.2 M (5)
6	$2.1 M (3)	$310 K (4)	$2.6 M (4)
7	$4.2 M (6)	$630 K (7)	$5.4 M (7)

(a) LCCRR = levelized life-cycle cost of radionuclide removal
AC = annualized cost
NPV = net present value

Option 3 had the best calculated LCCRR FOM and was therefore considered the best option from a strictly economic standpoint. Not unexpectedly, Option 1 had the best FOM for both the AC and NPV, because this is the no-action alternative. However, these are secondary FOMs, and the primary LCCRR FOM could not be calculated for Option 1, because there was no radionuclide removal (RR = 0).

Comment: This section should provide additional information on methods used in determining capital costs, operating and maintenance (O&M) costs, and decommissioning costs. Additional information is also needed on the levelized cost methodology, including cost assumptions, cost and cash flow calculations, and a description of the economic analysis for each of the candidate treatment options. The information presented needs to reflect the guidance provided in Chapter 6.0 and in Appendix A of DOE/EH-263T.

C.7 SELECTION OF BEST AVAILABLE TECHNOLOGY FOR RADIOACTIVE EFFLUENT CONTROL

Selection of the BATREC for the LRCF was a three-step process, using guidance provided in the main text of this document (DOE/EH-263T). Only technologies that comply with all applicable standards, limits, and regulations can be considered for the BATREC.

C.7.1 Technology Issues Matrix

The first step in the BATREC selection process was to assemble a technology issues matrix. A major part of this step was to determine the weighting factors for each of the issues identified during the evaluation phase. DOE/EH-263T requires that all weighting factors add up to 100, and that the environmental impact issues comprise at least 50% of the total weight. The weighting factors determined for each impact issue were incorporated into the evaluation tables for environmental, operational, and energy and resource impacts in Sections C.3.0, C.4.0, and C.5.0, respectively. In summary, however, environmental weighting factors totaled 57, operational weighting factors totaled 37, and energy and resource weighting factors totaled 6, which add up to 100.

Total weighted value factors (TWVFs) were calculated for each candidate technology, using the weighting factors and value factors determined during the evaluation phase. These are shown the summary matrix in Table C.17. Option 3, the filtration and confined discharge option, had the highest TWVF. This is the BAT based on technical issue categories only. Other options were ranked as shown in Table C.17.

C.7.2 Economic Figures-of-Merit

The second step in the final BATREC selection process was to select the appropriate type of economic FOM and assemble figures for each of the candidate treatment systems. Appendix A of this document the LCCRR as the preferred FOM, so the LCCRR was used in this analysis. Other types of FOM calculated but not used were the AC and NPV.

TABLE C.17. Technology Issues Matrix for the Laundry and Respirator-Cleaning Facility (LRCF)

Summary of Technology Issues in Control Technology Comparisons		No-Action Alternative (Option 1)	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Significant Nuclides (in liquid effluent stream after treatment)		^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{60}Co, ^{90}Sr ^{137}Cs, ^{3}H	^{3}H	^{3}H	^{3}H	^{3}H
ISSUE CATEGORY	W	WVF[b]	[a]WVF	WVF	WVF	WVF	WVF	WVF
Environmental Issues	57	285	374	497	513	475	490	408
Operational Issues	37	185	205	201	147	147	127	127
Energy and Resource Issues	6	30	30	30	18	18	12	6
Total Weighted Value Factor (rank)		500 (7)	609 (5)	728 (1)	690 (2)	640 (3)	635 (4)	541 (6)

(a) W = the total weight assigned to each issue category.
(b) WVF = weighted value factor.

C.7.3 Final Cost-Effect Analysis and Candidate Selection

The final step of the selection process was to assemble the information from the first two steps to analyze and rank the cost and effectiveness of the treatment options. The assembled information and results of the analysis are shown in Table C.18. The BATREC for the LRCF was clearly Option 3 (filtration and discharge of effluent to a lined evaporation pond). Option 3 had the highest TWVF, and, fortuitously, it also had the highest economic FOM, making the selection simple. Overall, Option 3 ranked second in environmental impact issues, second in operational impact issues, and tied for first in energy and resource impacts issues.

TABLE C.18. The Cost-Effect Analysis Table for Determining the LRCF BATREC

Treatment Option	TWVF[(a)]	Economic Figures-of-Merit LCCRR ($/Ci)	Overall BATREC Ranking		
			TWVF Only	80/20 T/E[(b)]	50/50 T/E
3	728	$1.5 M	1	1	1
4	690	$3.5 M	2	2	4
5	640	$3.3 M	3	4	5
6	635	$2.1 M	4	2	2
2	609	$1.9 M	5	4	2
7	541	$4.2 M	6	6	6
1 (NAA)	500	∞	7	---	---

(a) TWVF = Total weighted value factor
(b) T = technical issues (environment, operations, energy/resource)
E = economic issues

In addition to using only the TWVF to select the BATREC, a system of ranking the candidates based on TWVF and economic issues was developed. This system can help in ranking candidate technologies based on a pre-determined importance of technical (TWVF) and economic issues. For example, in Table C.18 two additional rankings are provided, based on 80% technical/20% economic, and 50% technical/50% economic issues. In all cases Option 3 was the top-ranked candidate. However, rankings of other technologies could vary considerably based on the relative importance of technical vs. economic factors and differences between TWVFs and FOM of the various options. The no-action alternative could not be ranked because no FOM could be determined for it.

In terms of economic issues, although the capital cost for Option 3 was one of the highest due to the need to build the lined evaporation pond, it had the lowest annual cost and life cycle cost (net present value) except for the no-action alternative (Option 1). The no-action alternative, of course, disposes waste water directly to the environment. The lined evaporation pond provides for the isolation of the only contaminated waste water stream (lower than the DCGs), but it is not total containment because of the possibility of release of contaminants to the environment through air pathways. The pond is used as a natural processing unit to separate the contaminants from the water by evaporation. Radionuclides (and other contaminants) will be concentrated in the pond water volume. Ultimate disposal of radionuclides and other contaminants will occur at the end of the pond or facility lifetime. Disposal may be accomplished by allowing all of the water to evaporate and removing the solid residue into double-lined drums for disposal at a low-level radioactive landfill.

The pond will be monitored to ensure the integrity of the liner. Controls will be in place to prevent animal entry into the pond or burrowing through the liner. Future recycling of the laundry's "hot" process streams may concentrate the contaminants inside the laundry prior to their release. Waste minimization within the laundry may cause the waste stream to be more contaminated, but the lined pond will provide separation from the environment until the contaminants can be permanently removed and disposed of.

C.8 REFERENCE

U.S. Department of Energy (DOE). 1990. *Radiation Protection of the Public and the Environment*. DOE 5400.5, Washington, D.C.

10 CFR Part 834. 1996. *Radiation Protection of the Public and the Environment*. (61 FR _____).