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Small System Compliance Technology List for the Non-Microbial Contaminants Regulated Before 1996

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1. INTRODUCTION

Section 1.1: Safe Drinking Water Act Implementation

The Safe Drinking Water Act (SDWA) Amendments were signed by the President on August 6, 1996. The 1996 SDWA contains over 70 statutory deadlines for the Environmental Protection Agency (EPA), presenting a challenging set of activities for EPA, States, Indian tribes, public water systems, and other stakeholders.

Due to the 1996 SDWA's emphasis on public information and participation, as well as EPA's desire to seek a broad range of public input, the stakeholder process that was begun during the 1995 drinking water program redirection effort has been greatly expanded. To provide focus, EPA has grouped many of the statutory deadlines into more general project areas. Each of these areas has a broad set of stakeholders that will provide information and comments.

One of these project areas focuses on small systems treatment technologies and is being addressed by EPA's Treatment Technology Team. This project area is a part of one of the primary objectives of the 1996 SDWA, which is to more fully consider the needs of small drinking water systems in developing and implementing drinking water regulations. The mission of the Treatment Technology Team is to identify and/or develop high quality, cost-effective treatment technologies to meet regulation development and program implementation objectives and deadlines. The team's short-term goals are to prepare: (1) by August 6, 1997, the list of technologies that small systems can use to comply with the Surface Water Treatment Rule (SWTR); (2) by August 6, 1998, the list of technologies that small systems can use to comply with all of the other (pre-August 1996) National Primary Drinking Water Regulations (NPDWRs); and (3) by August 6, 1998, the list of variance technologies for small systems for the appropriate NPDWRs. The long-term goals include the identification of: (1) small system compliance and variance technologies for all future regulations; (2) best available technologies (BATs) for larger systems in future regulations; and (3) emerging technologies that should be evaluated as potential compliance or variance technologies for both existing and future regulations.

The Environmental Protection Agency met the first of these short-term goals in August, 1997. A Federal Register notice dated August 11, 1997 published the compliance technology list for the surface water treatment rule (EPA 1997a). The notice also announced the availability of a guidance manual entitled "Compliance Technology List for the Surface Water Treatment Rule" (EPA 1997b), which provided more detailed background information supporting the list of technologies published in the Federal Register notice.

The Environmental Protection Agency updated the list of compliance technologies for the SWTR and published the list of compliance technologies for the total coliform rule in a Federal Register notice on August 6, 1998 (EPA 1998a). EPA is also publishing an update to the guidance manual that supported the original SWTR list of compliance technologies. The updated guidance manual is entitled "Compliance Technology List for the Surface Water Treatment Rule and the Total Coliform

Rule" (EPA 1998b). This document covers both update of the SWTR list and the compliance technologies identified for the Total Coliform Rule (TCR). These have been grouped into one publication as they both address microbial contaminants and their indicators in drinking water. The list of compliance technologies for the total coliform rule is one of the lists required by Section 1412(b)(4)(E)(iii) of the SDWA.

The Environmental Protection Agency met both the second and third of the short-term goals in August 1998. A Federal Register notice dated August 6, 1998 (EPA 1998a) published the list of compliance technologies that systems can use to comply with all of the other NPDWRs and the findings concerning variance technologies for the contaminants regulated before 1996. EPA did not list any variance technologies for contaminants regulated before 1996 in this notice. This guidance manual was developed to provide more detail on the list of compliance technologies for the non-microbial contaminants regulated before 1996. A guidance manual entitled "Variance Technology Findings for Contaminants Regulated before 1996" has been prepared to describe the procedures that were used to make the determination that there would be no variance technologies for contaminants regulated before 1996 at this time (EPA 1998c).

Section 1.2: Need for a Small System Technology Requirement

The 1986 SDWA identified a process for setting maximum contaminant levels (MCLs) as close to the maximum contaminant level goal (MCLG) as is "feasible." The Act states that the term "feasible" means feasible with the use of the best technology, treatment techniques and other means which the Administrator finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (taking cost into consideration) [Section 1412(b)(4)(D)]. The technologies that met this feasibility criterion are called "best available technologies" (BATs) and are listed in the final regulations. This process is retained in the 1996 SDWA. All of the existing MCLs covered in this document were developed using this process.

One of the regulations covered in this document is the Lead and Copper Rule, which requires compliance with a treatment technique rule rather than an MCL. Section 1412(b)(7)(A) of the 1986 SDWA listed the conditions under which a treatment technique could be promulgated in lieu of an MCL. When these conditions are met, the Act states that ". . . the Administrator must identify those treatment techniques which, in the Administrator's judgement, would prevent known or anticipated adverse effects on the health of persons to the extent feasible". The definition of feasible listed above would also apply in the technology determinations for treatment techniques like the Lead and Copper Rule.

There is one other treatment technique rule in the group of non-microbial contaminants regulated before 1996: epichlorohydrin and acrylamide are regulated through the Phase II Rule (see Chapter 2) via a treatment technique rather than with MCLs. Unlike the technology-based treatment techniques established by the SWTR or the Lead and Copper Rule, the treatment techniques for these two contaminants are not based on the use of treatment technologies to remove or reduce the contaminant concentration. Instead, the treatment technique for these two contaminants requires

those public water systems using acrylamide or epichlorohydrin in a treatment process to provide written certification annually to the State that the combination of dose and monomer level does not exceed specified levels. Since technologies are not being utilized for these NPDWRs, neither compliance nor variance technologies will be listed for these contaminants.

Before the 1996 Amendments, cost assessments for the treatment technology feasibility determinations were based upon impacts to regional and large metropolitan water systems. This protocol was established when the SDWA was originally enacted in 1974 (Congressional Record 1974) and was carried over when the Act was amended in 1986 (Congressional Record 1986). The population size categories that EPA has used to make feasibility determinations for regional and large metropolitan water systems has varied among different regulation packages. The most common population size categories used were 50,000 - 75,000 people and 100,000 - 500,000 people. The technical demands and costs associated with technologies that are feasible based on regional and large metropolitan water systems often make these technologies inappropriate for small systems. The 1996 Amendments attempt to redress this problem in part through the previously described series of small system compliance technologies. This guidance is the second part of a series of publications aimed at helping small systems comply with the existing regulations.

Section 1.3: Small System Treatment Technology Requirements of the 1996 SDWA

Since large systems were used as the basis for the feasibility determinations, some of the existing BATs for MCLs and the existing treatment techniques may not be appropriate for small systems. In response to this concern, the 1996 SDWA specifically requires EPA to make technology assessments relevant to the three categories of small systems respectively for both existing and future regulations, in addition to the pre-1996 Amendments BAT protocol. The three population-served size categories of small systems defined by the 1996 SDWA are: 10,000 - 3,301 persons, 3,300 - 501 persons, and 500 - 25 persons.

The 1996 SDWA identifies two classes of technologies for small systems: compliance technologies and variance technologies. A "compliance technology" may refer to both a technology or other means that is affordable and that achieves compliance with the MCL and to a technology or other means that satisfies a treatment technique requirement. Possible compliance technologies include packaged or modular systems and point-of-entry (POE) or point-of-use (POU) treatment units [see Section 1412(b)(4)(E)(ii)]. Variance technologies are only specified for those system size/source water quality combinations for which there are no listed compliance technologies [Section 1412(b)(15)(A)]. Thus, the listing of a compliance technology for a size category/source water combination prohibits the listing of variance technologies for that combination. While variance technologies may not achieve compliance with the MCL or treatment technique requirement, they must achieve the maximum reduction or inactivation efficiency that is affordable considering the size of the system and the quality of the source water. Variance technologies must also achieve a level of contaminant reduction that is protective of public health [Section 1412(b)(15)(B)].

The variance procedure for small systems has been significantly revised in the 1996 SDWA. The

1986 SDWA required non-compliant water systems to install a "best available technology" (BAT) before applying for a variance: if they were unable to meet the MCL after treatment, they could then apply for a variance. The 1996 Amendments have given the variance option additional flexibility in that variances can be applied for and granted *before* the variance technology is installed, thus ensuring that the system will have a variance before it invests in treatment. This new variance procedure applies specifically to small water systems (systems serving less than 10,000) and is referred to as the "small system variance". The difference between the original variance and the small system variance procedures is the basis for the feasibility (technical and affordability) determination. For the former, large systems are the basis; for the latter, small systems are the basis. If there are no affordable compliance technologies listed by the EPA for a small system size category/source water quality combination and EPA has identified small systems variances technologies for that combination, then the system may apply for a small system variance. One of the criteria for obtaining a small system variance is that the system must install a variance technology listed for that size category/source water quality combination [Section 1415(e)(2)(A)]. A small system variance may only be obtained if alternate source, treatment, and restructuring options are unaffordable at the system-level.

There are some additional statutory requirements for small system variances that affect the listing of variance technologies. Small system variances are not available for any MCL or treatment technique for a contaminant with respect to which a national primary drinking water regulation was promulgated prior to January 1, 1986 [Section 1415(e)(6)(A)]. The final Variance and Exemption Rule provides EPA's interpretation of this requirement (EPA 1998d). In a case where a pre-1986 NPDWR is updated, EPA has determined that small system variances would not be available if the pre-1986 MCL is either retained or raised. Small system variance would only be available if the pre-1986 MCL was lowered (could apply to updates of the existing arsenic and radionuclides MCLs if the pre-1986 MCLs are lowered). Nor are small system variances allowable for NPDWRs (including treatment techniques) for microbial contaminants or microbial contaminant indicators, i.e., bacteria, viruses, other regulated pathogens, or regulated indicators, like turbidity [Section 1415(e)(6)(B)]. Variance technologies were not specified for those contaminants for which small system variances are not allowable by the SDWA.

The process for identifying compliance and variance technologies for future regulations was summarized in the preceding paragraphs. The language in the 1996 SDWA Amendments is different for the existing regulations. There are two mandatory lists of compliance technologies that will be developed for the existing rules. By August 6, 1997, the Administrator was required to list technologies that meet the SWTR for each of the three size categories [Section 1412(b)(4)(E)(v)]. By August 6, 1998, after consultation with the States, the Administrator was required to issue a list of technologies that achieve compliance with the MCLs or treatment technique requirements for other existing NPDWRs. Also by August 6, 1998, after consultation with the States, the Administrator was required to issue guidance or regulations for variance technologies for the existing NPDWRs for which a small system variance can be granted. Figure 1 summarizes the requirements for compliance and variance technologies and differentiates between existing and future regulations.

FIGURE 1
SMALL SYSTEM REQUIREMENTS
COMPLIANCE VS. VARIANCE TECHNOLOGIES

	COMPLIANCE TECHNOLOGY	**VARIANCE TECHNOLOGY**
EXISTING REGULATIONS:		
Meet affordable technology criteria	Not Explicitly Required	Inherently Required
Source Water Quality	GOOD	POOR
Endpoint	MCL	Maximum Reduction that is Affordable
Health Requirements Separate from MCL	NONE	Must be protective of public health
FUTURE REGULATIONS:		
Meet affordable technology criteria	Required	Required
Source Water Quality	GOOD	POOR
Endpoint	MCL	Maximum Reduction that is Affordable
Health Requirements Separate from MCL	NONE	Must be protective of public health

The two major concerns regarding technologies for small systems are affordability and technical complexity. Regarding affordability, per household costs tend to be higher for the smaller system customers for most central treatment technologies, leading to many cases where small systems simply cannot afford to install a prescribed technology. Regarding technical complexity, small systems often do not have access to well-trained water system operators. Although the statute is silent concerning

whether small system compliance technologies for *existing* regulations should be affordable, EPA believes that the better approach under the statute is that affordability *should* be evaluated for future regulations and existing regulations where the statute allows variance technologies. If the candidate technologies are not evaluated against an affordable technology criterion, then compliance technologies would exist for all of the existing regulations regardless of the source water quality. The existing best available technologies (BATs) or treatment techniques would automatically become the compliance technologies for small systems, which was the case prior to the 1996 Amendments. EPA does not believe that result to be what Congress intended. As a result, EPA will evaluate small system technologies against an affordable technology criterion for those existing regulations where small system variances or variance technologies are not prohibited by the SDWA. When affordable compliance technologies are identified for these contaminants, technologies that can achieve compliance but did not meet the affordability criterion will also be identified. This is consistent with EPA's approach to the compliance technology list for the SWTR and the views of stakeholders. EPA will list these technologies and indicate that they did not pass the affordable technology criterion rather than limit the information on options available to systems. For those regulations where the SDWA prohibits small system variances or variance technologies, affordability will not be considered in the evaluation of compliance technologies because there would be no function to doing so (all systems subject to the rule must comply).

The flow chart in Figure 2 shows the role of the affordable technology criteria in the treatment technology arena. The primary function of the criteria is to determine whether a system of a given size/source water quality combination should proceed down the compliance or variance technology pathway (assuming an affordable variance technology can be identified). The secondary function is to define the universe of technologies within the compliance or variance technology pathway. These affordable technology criteria are different from the affordability criteria to be used by States in granting small system variances under Section 1415(e). The criteria used by States will be applicable to individual systems ("system-level affordability criteria"). Options that States can use for system-level affordability criteria were developed in the Small System NDWAC Working Group process and are available in "Information for States on Developing Affordability Criteria for Drinking Water." This document was published on February 4, 1998 (EPA 1998e) and can be downloaded at http://www.epq.gov/OGWDW/smallsys/afford.html. In contrast, the affordable technology criteria to be developed under Section 1412(b)(4) can be viewed as "national-level affordability criteria" (EPA 1998f). Technologies that meet the national-level criteria may not be affordable for a particular system within the size category ("system-level affordability criteria"). In these cases, the system should explore the options of restructuring or finding an alternate source of water. If these options are not available, grants and exemptions may be available. These issues are discussed in more detail in Chapter 4. The respective roles of the national-level and system-level affordability criteria are summarized in Figure 2.

FIGURE 2
AFFORDABLE COMPLIANCE TECHNOLOGIES*


```
                          ┌─────────────────┐
                          │   System Out    │
                          │  of Compliance  │
                          └─────────────────┘
                                   │
                                   ▼
                          ╱─────────────────╲
              YES        ╱    Affordable     ╲        NO
          ┌─────────────     Compliance       ─────────────┐
          │             ╲   Technology?      ╱              │
          ▼              ╲─────────────────╱                ▼
    ╱───────────╲                                    ╱───────────────╲
YES╱   Can       ╲ NO                            YES ╱  Can System     ╲ NO
 ──   system afford                           ┌──── afford Treatment    ────┐
   ╲  a compliance╱                           │   ╲ Alt. Source or    ╱     │
    ╲ technology?╱                            │    ╲ Restructuring?  ╱      │
     ╲─────────╱                              ▼     ╲──────────────╱        │
                                        ┌──────────┐    │ YES RS            │
                                        │ Implement │    ▼                  │
                                        │ Treatment,│ ╱──────────╲          │
                                        │ Alt Source│╱  Is        ╲         │
                    ╱──────────╲        │ or        │  Restructuring YES     │
                   ╱ Can System ╲       │Restructuring╲ practicable? ───┐    │
                  ╱  Restructure  ╲ YES └──────────┘  ╲──────────╱      │    │
                 ╲   or afford Alt ─────┘                 │ NO          │    │
                  ╲  Source?     ╱                        │             ▼    ▼
                   ╲───────────╱                          │      ┌───────────────┐
                        │ NO                              │      │  Implement     │
 ┌────────────┐    ╱─────────╲ NO                         └─────▶│  Affordable    │
 │ Implement  │◀──╱   Are     ╲                                  │  variance      │
 │ Compliance │   ╲ Exemptions ╱ NO                             │  technology    │
 │ Technology │    ╲Available ╱                                  └───────────────┘
 └────────────┘     ╲───────╱                                           │
                     │ YES                                              ▼
                ┌──────────┐                                    ┌───────────────┐
                │ Exemption │                                    │ Obtain Small  │
                │Process(State                                   │ System Variance│
                │sets schedule                                   └───────────────┘
                │for compliance)│
                └──────────┘
                     │
                ╱─────────╲
          NO   ╱   Has      ╲  YES
          ┌───╱  exemption    ╲
          │   ╲ period run    ╱
          │    ╲  out?       ╱
          │     ╲──────────╱
          │        │ YES
          └────────┘
```

*NOTE: This approach covers the regulations that pass all of the
        screening criteria for variance technologies.

For those existing regulations where the SDWA prohibits small system variances or variance technologies, the candidate technologies will not be evaluated against an affordable technology criterion. There are two statutory prohibitions on small system variances and one prohibition on variance technologies. As previously mentioned, small system variances are not available for any NPDWR for a microbial contaminant (or indicator). The compliance technologies for the six microbial contaminants were not evaluated against the affordable technology criterion (EPA 1998b). Small system variances are also not available for any MCL or treatment technique with respect to which a NPDWR was promulgated prior to January 1, 1986. Technologies were not evaluated against an affordable technology criterion for the 12 contaminants where the pre-1986 MCL has been retained or raised. The statutory prohibition on variance technologies is found in Section 1412(b)(15)(B) of the SDWA. The Administrator shall not identify any variance technology under this paragraph, unless the Administrator has determined, considering the quality of the source water to be treated and the expected useful life of the technology, that the variance technology is protective of public health. For 19 contaminants, it was determined that in order to be protective of public health, the MCL had to be met. Thus, affordable compliance technology determinations were not done for 31 of the 71 contaminants with listed compliance technologies or for the six microbial contaminants, which are covered in another document. The flow chart in Figure 3 shows the simplified process for these regulations. In this figure, "no affordability" refers to the fact that affordability considerations are not allowed for these contaminants.

FIGURE 3
COMPLIANCE TECHNOLOGIES (No affordability)*

```
                    ┌─────────────────┐
                    │   System Out    │
                    │  of Compliance  │
                    └────────┬────────┘
                             │
                             ▼
         YES              ◇ Can ◇              NO        ┌──────────────┐
    ┌───────────────  system afford  ───────────┐       │  Implement   │
    │               a compliance                 │       │ Alt. Source  │
    │                technology?                 │       │     or        │
    │                    ◇                       │       │ Restructuring │
    │                                            ▼       └──────▲───────┘
    │                              ◇ Can System ◇                │
    │                                Restructure                 │
    │                               or afford Alt    YES         │
    │                                  Source?  ─────────────────┘
    │                                    ◇
    │                                    │ NO
    │                                    ▼
    │          NO           ◇   Are    ◇          NO
    │      ┌──────────────  Exemptions  ─────────────────┐
    │      │                Available                    │
    ▼      ▼                    ◇                         │
 ┌─────────────┐               │ YES                     │
 │  Implement  │               ▼                         │
 │ Compliance  │     ┌──────────────────┐               │
 │ Technology  │     │   Exemption      │               │
 └──────▲──────┘     │ Process(State    │               │
        │            │ sets schedule    │               │
        │            │ for compliance)  │               │
        │            └────────┬─────────┘               │
        │                     │                         │
        │                     ▼                         │
        │            ◇   Has   ◇                        │
        │              exemption                        │
        │            period run    YES                  │
        │      NO       out?   ────────────────────────┘
        │                ◇
        │                │ YES
        └────────────────┘
```
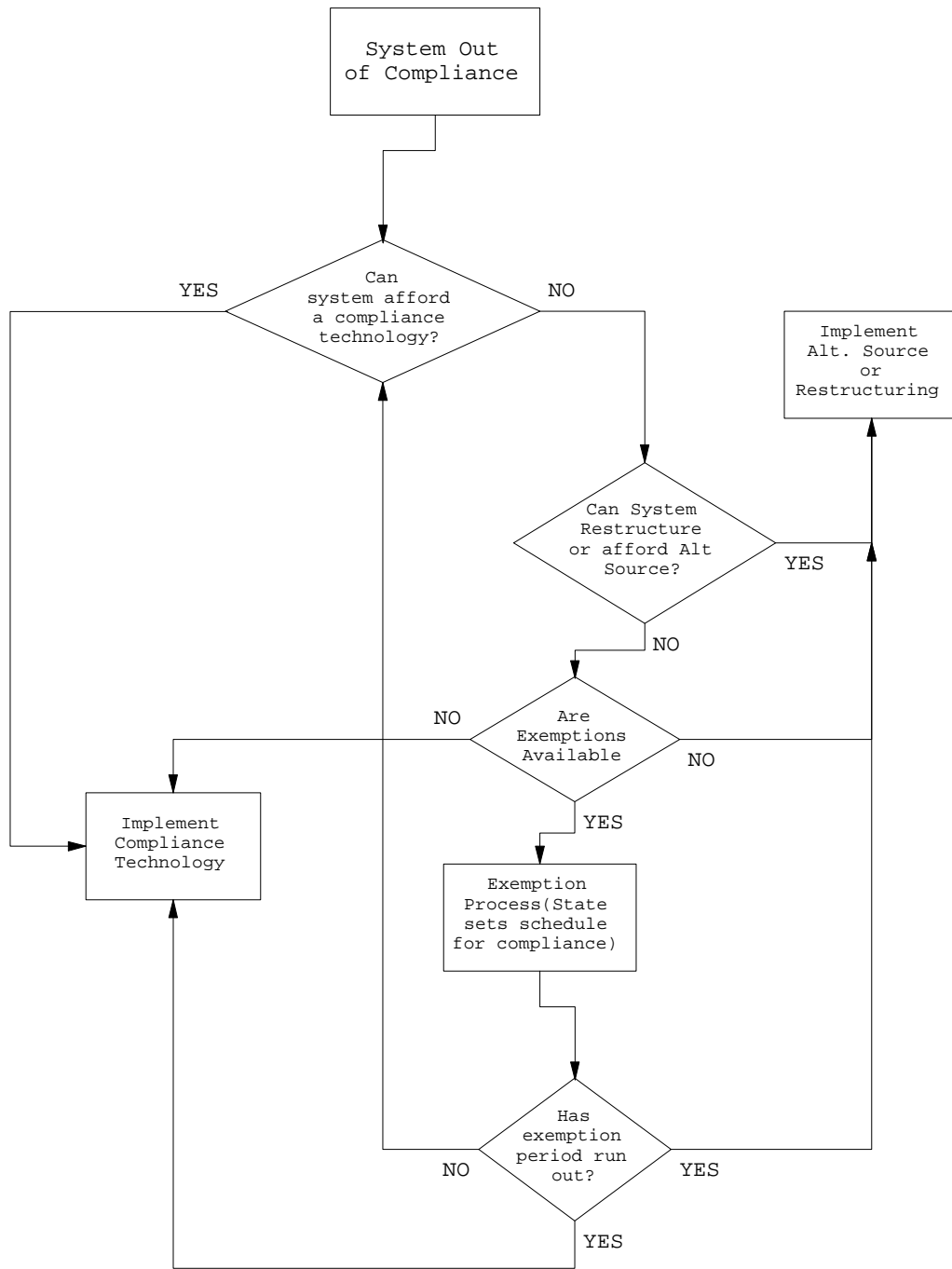
  *NOTE: This approach covers all regulations where the contaminant
 failed to meet one of the screening criteria for variance technologies.

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Section 1.4: Point-Of-Entry and Point-of-Use Treatment Units as Compliance Technologies

Section 1412(b)(4)(E)(ii) of the SDWA identifies both Point-of-Entry (POE) and Point-of-Use (POU) treatment units as options for compliance technologies. A POE treatment device is a treatment device applied to the drinking water entering a house or building for the purpose of reducing contaminants in the drinking water distributed throughout the house or building. A POU treatment device is a treatment device applied to a single tap used for the purpose of reducing contaminants in drinking water at that one tap. POU devices are typically installed at the kitchen tap.

The SDWA identifies requirements that must be met when POU or POE units are used by a water system to comply with a NPDWR. Section 1412(b)(4)(E)(ii) stipulates that "point-of-entry and point-of-use treatment units shall be owned, controlled, and maintained by the public water system or by a person under contract with the public water system to ensure proper operation and maintenance and compliance with the MCL or treatment technique and equipped with mechanical warnings to ensure that customers are automatically notified of operational problems." Other conditions in this section of the SDWA include the following: "If the American National Standards Institute has issued product standards applicable to a specific type of POE or POU treatment unit, individual units of that type shall not be accepted for compliance with a MCL or treatment technique unless they are independently certified in accordance with such standards."

In order to list POU treatment units as compliance technologies, EPA had to delete the part of 40 CFR §141.101 that prohibited POU devices to be used to comply with an MCL. A final rule was published in the Federal Register on June 11, 1998 (EPA 1998g) deleting the prohibition on the use of POU devices as compliance technologies. As previously mentioned, POU devices are listed as compliance technologies for inorganic contaminants, synthetic organic contaminants, and radionuclides. POU devices are not listed for volatile organic contaminants because they do not address all routes of exposure. POE devices are still considered emerging technologies because of waste disposal and cost considerations. POE devices may be included on an updated list in 1999. For more detail on POU and POE devices, see the supporting document entitled "Cost Evaluation of Small System Compliance Options: Point-of-Use and Point-of-Entry Treatment Units" (EPA 1998h).

Section 1.5: Format and Content of the Small System Compliance Technology List for the Non-Microbial Contaminants Regulated Before 1996

The 1996 SDWA does not specify the format for the compliance technology lists. Section 1412(b)(15)(D) states that the variance technology lists can be issued either through guidance or regulations. EPA believes that the compliance technology list may also be appropriately provided through guidance for pre-August 1996 rules, rather than through rule-making. Since the listing provided in this guidance is meant to be informational, it does not require any changes to existing rules or the promulgation of new ones. The purpose of this guidance is to provide small systems with information concerning the types of technologies that can be used to comply with the requirements of the existing non-microbial regulations. It does not over-ride any of the requirements of those

regulations. In summary, EPA has chosen to issue the list through a guidance document because regulation development is unnecessary and could considerably delay publication of the list. Issuing the list without rule-making allows EPA to meet the statutory deadline and to provide information to more small systems as they make their treatment technology decisions. It is also much easier and faster to update a guidance rather than a rule to incorporate advances in technology performance.

The SDWA does not specify the content of the compliance technology lists. These initial lists (63 FR 42032) are very general and expand the lists of technology options listed in the existing non-microbial regulations. These lists may be updated to incorporate new technologies or additional information on parameters that can affect the selection of treatment. The lists will evolve over time, but will not be product-specific. The compliance technology lists will not be product-specific because EPA's Office of Ground Water and Drinking Water does not have the resources to review each product for each potential application; nor does EPA feel it would be appropriate to do so.

Information on specific products will be available through another mechanism. EPA's Office of Research and Development has a pilot project under the Environmental Technology Verification (ETV) Program to provide treatment system purchasers with performance data from independent third parties. The EPA and National Sanitation Foundation International (NSF) are cooperatively organizing and conducting this pilot project to allow for verification testing of packaged drinking water treatment systems for meeting community and commercial needs. This pilot project includes the development of verification protocols and test plans, the independent testing and validation of packaged equipment, the fostering and supporting of government/industry partnerships to obtain credible cost and performance data, and the preparation of product verification reports for wide-spread distribution.

Section 1.6: Stakeholder Involvement

EPA held a stakeholder meeting on May 18 and 19, 1998. Approximately 50 people registered and participated in the meeting. Key stakeholders included States, water systems, and equipment manufacturers. Representatives from nine States were present at the meeting (either at the meeting or on conference lines) and several others received the material that was sent out prior to the meeting for review. A draft of the "Cost Evaluation of Small System Compliance Options: Point-of-Use and Point-of-Entry Treatment Units" was sent out prior to the meeting.

During the meeting, compliance technology options were presented for each group of contaminants: inorganic contaminants (IOCs), volatile organic contaminants (VOCs), synthetic organic contaminants (SOCs), and radionuclides. There was also a presentation on POU and POE devices that followed the sessions on the contaminant groups. Since most of the compliance technologies identified for these groups of contaminants were the BATs listed in the regulations, there were few significant comments on those presentations.

One major topic discussed at the meeting was the format of the document. The two options were separate documents for each contaminant group or one document with separate chapters

devoted to each contaminant group. Stakeholders preferred a document organized by contaminant groups rather than by individual technologies, since many technologies can treat for more than one contaminant group. For example, the technologies used for VOCs removal can also be used to remove some SOCs. There is also a lot of cross-over between technologies that can treat IOCs and radionuclides.

Stakeholders reiterated that they thought the list of compliance technologies should be as comprehensive as possible. Rather than exclude possible options that have technical limitations, stakeholders preferred EPA to list the technologies along with the discussions of and guidance for dealing with these limitations. Examples of limitations include treatment technological complexity, which raises the concern of whether small systems could successfully operate complex processes. Stakeholders indicated that a more comprehensive compliance technology list that included more technology options for individual systems would be preferable to a more conservative list that disallows for the fact that many small systems have the capacity to operate more complex technologies. EPA has also incorporated this philosophy into the identification of affordable compliance technologies. EPA identified compliance technologies that did not meet the affordability criteria in addition to those that did, as discussed in Section 1.3.

The initial lists of technologies are not intended to be definitive: systems may choose any technologies that meet the requirements of the regulations. In each chapter, there are technologies identified as "emerging technologies" that are not listed. These technologies either have data needs or require further evaluation before being listed as compliance technologies. Data needs are identified in the technology discussions in Chapter 3 and in the chapters discussing each of the individual contaminant groups. List updates could include new technologies and could include additional information regarding the already listed technologies.

Section 1.7: Organization of the Document

This document is organized into several chapters describing the small system compliance technologies for the non-microbial contaminants regulated before 1996. Chapter 1 discusses the requirements of the 1996 SDWA and the approach EPA is following to meet those requirements. Chapter 2 provides background on the existing non-microbial regulations, including the dates of promulgation. Chapter 3 provides a description of technologies that can be used to treat more than one group of contaminants. Technologies that only apply to one group of contaminants are described in the chapter devoted to that contaminant group. Chapter 4 summarizes the national-level affordability criteria and describes when and how these criteria were used to identify affordable compliance technologies. Chapter 5 describes the compliance technologies for each of the IOCs, including corrosion by-products. Chapter 6 describes the compliance technologies for each of the radionuclides. Chapter 7 describes the compliance technologies for each of the VOCs. Chapter 8 describes the compliance technologies for each of the SOCs.

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2. BACKGROUND ON EXISTING NATIONAL PRIMARY DRINKING WATER REGULATIONS

This chapter discusses the regulatory history that has resulted in the existing drinking water regulations. The discussion is meant to briefly describe the relevant parts of the charge given to EPA by the 1974 Safe Drinking Water Act (SDWA) and its 1986 Amendments and to briefly explain the evolution of the National Primary Drinking Water Regulations (NPDWRs) that were promulgated in response. It is not meant to be a detailed explanation or history of these events, but rather is intended to provide the reader with enough information regarding the NPDWRs so that he or she will know which NPDWR is associated with a particular contaminant. It also meant as a catalogue of the Federal Register citations of the various NPDWRs.

Through the SDWA, Congress requires EPA to regulate contaminants which present health risks and which are known to occur in some public drinking water supplies. Under the current SDWA, EPA sets legal limits on the levels of certain contaminants in drinking water through Maximum Contaminant Levels (MCLs) and treatment techniques. The legal limits are as protective of human health as is "feasible", where feasibility is determined by treatment removal efficiencies using the best available technologies, the levels of the contaminant found in drinking water sources and other water quality parameters, and the levels at which the contaminant can be accurately quantified analytically. In cases where available analytical methods are inadequate or normal monitoring schemes are inadequate, EPA may impose treatment techniques to be followed under specified conditions. For rules that involve MCLs, "best available technologies" for treating contaminated water and analytical methods are listed. SDWA gives individual states the opportunity to set and enforce their own drinking water standards as long as the standards are at least as stringent as EPA's national standards. Most states and territories directly oversee the regulatory programs for water systems within their borders.

The United States Congress enacted the Safe Drinking Water Act (SDWA) on December 16, 1974 (Public Law 93-523). In response to SDWA, EPA regulated 23 contaminants between 1975 and 1985. The 1974 SDWA called for EPA to regulate drinking water contaminants in two steps. The first step involved the creation of the National Interim Primary Drinking Water Regulations (NIPDWRs), based largely on the 1962 U.S. Public Health Service standards. The second step involved the revision of these standards, as deemed necessary, following a comprehensive review by the National Academy of Sciences of the risks posed to water consumers from the regulated contaminants. The NIPDWRs were fully enforceable after their respective stated "effective dates". The first NIPDWRs were promulgated in 1975, the Radionuclides NIPDWRs in 1976, the Trihalomethanes NIPDWRs in 1979, and the Fluoride Rule in 1986, shortly before the 1986 Amendments.

Congress amended SDWA on June 19, 1986 (Public Law 99-339). The 1986 Amendments required EPA to set Maximum Contaminant Level Goals (MCLGs) and National Primary Drinking Water Regulations (NPDWRs) for 83 specific contaminants. The Amendments declared that the existing NIPDWRs were finalized as NPDWRs upon enactment of the 1986 SDWA, included

provisions for periodic review of the data and studies affecting the basis of the MCLGs and MCLs, and made provisions for allowing variances under specified conditions.

The list of 83 contaminants included 22 with NIPDWRs (excluded total trihalomethanes) and remainder were new contaminants. The amendments also required EPA to regulate 25 additional contaminants every three years, effective January of 1991 and continuing indefinitely. In addition, each NPDWR was to be reviewed triennially to ensure the continued adequacy of the MCLG and MCL. In 1987, EPA exercised discretion provided by SDWA in substituting ethylbenzene, styrene, heptachlor, heptachlor epoxide, nitrite, aldicarb sulfoxide, and aldicarb sulfone for 7 of the 83 contaminants listed for regulation. EPA chose to regulate the 83 contaminants in phases, according to the availability of data and studies supporting the setting of MCLGs and NPDWRs. The Phase I Rule, otherwise known as the VOC/Unregulated Contaminants Rule, was promulgated in 1987, the Phase II Rule, the Lead and Copper Rule, and the Phase II-b Rule in 1991, and the Phase V Rule in 1992. The Phase III Rule became known as the Radionuclides Rule and is currently being reviewed. The Phase IV Rule became known as the Disinfection-By-Products Rule, which is due to be promulgated in November of 1998. All of the relevant rules are discussed in more detail below.

Congress again amended SDWA on August 6, 1996. The 1996 Amendments resulted in several provisions related to the Small Systems Compliance Technology Lists, as discussed in the first chapter. However, the Small Systems Compliance Technology List deadline covered by this document applies only to the pre-1996 regulated contaminants, so the impact of the 1996 SDWA on future rules and updates need not be discussed here.

Section 2.1 National Interim Primary Drinking Water Regulations (NIPDWRs) (40 FR 59566)

The National Interim Primary Drinking Water Regulations (NIPDWRs) were promulgated on December 24, 1975. This rule established Maximum Contaminant Levels (MCLs) for 6 synthetic organic contaminants, 10 inorganic contaminants, turbidity, and total coliform. The rule also established requirements for monitoring, analytical methods, reporting, record keeping, and public notification for each of the contaminants. The MCLs established by this rule were designed to be enforceable until revised.

Section 2.2: Radionuclides NIPDWRs (41 FR 28402)

The Radionuclides NIPDWRs were promulgated on July 9, 1976. This rule established MCLs for combined radium-226 and -228 and two classes of radionuclide contaminants. It also established requirements for monitoring, analytical methods, reporting, and record keeping for these contaminants. The MCLs established by this rule were designed to be enforceable until revised. The MCLs established by this rule are currently in effect, although the rule is being reviewed at the time of this writing.

Section 2.3: Trihalomethanes NIPDWRs (44 FR 68624)

The Trihalomethanes NIPDWRs were promulgated on November 29, 1979. This rule established MCLs and requirements for monitoring, analytical methods, and reporting for total trihalomethanes. "Total trihalomethanes" is defined as the summed concentrations of the four trihalomethane chemicals defined in the rule. This rule only applies to community water systems serving 10,000 persons or more that add a chemical disinfectant during any part of the drinking water treatment process. *Since this rule does not apply to small drinking water systems, total trihalomethanes will not be considered in terms of small systems compliance or variance technologies.*

Section 2.4: Fluoride Rule (51 FR 11396)

The Fluoride Rule was promulgated on April 2, 1986, updating the Fluoride NIPDWR, which was included in the 1975 NIPDWRs. This rule established an MCL and secondary MCL for fluoride and applies only to community water systems. The rule also established a procedure by which public water systems could obtain variances from the interim and revised regulations for fluoride. The variance procedure includes the identification and installation of best available technology (BAT) for fluoride removal. EPA later revised the monitoring requirements (EPA 1995b) for fluoride by including it into the Standardized Monitoring Framework promulgated under the Phase II Rule (January 30, 1991).

Section 2.5: Phase I Rule (52 FR 25690)

The Phase I Rule was promulgated on July 8, 1987. This rule establishes MCLs and requirements for monitoring, reporting, and public notification for 8 volatile organic contaminants (VOCs). The rule also establishes monitoring requirements for 51 other synthetic organic contaminants not regulated by NPDWRs, i.e., unregulated contaminant monitoring. The rule applies to community water systems and non-transient, non-community water systems.

Section 2.6: Phase II Rule (56 FR 3526) and Phase II-b Rule (56 FR 30266)

The combined Phase II Rule was promulgated in two rule makings, the "Phase II Rule" on January 30, 1991 and the "Phase IIb Rule" on July 1, 1991. Combined, the two rule makings establish new requirements for the regulation of 38 chemicals, 11 of which were previously regulated under the 1975 NIPDWRs, including barium, cadmium, chromium, mercury, nitrate, selenium, 2,4-D, lindane, methoxychlor, toxaphene, and 2,4,5-TP. Additionally, the Phase II Rule removed silver from the list of NPDWRs and developed SMCLs for silver and aluminum.

The Phase II Rule (January 30, 1991) establishes Maximum Contaminant Level Goals (MCLGs), MCLs, and requirements for monitoring, analytical methods, and public notification for 26 synthetic and volatile organic contaminants (SOCs, VOCs) and 7 inorganic contaminants (IOCs). The rule also reproposes MCLs for 5 contaminants. Some of the regulations apply to all public water supplies and

others only to community water systems and non-transient, non-community water systems.

The Phase IIb Rule finalizes the MCLGs and NPDWRs for the 5 contaminants reproposed in the Phase II Rule. It also changes the monitoring requirements to the standardized monitoring framework for the 8 VOCs regulated in the Phase I Rule.

Two contaminants regulated by the Phase II Rule, acrylamide and epichlorohydrin, are not applicable to the determination of small system compliance technology lists or small system variances. These two compounds are associated with chemical additives used in drinking water treatment and are regulated through a treatment technique that requires a certification that the product of the dose and monomer concentration will not exceed certain levels. No treatment technology is required to be installed to reduce contaminant levels under this treatment technique. As such, *there are no compliance or variance technologies for either acrylamide or epichlorohydrin.*

On May 27, 1992 EPA postponed the effective date of the MCLs and amended the monitoring requirements for aldicarb, aldicarb sulfone, and aldicarb sulfoxide (56 FR 221778). This stay will remain in effect while EPA conducts a revised risk assessment and solicits public comment on the risk assessments. During this time, these pesticides are being monitored as unregulated contaminants.

Section 2.7: Lead and Copper Rule (56 FR 26460)

The Lead and Copper Rule was promulgated on June 7, 1991 and became effective on December 7, 1992. This rule establishes MCLGs and NPDWRs for controlling lead and copper levels in drinking water. Although all rules establishing treatment techniques are unique, the Lead and Copper Rule stands out because it is the only NPDWR that attempts to minimize contamination introduced by the action of the water itself on the distribution system. Other treatment techniques either address contaminants in the source water (e.g., the Surface Water Treatment Rule) or contaminants that may result from the treatment processes themselves (e.g., NPDWR for epichlorohydrin).

Lead and copper contamination of drinking water mainly occurs after the water is in the distribution system, so monitoring at the treatment plant is not adequate. The contamination results from corrosion of pipes and plumbing in the distribution system. The Lead and Copper Rule requires community water systems and non-transient, non-community water systems to complete a materials evaluation of their distribution system and/or review other information to target homes that are at high risk of lead and copper contamination. Water systems are required to monitor at the tap in these high risk homes, with the number of tap-sampling sites being proportional to the population served. Those systems with lead levels above the action level[1] are required to apply a treatment technique for mitigation, that may include corrosion control treatment, source water treatment, lead service line replacement, and public education. Replacement of lead containing materials within a distribution system is only required if corrosion control measures do not bring lead levels below the action level.

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[1] Action levels are different from MCLs in that, rather than being a legal limit on a contaminant like an MCL, they are triggers for taking prescriptive prevention or removal steps.

Systems with elevated copper levels should apply corrosion control treatment, since replacement of the copper piping source material is generally cost prohibitive.

Section 2.8: Phase V Rule (57 FR 31776)

The Phase V Rule established MCLGs and promulgated NPDWRs for 18 synthetic organic contaminants and 5 inorganic contaminants. The monitoring framework for these contaminants are in the standardized monitoring framework format. This rule applies to community water systems and non-transient, non-community water systems. The NPDWR for nickel was revoked.

Section 2.9: Summary of National Primary Drinking Water Regulations (NPDWRs)

Table 2.11 tabulates the various regulated drinking water contaminants, providing information on contaminant type, the governing NPDWR, and the promulgated MCLs and BATs. For more information on the NPDWRs, visit the Office of Ground Water and Drinking Water's Internet homepage (http://www.epa.gov/OGWDW). The homepage has a table (http://www.epa.gov/OGWDW/wot/appa.html) of current NPDWRs that includes information on health effects from ingestion of the regulated contaminants and the sources responsible for their occurrence in drinking water. Further information on the drinking water regulatory history can be found on the OGWDW homepage at "http://www.epa.gov/safewater/source/therule.html". Each of the BATs is discussed in later chapters.

Summary of Current National Primary Drinking Water Regulations (NPDWRs)				
Contaminant	Type	NPDWR	BATs	MCL (μg/L)
Benzene	VOC	Phase I Rule	GAC, PTA	5
Carbon Tetrachloride	VOC	Phase I Rule	GAC, PTA	5
Chlorobenzene	VOC	Phase II Rule	GAC, PTA	100
cis-1,2 Dichlorobenzene	VOC	Phase II Rule	GAC, PTA	7
Dibromochloropropane	VOC	Phase II Rule	GAC, PTA	0.2
1,2- Dichloroethane	VOC	Phase I Rule	GAC, PTA	5
1,1- Dichloroethylene	VOC	Phase I Rule	GAC, PTA	7
Dichloromethane	VOC	Phase II Rule	GAC, PTA	5
1,2- Dichloropropane	VOC	Phase II Rule	GAC, PTA	5
Ethylbenzene	VOC	Phase II Rule	GAC, PTA	700
Ethylene dibromide	VOC	Phase II Rule	GAC, PTA	0.05
o-Dichlorobenzene	VOC	Phase II Rule	GAC, PTA	600

p-Dichlorobenzene	VOC	Phase I Rule	GAC, PTA	78.5
Styrene	VOC	Phase II Rule	GAC, PTA	100
Tetrachloroethylene (PCE)	VOC	Phase II Rule	GAC, PTA	5
Toluene	VOC	Phase II Rule	GAC, PTA	1000
trans-1,2-Dichloroethylene	VOC	Phase II Rule	GAC, PTA	100
1,2,4- Trichlorobenzene	VOC	Phase V Rule	GAC, PTA	70
1,1,1- Trichloroethane	VOC	Phase I Rule	GAC, PTA	200
1,1,2- Trichloroethane	VOC	Phase V Rule	GAC, PTA	5
Trichloroethylene (TCE)	VOC	Phase I Rule	GAC, PTA	5
Vinyl Chloride	VOC	Phase I Rule	GAC, PTA	2
Xylenes (total)	VOC	Phase II Rule	GAC, PTA	10,000
Alachlor	SOC	Phase II Rule	GAC	2
Atrazine	SOC	Phase II Rule	GAC	3
Carbofuran	SOC	Phase II Rule	GAC	40
Chlordane	SOC	Phase II Rule	GAC	2
Dibromochloropropane	SOC	Phase II Rule	GAC, PTA	0.2
2,4-D	SOC	Phase II Rule	GAC	70
Ethylene Dibromide	SOC	Phase II Rule	GAC, PTA	0.05
Heptachlor	SOC	Phase II Rule	GAC	0.4
Heptachlor Epoxide	SOC	Phase II Rule	GAC	0.2
Lindane	SOC	Phase II Rule	GAC	0.2
Methoxychlor	SOC	Phase II Rule	GAC	40
Polychlorinated Biphenyls	SOC	Phase II Rule	GAC	0.5
Pentachlorophenol	SOC	Phase II Rule	GAC	1
Toxaphene	SOC	Phase II Rule	GAC	3
2,4,5-TP	SOC	Phase II Rule	GAC	50
Benzo(a)pyrene	SOC	Phase V Rule	GAC	0.2
Dalapon	SOC	Phase V Rule	GAC	200
Di(2-ethylhexyl) adipate	SOC	Phase V Rule	GAC, PTA	400

Di(2-ethylhexyl) phthalate	SOC	Phase V Rule	GAC	6
Dinoseb	SOC	Phase V Rule	GAC	7
Diquat	SOC	Phase V Rule	GAC	20
Endothall	SOC	Phase V Rule	GAC	100
Endrin	SOC	Phase V Rule	GAC	2
Glyphosate	SOC	Phase V Rule	oxidation (Cl_2 or O_3)	700
Hexachlorobenzene	SOC	Phase V Rule	GAC	1
Hexachlorocyclopentadiene	SOC	Phase V Rule	GAC, PTA	50
Oxamyl	SOC	Phase V Rule	GAC	200
Picloram	SOC	Phase V Rule	GAC	500
Simazine	SOC	Phase V Rule	GAC	4
2,3,7,8-TCDD (Dioxin)	SOC	Phase V Rule	GAC	3×10^{-5}
Acrylamide	SOC	Phase II Rule	treatment technique	TT
Epichlorohydrin	SOC	Phase II Rule	treatment technique	TT
Antimony	IOC	Phase V Rule	CF, RO	6
Asbestos	IOC	Phase II Rule	CF, Corrosion Control, Direct Filt, Diatom Filt	7 million fibers/liter (longer than 10 μm)
Cyanide	IOC	Phase V Rule	IX, RO, alkaline Cl_2	200
Lead	IOC	Lead and Copper, Final Rule	treatment technique	TT
Arsenic	IOC	NIPDWR for arsenic	CF, LS, IX, RO, EDR	50
Barium	IOC	Phase II Rule	IX, LS, RO, EDR	2000
Beryllium	IOC	Phase V Rule	AA, CF, LS, IX, RO	4
Cadmium	IOC	Phase II Rule	CF, IX, LS, RO	5
Chromium	IOC	Phase II Rule	CF, IX, LS, RO	100
Copper	IOC	Lead and Copper, Final Rule	treatment technique	TT
Fluoride	IOC	Fluoride, Final Rule	AA, RO	4000

Mercury	IOC	Phase II Rule	CF, GAC, LS, RO	2
Nitrate	IOC	Phase II Rule	IX, RO, EDR	10000 (as N)
Nitrite	IOC	Phase II Rule	IX, RO	1000 (as N)
Nitrate + Nitrite	IOC	Phase II Rule	- See individual contaminants -	10000 (as N)
Selenium	IOC	Phase II Rule	AA, CF, IX, LS, RO, EDR	50
Thallium	IOC	Phase V Rule	AA, IX	2
combined radium-226 and radium-228	RAD	Radionuclides Rule	IX, LS, RO	5 pCi/L
gross alpha particle activity	RAD	Radionuclides Rule	RO	15 pCi/L
total beta particle activity and photon activity	RAD	Radionuclides Rule	IX, RO	4 mrem/yr

Notes: GAC = granular activated carbon, PTA = packed tower aeration, IX = ion exchange, LS = lime softening, RO = reverse osmosis, CF = coagulation/filtration, EDR = electrodialysis/electrodialysis reversal, AA = activated alumina.

3. DESCRIPTIONS OF TREATMENT TECHNOLOGIES FOR SMALL SYSTEMS

This chapter discusses small systems treatment technologies that can be used for the removal of more than one class of the currently regulated drinking water contaminants. Each process is briefly described and issues specific to small systems needs are highlighted. Advantages, limitations, and special considerations are emphasized where applicable. Small systems treatment strategies include centralized treatment, including package plants, and point-of-use/entry (POU/E) technologies. Each strategy is discussed in general, then individual technologies are discussed. The choice of strategy to be used in a specific situation depends on the source water quality, the nature of the contaminant to be removed, the desired qualities of the finished water, and the size of the drinking water system.

Centralized Treatment

For small systems, centralized treatment refers to both full scale conventional treatment and to centrally located package plant treatment. This section will focus on full scale conventional treatment; package plants are discussed below. Centralized treatment refers to the practice of treating water at a centralized location before it enters the distribution system. Centralized treatment at more than one entry point is sometimes referred to as "de-centralized treatment". This point is important because it clarifies the differentiation between multiple entry point centralized treatment and POU/E treatment. Within this document, "centralized treatment" will include both single entry point centralized treatment and multiple entry point treatment.

In general, centralized treatment is preferred to POU/E technologies since monitoring and maintenance can be centrally managed, which is the most reliable way to ensure safe water. Full scale conventional treatment is the most common strategy for systems serving more than a few thousand persons (EPA 1993, p. 97). Full scale treatment is designed by a consulting engineer and makes use of originally designed and fabricated concrete and steel structures, as opposed to pre-fabricated package plant units. Larger systems can pass the higher engineering and construction costs through the large customer base at a generally reasonable per user cost. The costs associated with fully engineered treatment technologies can be prohibitive for the smallest of water systems, but for some technologies, e.g., packed tower aeration, full scale treatment may be cost-effective down to very small system sizes.

Package Plant Treatment

Package plants are skid mounted factory assembled centralized treatment units that arrive on site "virtually ready to use" (Goodrich et al. 1992, EPA 1993). Package plants offer several advantages. First, since they combine elements of the treatment process into a compact assembly (such as chemical feeders, mixers, flocculators, basins, and filters), they tend to require lesser construction and engineering costs. Another advantage is that many package plant technologies are becoming more automated and thus can be less demanding of operators than their fully engineered counter-parts (EPA 1990). However, pilot testing requirements can significantly increase package treatment costs. Some states require pilot tests of all package plant installations. Often package plant pilot testing is

required on a case by case basis, so that results from one situation can not be "transferred" to another situation, regardless of how similar the situations may be. Since pilot testing is resource intensive and can last from several weeks to a year or more, it can add significant costs, e.g., more than thirty percent to the original equipment costs in some cases (Goodrich et al. 1992). Since it is, of course, essential to confirm that installed treatment is working properly, the need for site specific pilot testing can not be entirely eliminated, but it can be reduced (EPA 1993). To this end, verification of package plant performance by an independent party would reduce costs by reducing in degree the need for pilot testing. It is important to keep in mind that pilot testing needs are specific both to the technology in question and to source water quality. For a discussion of pilot testing needs for individual technologies, see, e.g., NRC's <u>Safe Water from Every Tap</u> (NRC 1997).

This need for package plant performance verification is currently being addressed by EPA in cooperation with National Sanitation Foundation (NSF) International through an EPA Environmental Technology Verification project. Together they are cooperatively organizing and developing a pilot project (Package Drinking Water Treatment Systems Pilot Project) to allow for verification testing of package plant units. The aims of the project include developing verification testing protocols and test plans, independently testing and validating package plant equipment, conveying and supporting government/industry partnerships to obtain credible cost and treatment performance data, and preparing product verification reports for public use. It is expected that the program will become financially self-sustaining through user fees and leveraged resources. More information regarding this program may be found on the NSF Internet website at "http://www.nsf.org/verification/html/overview.html".

Whether or not a small system can afford a package plant technology is only part of the question. In addition, the system must have an operator or contractor who can properly operate and maintain the equipment. Fortunately, many package plant technologies are becoming more automated and simpler to use. For example, modern filtration membrane technologies have the ability to backwash automatically, greatly simplifying their use. In cases where a technology requires more advanced skills, recent advances (NRC 1997) in telemetry devices or remote monitoring and control devices have made it possible for a single operator to monitor and operate several small water systems within a given area. These "circuit rider" operators can work from a central location while receiving information (including alarms) from the various plants via FAX or modem. Remote control capabilities allow the circuit rider operator to control certain aspects of the treatment process (e.g., chemical coagulant dosage or disinfection dosage) via a modem or other means. This reduces operator costs to a single system and can reduce the amounts of chemicals required for treatment. These telemetric devices may make those technologies requiring a full-time operator more feasible for many small systems. The combined use of package plants and telemetric monitoring and control may well extend many of the more complex water treatment technologies to the universe of technologies appropriate for small systems.

Point-of-Use/ Point-of-Entry Technologies

Point-of-entry (POE) treatment units (Goodrich et al. 1992, Lykins et al. 1992) treat all of the water entering a household or other building, with the result being treated water from any tap. Point-of-use (POU) treatment units treat only the water at a particular tap or faucet, with the result being treated water that one tap, with the other taps serving untreated water. POE and POU treatment units often use the same technological concepts employed in the analogous central treatment processes, the main difference being the much smaller scale of the device itself and the flows being treated. Sometimes the POE/U technology uses essentially the same process as its full-scale counterpart, but in some instances process modifications are required to account for the much smaller flows being treated. For example, full-scale filtration technologies often use periodic backwashings to extend the lifetime of the filter bed, whereas POU filtration technologies are often used until exhausted and then simply discarded.

POE/U devices have disadvantages to their use and so are generally used only when a centralized treatment facility is not technically or financially feasible for a water system. Regarding POU devices, if one is placed under the kitchen sink to treat food for drinking and cooking, only that water is potable; water from a bathroom tap would be untreated, and thus exposure to contaminants during teeth brushing, etc. is possible (NRC 1997). In some cases, POU technologies are simply not applicable, e.g., in cases of volatile contaminants which would volatilize into the indoor air during showering and other water uses. In these cases, only POE treatment or centralized treatment is appropriate. POE treatment units also have limitations. For example, some POE filters require backwashing or regeneration to maintain a reasonable filter bed/resin lifetime (number of bed volumes before the filter bed or resin needs replacement). If the backwash requires special disposal methods, costs may increase prohibitively. In the case of acute contaminants, which can cause adverse health effects after short term exposures, POE/U treatment is generally not viewed as appropriate (NRC 1997). For example, the 1998 Small Systems Compliance Technologies Lists for the Surface Water Treatment Rule and the Total Coliform Rule (EPA 1998a) does not list any POE/U devices for the microbial contaminants or microbial indicators. The legal requirements for the use of POE/U devices as compliance technologies are discussed in Section 1.4.

Technologies that are amenable to POE/U scale treatment include activated alumina, granular activated carbon, reverse osmosis, ion exchange, and air stripping. Each of these applications is discussed below along with its centralized treatment analogue. There are also discussions of POE/U technologies in the chapters dealing with compliance technologies for specific contaminants.

Before installing POE/U treatment units, water systems should evaluate the units for treatment efficacy and efficiency. For devices that employ cartridges (e.g., GAC and activated alumina), the NRC (1997) recommends that water systems pilot test to develop estimates of the unit's service life for their particular source water. In other cases, evaluations may be simpler, e.g., for RO it may only be necessary to confirm that membrane fouling will not be a problem. These concerns are discussed in more detail in the individual technologies discussions below.

Effective operation, monitoring, and maintenance are vital to the successful use of POE/U treatment units for compliance purposes (Goodrich et al. 1992, NRC 1997). As discussed in Section 1.4, the units are required by the SDWA to be "owned, controlled, and maintained by the public water system or by a person under contract with the public water system to ensure proper operation and maintenance and compliance with the MCL or treatment technique and equipped with mechanical warnings to ensure that customers are automatically notified of operational problems". Proper installation is of course essential. After installation, the PWS needs a well-defined operation and maintenance program to assure a continuous supply of safe drinking water. The PWS also needs a routine monitoring program to confirm that the operation and maintenance program is adequate and that the treated water meets drinking water standards.

Specific Technologies

Specific technologies that apply to more than a single class of chemical contaminants are discussed below.

Activated Alumina

Activated Alumina (AA) is a physical and chemical process in which ions in the feed water are sorbed to an oxidized AA surface. AA is prepared through dehydration of $Al(OH)_3$ at high temperatures and consists of amorphous and gamma alumina oxide. AA is used in packed beds to remove contaminants such as fluoride, arsenic, selenium, silica, and natural organic matter. Feed water is continuously passed through the bed to remove contaminants. The contaminant ions are exchanged with the surface hydroxides on the alumina. The adsorption ability of AA media must eventually be replenished. When all adsorption sites on the AA surface are filled, the bed must be regenerated. Regeneration is accomplished through a sequence of rinsing with regenerant, flushing with water, and neutralizing with acid. The regenerant is a strong base, typically sodium hydroxide; the neutralizer is a strong acid, typically sulfuric acid (EPA 1998b). The alumina dissolves slightly in sodium hydroxide. Over time the media will dissolve and require replacement.

AA is useful for removing negatively charged ions. AA displays amphoteric properties, meaning its surface charge changes with solution pH. AA is not charged at a pH of 9.5, is positively charged below this pH, and is negatively charged above it (NRC 1997). Anions are best adsorbed below this pH.

Water quality strongly influences the residence times and flow rates necessary for proper operation of activated alumina columns. In particular, the potential for preferential exchange of anions other than the target compounds in the raw water must be evaluated for each source water that will be treated with AA (NRC 1997).

As with ion exchange, regenerant disposal can be a problem. Some facilities discharge the regenerant brine solution to lined evaporation ponds designed for this purpose. After the water evaporates from the salts, the dried salts are disposed of in a landfill. Disposal costs can make up

much of the operating cost of this technology.

AA may be well suited for small systems. The columns can be scaled and more added if necessary. Small systems should be concerned, however, about cost and operational complexity (NRC 1997). For instance, small systems should be concerned about the chemicals that may be required to operate AA. Stakeholders agreed that small systems would not likely regenerate on sight. Regenerating the media off-site or disposing of the spent media may be possibilities. Small systems should also be concerned about highly concentrated waste streams.

Activated Carbon

Activated carbon is similar to charcoal in composition, but is surfacially altered to enhance its sorption properties. The base carbon material (typically bituminous coat, lignite, petroleum coke, or bone char) is carbonized through heating it in the absence of air and then activated by oxidation at high temperature (200°C to 1000°C). The activation process results in a highly porous, high surface area per unit mass material with a large sorption capacity for many water impurities, including synthetic organic contaminants (SOCs), taste and odor causing compounds, and some species of mercury. (Snoeyink 1990, NRC 1997, AWWA - ASCE 1998).

Granular activated carbon (GAC)

GAC treatment removes contaminants via the physical and chemical process of sorption, by which the contaminants accumulate at the carbon surface as the water passes through the carbon bed. Removal efficiencies for many organic contaminants are excellent under ideal circumstances, but can be significantly affected by water quality parameters, like dissolved natural organic matter levels, pH, and temperature. Removal efficiencies change drastically once the bed nears exhaustion. At exhaustion, contaminant breakthrough occurs, which is often defined as the point in time when the contaminant concentration in the effluent equals that in the influent. Before this occurs, the carbon bed must be regenerated or replaced to ensure proper removals (Snoeyink 1990).

Information regarding GAC contactor configurations, operational modes, and design factors can be found in many sources (e.g., AWWA 1990, EPA 1990, Snoeyink 1990, AWWA - ASCE 1998). Operating problems encountered when using activated carbon are similar to those associated with rapid sand and dual-media filters. Common operating problems include: controlling the carbon depth, (when applicable) ensuring proper backwashing and maintaining depth and bed density after backwashing, removing carbon from the contactors and storage tanks, regenerating the carbon, controlling contactor flow rate, and controlling biological growth in the carbon bed (AWWA - ASCE 1998).

GAC often requires pre-filteration to remove particulate matter from the source water to prevent clogging of the GAC bed. An alternative is to use the GAC column itself as a filter medium, performing both filtration and sorption simultaneously. The disadvantage of this latter approach is that frequent backwashing of the column is required. Backwashing may cause spent carbon to come

into contact with the treated water: if this can be tolerated, then the technology is straightforward and compact (NRC 1997).

Competitive sorption can also significantly affect the removal efficiency of an activated carbon system. Naturally occurring dissolved organic matter may compete with organic contaminants for GAC sorption sites, decreasing the removal efficiency for a given GAC column and thus increasing the amount of GAC needed to achieve the optimal efficiency. Competing organic compounds can also displace (cause the desorption of) contaminants. If influent water quality changes result in a high concentration of the competing compound, the contaminant desorption process may temporarily cause the contaminant level in the effluent to exceed that in the influent. Because of this, competing chemicals need to be removed from the water prior to GAC treatment, or the GAC system should be designed to accommodate the fluctuation in concentrations of the competing compounds (Snoeyink 1990).

Single-stage GAC systems (in which all of the water being treated flows through one column, rather than through two or more in series) must be monitored to ensure that breakthrough does not occur. If an exhausted GAC column is not regenerated or replaced, desorption may result in the effluent having higher concentrations of the contaminant than the untreated water. Monitoring for some organic compounds may require an advanced operator or the services of an outside laboratory. In general, GAC is straightforward to apply on a small scale. Small columns may be easily obtained and installed. If virgin carbon is required (which can be the case with drinking water applications), the operating costs are often higher.

Powdered activated carbon (PAC)

Powdered activated carbon (PAC) treatment works in much the same way as GAC. The main difference is the mode of application and the grain size of the activated carbon. PAC grains are ten to one hundred times smaller than GAC grains, but the water being treated comes into contact with much less carbon material per unit volume treated, so the process is not as efficient as GAC. The carbon powder is added directly to the raw water line or to a mixing basin. For efficient removals, all of the water being treated should come into contact with the carbon. The sorption process is very quick because of the small carbon particle size (which increases the specific surface area of the activated carbon) and thus the normal mixing basin contact times used for other elements of the treatment train are sufficient for sorption. In such cases, no modifications to the existing structure of the treatment plant need be made. Testing prior to design determines the required contact time. After proper contact, the PAC is settled or filtered from the water and disposed of with the plant sludge. Proper removal of the PAC after sorption is required to ensure contaminant removal and to prevent discoloration of the effluent (NRC 1997). The same argument concerning competitive sorption for GAC treatment applies to PAC treatment.

PAC can be very economical if required only periodically (e.g., seasonally) in response to changes in water quality. If the dose can be optimized and adjusted in response to variations in influent water quality, then further savings can be incurred. In general, PAC is simple to employ on

a small scale if the plant already has a treatment train in place that includes mixing, precipitation or sedimentation, and filtration.

PAC may adsorb some chemicals that are added during the treatment process, e.g., chlorine and potassium permanganate. For this and other reasons, the best point of application is usually at the head of plant, either in the source water pipeline or in a mixing basin (AWWA - ASCE 1998).

Air Stripping (Aeration)

Air stripping, or aeration, involves the continuous contact of air with the water being treated, allowing volatile dissolved contaminants to transfer from the source water to the air. After contact, the "contaminated air" is swept from the system, taking the contaminants, e.g., volatile organic chemicals, taste- and odor- causing compounds, and radon, out of contact with the treated water. The driving force for the water-to-air transfer of the volatile contaminants is related to the contaminant concentration gradient between the water and air. In designing aeration treatment, it is important to consider both the total amount of transfer possible, i.e., the amount that would be transferred to reach equilibrium, and the rate at which transfer takes place. The amount of possible transfer is dependent on a combination of the physiochemical characteristics of the contaminant (such as molecular weight, molecular charge/polarity and shape, etc., all of which also affect the water solubility), site specific conditions, like temperature and water quality, and the design of the aeration system, e.g., air/water ratio. The Henry's Law coefficient is a commonly used indicator of the tendency of a contaminant to partition from water to air. A large value (by common definitions[2]) indicates that the contaminant can be significantly stripped from water. Efficient stripping is also a function of the rate of transfer, which depends on both the properties of the contaminant, the site specific conditions, and the aeration design, e.g., an effective contact surface area between the air and water (Cornwell 1990).

The key factors which are considered in the design of aeration systems include contact time (time of exposure); air-to-water ratio; proper dispersal of waste gases into atmosphere; physical chemistry of the contaminant; influent concentration of the contaminant; water and surrounding air temperatures (AWWA and ASCE 1998). The most common types of aeration systems include packed tower aerators, diffuser aerators, including multi-stage bubble aerators, multi- or shallow tray aerators, spray aerators, mechanical aerators, and gas permeable membrane aerators.

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[2] The Henry's Law coefficient (H_L) can be defined any number of ways, and so can be reported in various units. Here, we are assuming that $H_L = C_a / C_w$, where C_a is the concentration of the contaminant in air at equilibrium with C_w, the concentration of the contaminant in water.

Packed tower aerators

In packed tower aerators (PTA), the contaminated water flows downward by gravity over a bed of packing material such as fixed plastic grids, loose plastic rings, or loose ceramic saddles, while air is blown upward through the column. The packing material breaks the surface area for contact between air and water thus promoting transfer of the contaminant into the gaseous phase.

The removal efficiency of contaminants using PTAs depends upon the air to water ratio, contact time, available surface area, water loading rate, physical and chemical characteristics of the contaminant, and water and air temperature.

The air flow requirements for a packed tower depend on the Henry's Law coefficient for the particular compound to be removed from the water. In an ideal system, the greater the Henry's Law coefficient for a compound, the less air is required to remove a contaminant from water. However, air to water ratios used to achieve a given removal efficiency are greater than the ideal system.

The contact time is a function of the depth of the packing material. As the depth of packing materials increases, the contact time between the water and air increases, thereby causing high percent removals of the contaminant.

The available surface area for mass transfer depends upon the packing material. Smaller packing materials provide greater available area for mass transfer per volume of material thus increasing the mass of contaminant removed. The pressure drop for the air passing through the column must be considered when selecting packing materials.

The water loading rate is the amount of water that passes through the tower and is largely a function of diameter of the tower. The water loading rate typically ranges from 25 to 30 gpm/ft^2 (AWWA and ASCE 1998).

PTAs are very efficient in removing several compounds from water. PTAs are considered Best Available Technologies (BAT) for several organic compounds. PTA can generally be used with systems of all sizes. A typical PTA consists of a packed column or tower, blower, pumping unit, and an effluent storage unit. Pretreatment may be necessary for removal of microorganisms, iron, Mn, and excessive particulate matter. PTAs are usually located outdoors, therefore piping may need to be protected in cold climates.

Diffuser aerators

Diffused aeration (DA) is the process of bubbling air into a water-filled contact chamber through a diffuser mechanism located at or near the bottom of the chamber. The chamber can either be a column or basin. The efficiency of diffused aeration for removing organics depends upon the diffuser type, air-to-water ratio, depth of the water in the contact chamber, detention time, and water temperature. Diffused aerators are generally used only to adapt existing plant equipment.

Multi-stage bubble aerators (MSBA) are a form of commercially available package plant. These are a variation to the traditional diffused aerator. Typical commercial units consist of a high-density polyethylene vessel partitioned into multiple stages with an individual aerator for each stage. MSBAs are compact, with water depths typically less than 1.5 ft (compared to depths of 10 to 20 ft for typical aeration basins). If housing is required for the aeration unit, MSBA's compactness can be very attractive. Other advantages of MSBA include removal efficiencies that are competitive with PTA.

The advantages of a diffuser aeration system is that an existing basin or storage tank can be modified to be used as a diffuser aeration unit. Due to reduced pumping costs, no packing material costs, and potentially lower energy costs, marginal savings may be incurred. However, an increase in contact time and air-to-water ratios may be needed to achieve good removals because DA generally does not provide for convective movement of the water and thus does not allow as much contact between the air and water as other methods.

Point-Of-Use/Point-Of-Entry Aeration Technologies

Point-of-use aeration technologies are not practical for volatile contaminants because routes of exposure can occur through inhalation, direct contact, and ingestion from a secondary faucet. Therefore, POU aeration technologies are not considered for compliance technology listing.

Air stripping technologies such as PTA and diffused bubble aerators have been used in POE systems to remove VOCs from ground water (NRC 1997). Similar to other aeration technologies, these systems rely on mass transfer to remove VOCs from water. While POE aeration is technically feasible, it is not commonly used for public water systems and may not be as cost effective as other aeration systems.

Multiple tray aerators

Tray aerators (Cornwell 1990, AWWA-ASCE 1998) consist of a series of trays with slats, perforations, or wire mesh bottoms over which water flows and collects at the base of the unit. The thin film of water formed as the water flows over the media provides a large surface area for mass transfer of the contaminant from water to air. These aerators can be operated with a natural draft or with a forced draft using an air compressor. Using the natural draft reduces operating costs, but is less efficient than using a forced draft.

Shallow tray aerators (STA) are another form of low-profile package plant. In STA, the contaminated water flows along the trays while air is blown through hundreds of holes in the bottom of the trays, creating a large mass-transfer surface area where contaminants are volatilized. These units are analogous to MSBA in terms of their advantages, including potentially high removal efficiencies and compactness.

Multiple tray aerators can be used with systems of all sizes. These aerators are very efficient in removing co-occurring VOCs. However, higher air-to-water ratios may be required to ensure volatilization of the contaminants. One disadvantage is that slime and algae can grow on the trays, possibly necessitating the addition of copper sulfate or chlorine to control growth (NRC 1997). However, in shallow tray aerators, precipitation and biofilm development is minimal because of the vigorous bubbling action created by air flowing through the tiny holes (Lamarre 1993).

Spray Aerators

Spray aerators produce small water droplets by spraying water through nozzles. The small droplets produced expose a large interfacial surface area through which contaminants can migrate from the liquid phase to the gaseous phase. Installations commonly consist of fixed nozzles on a pipe grid.

The factors which affect the removal efficiency of spray aerators are size of the water droplets formed (area for mass transfer), height of spray (contact time), and temperature. The advantages of spray aerators include the capability of achieving efficient mass transfer due to the small water droplets created by the fixed nozzles and the lack of any packing costs. The disadvantages includes the need for large operational area.

Mechanical aerators

Mechanical aeration introduces air into the water by rapidly agitating the water surface with a mechanical mixer. The advantage to using mechanical aerators is that they are adaptable to existing basins, and are often installed as a system retrofit. However, these units are not as efficient as other aeration units. Because of the limited contacting system between air and water, large basins, long residence times, and high energy inputs may be needed to increase the efficiency of the aerator. These systems are applicable when low level contaminant removal is needed to reach the MCL.

Gas-permeable membrane aeration

Gas-permeable membrane aeration processes consist of a membrane module made up of highly porous, small diameter, hollow fiber membranes as a contacting device, providing an air-water contact area per equipment volume nearly an order of magnitude greater than packed tower air strippers (Semmens et al.; Zander et al. 1989). Water flows through the interior of hollow membrane tubes constructed of a material that allows gases but not liquids to pass through. The large surface area for air-water contact allows for removal of semivolatile and volatile organic chemicals (NRC 1997). Gas-permeable membrane systems offer the highest removal efficiencies of all contacting devices. Membrane technology has to be considered emerging because long-term performance has not been evaluated.

Air Stripping Suitability for Small Systems

Overall an aeration system can generally be installed for a fairly low cost, and most aeration units are not complex. The treatment process is highly adaptable to small treatment plants, often involving a simple retrofit to existing treatment basins. Cost and treatment efficiency both increase with increasing system complexity. If contaminant concentrations are high and regulations require treatment of the air leaving the system, however, costs increase dramatically. The specific type of aerator depends only on the degree of contaminant reduction desired. Also, because mixtures of contaminants exist in contaminated water and even though the effectiveness of the process varies for each contaminant, aerating to remove one specific contaminant will also reduce concentrations of the others.

Air Stripping Limitations

The secondary effects of aeration may be a problem. These include potential air quality problems created by exhaust gases from the aerator, and the potential for water quality deterioration from airborne particulates, oxidized inorganics, instability resulting in corrosion, and biological growth in the aeration device. Post-treatment disinfection may be needed after treatment with some of the aeration units. Depending on the water system's location, off-gas may have to be treated using a scrubber, thereby increasing the complexity and the cost of the aeration units.

Coagulation/ Filtration

Coagulation/filtration (C/F) processes involve the addition of chemicals like iron salts, aluminum salts, or cationic polymers that coagulate and de-stabilize particles suspended in the influent, so that they may be ultimately removed via clarification and/or filtration. The C/F processes described in "Small System Compliance Technology List for the Surface Water Treatment Rule and Total Coliform Rule" (EPA 1998c) include "conventional filtration", which includes a clarification step before filtration, and "direct filtration", which does not. This discussion assumes that C/F processes would be added primarily to deal with microbial contaminants. As such, it is recommended that the compliance technology guidance for the SWTR (EPA 1998c) be consulted for details.

Conventional Filtration

Conventional filtration includes pre-treatment steps of chemical coagulation, rapid mixing, and flocculation, followed by floc removal via sedimentation or flotation. After clarification, the water is then filtered. Common filter media include sand, dual-media, and tri-media. Design criteria for specific sites are influenced by site-specific conditions and thus individual components of the treatment train may vary in design criteria between systems. Most of the concerns regarding conventional filtration are specific to the Surface Water Treatment Rule (SWTR) and are discussed elsewhere (EPA 1998c). The main issue is that conventional filtration does not work properly if the coagulation chemistry is incorrect, so that operator skill is of paramount importance, since the operator must frequently monitor water quality and must know how to correct coagulant dosages in response to water quality changes (EPA 1990, NRC 1997).

Direct Filtration

Direct filtration has several effective variations, but all include a pre-treatment of chemical coagulation followed by rapid mixing. The water is then filtered through dual- or mixed-media using pressure or gravity filtration units. Pressure units, which are used primarily by small systems, have the advantage of not requiring repumping for delivery of the filtrate to the point of use. Gravity units have the advantage of allowing easy visual inspection of the filter medium during and after backwash. Besides the mode of filtration, variations of direct filtration include filter media and mixing requirements. In-line filtration is the simplest form of direct filtration and consists of filters preceded by direct influent chemical feed and static mixing. In general, direct filtration usually requires low turbidity raw water and is attractive mainly because of its low cost relative to conventional treatment. Again, advanced operator skill and proper monitoring are required.

Ion exchange

Ion exchange (IX) involves the selective removal of charged inorganic species from water using an ion-specific resin (AWWA 1990, AWWA-ASCE 1998). The surface of the ion exchange resin contains charged functional groups that hold ionic species by electrostatic attraction. As water containing undesired ions passes through a column of resin beds, charged ions on the resin surface are exchanged for the undesired species in the water. The resin, when saturated with the undesired species, is regenerated with a solution of the exchangeable ion. A large variety of synthetic resins is available for specific applications.

Generally, resins can be categorized as anion exchange or cation exchange resins. Anion exchange resins selectively remove anionic species such as nitrate (NO_3^-) and fluoride (F^-). Anion exchange resins are often regenerated with sodium hydroxide or sodium chloride solutions, which replace the anions removed from the water with hydroxide (OH^-) or chloride (Cl^-) ions, respectively. Cation exchange resins are used to remove undesired cations from water and exchange them for protons (H^+), sodium ions (Na^+) or potassium ions (K^+).

Water to be treated by IX must be low in solids to avoid fouling the resin. In particular, reduced iron species in ground water may become oxidized when the water is exposed to oxygen in the atmosphere and form precipitates that can damage the resin.

A resin may preferentially remove certain ions from solution. In general, it will remove highly charged ions more easily than it will remove monovalent ions. Calcium, magnesium, and reduced iron ions will be removed preferentially to other cations. The presence of such species may reduce removal efficiencies (NRC 1997).

An operator must monitor the system to determine the extent of resin saturation or the breakthrough of the ion to be removed. On ion breakthrough, the resin must be removed from service and regenerated. IX units can be controlled automatically, freeing the operator to make daily visits (rather than attending to the systems full-time) to assure proper operation.

In either the cation or anion exchange process, the regeneration solution, which contains high concentrations of the undesired ions, must be carefully disposed of. Disposal can be quite costly, especially in the case of concentrated radionuclides (NRC, 1997).

Stakeholders requested that EPA state that IX can be operated in a "merry-go-round" configuration to achieve low levels of contaminants in the effluent and to minimize regeneration frequency. An example would be the use of three beds in series: two in production and one in regeneration mode at any given time. When exchange capacity of the first bed in series is exhausted, the first bed is removed from service to be regenerated. The second bed in series then becomes the first and a fresh regenerated bed is brought on-line to become the second. This maximizes the exchange capacity of the beds and prevents leakage since a fresh bed is always last in line (EPA 1994). In addition to the "merry-go-round" approach, single, deep bed, counter-

current flow processes can also increase the usable capacity of the IX bed and reduce leakage (EPA 1995).

IX is a common water treatment technology for small systems. IX is available in the form of point-of-use (POU) and point-of-entry (POE) devices as well as in the form of full-scale treatment. An advantage to IX is that it can be used under fluctuating flow rates (NRC 1997). The technology does produce highly concentrated waste by-product streams that may be an issue; brine recycling might reduce this impact somewhat. With IX, the primary factor in calculating costs is the regeneration frequency, and competition with other ions will affect the run length. For example, anion exchange would be recommended primarily for small ground water systems with low sulfate and TDS.

Lime softening

In the lime-softening (LS) process, the pH of the water being treated is raised sufficiently to precipitate calcium carbonate and, if necessary, magnesium hydroxide. Calcium and magnesium ions in water cause hardness; hard water can cause scaling problems in water heaters, and soap lathers poorly in hard water. In small systems, LS would typically be practiced by adding hydrated lime to raw water to raise the pH to approximately 10. This removes calcium carbonate. If magnesium removal is also required, the pH during softening would need to be closer to 11. In some waters, addition of soda ash is needed for effective hardness removal. After mixing, flocculation, sedimentation, and pH readjustment, the softened water is filtered (NRC 1997). In addition to removing calcium and magnesium, LS also removes radium and several inorganics (including arsenic).

Many large water systems use LS to treat surface waters. However, the combination of variable source water quality and the complexity of the chemistry of LS may make it too complex for small systems that use surface water sources. LS may be more appropriate for small systems that use ground water because of the relative uniform quality of ground water. Once the softening chemistry for a ground water is determined, it should not change much. In comparison, chemical additions to surface waters need to be modified frequently in response to water quality changes (NRC 1997).

One of the difficult aspects of LS is the operation and maintenance of lime feeders and lines carrying lime slurry to the point of application. In addition, plant operators must understand lime softening chemistry. Measurement of pH must be accurate, and the operator must know that the pH meter is properly calibrated. Failure to maintain the proper pH in softened water prior to filtration at a lime softening plant could result in precipitation of excess lime in the filter beds and formation of calcium carbonate deposits within the filters.

LS is similar to coagulation/filtration in that pre-fabricated equipment is available. LS may be a feasible technology in the larger small ground water systems. For the smaller categories, LS may be feasible by using some form of contract or satellite operation that would enable a trained

operator to monitor the process periodically.

Membrane Processes

Four membrane processes are discussed in this document: reverse osmosis (RO), ultrafiltration (UF), nanofiltration (NF), and electrodialysis/electrodialysis reversal (ED/EDR). All of these processes share certain characteristics, since they all involve membranes, but RO is distinct in that it involves a non-porous membrane and ED/EDR in that it involves a ion selective membrane. Membranes are manufactured in a variety of configurations, materials and pore size distributions. The selection of membrane treatment for a particular drinking water application is determined by a number of factors, including: targeted material(s) to be removed, source water quality characteristics, treated water quality requirements, membrane pore size, molecular weight cutoff[3] (MWCO), membrane composition, and system/treatment configuration (Jacangelo 1991).

In general, membrance processes show little economy of scale, since capital costs per volume of water treated do not increase dramatically as design flows decrease. For this reason, and others discussed below, membrane technologies can be a good choice for addressing many small systems water quality problems. For ground water systems not requiring pre-treatment, membrane technology addition requires little more than a feed pump, a cleaning pump, the membrane modules, and holding tanks (NRC 1997). Membrane technologies can be more cost-effective than more conventional treatments for controlling a host of water quality problems (Wiesner et al. 1994, Bergman 1996).

Ultrafiltration and Nanofiltration

Ultrafiltration and nanofiltration are "membrane filtration" processes, in that they work by excluding contaminants due to pore size constraints (Adham et al. 1996, Agbekodo et al. 1996). The water is forced by pressure from the source water side (concentrate) through the pores of a semi-permeable membrane to the produced water side (permeate). Impurities are prevented from passing through the membrane by size exclusion, and so are retained in the concentrate. The permeate is generally of a very high quality (NRC 1997).

Membrane classification standards vary between manufacturers. For example, one supplier may classify a membrane as nanofiltration, while another supplier may classify a similar membrane as ultrafiltration. Also, some manufacturers refer to average pore size and some to maximum pore size. For these reasons, water systems should make sure that the reported pore size is adequate for the required purposes by looking directly at pore size, MWCO, and the required applied pressure.

The operation of ultrafiltration and nanofiltration processes are substantially less

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[3] MWCO is defined as an estimate of the molecular weight of the smallest molecule that will be retained by the membrane.

complicated than the operation of the treatment trains needed to achieve similar removals via conventional technologies. In particular, membrane processes may be very appropriate for small systems attempting to remove multiple contaminants. If pre-treatment is required, the complexity of the required operations can of course increase appreciably. In addition, specific site testing to analyze the potential for organic fouling may be required. However, there are few limitations to the types of raw water that can be handled by membrane processes and, if needed, pre-treatment (NRC 1997, AWWA - ASCE 1998).

Reverse Osmosis

Reverse osmosis (RO) is a highly efficient removal process for inorganic ions, some organic contaminants, and, in some cases, microbiological contaminants (EPA 1990, Logsdon et al. 1990, NRC 1997, AWWA-ASCE 1998). RO resembles membrane filtration processes since they all involve passing water through a semi-permeable membrane. However, in the case of RO, the principle involved is not filtration. Instead, it involves the use of applied hydraulic pressure to oppose the osmotic pressure[4] across a non-porous membrane, forcing the water from the concentrated solution side to the dilute solution side. Since the membrane is non-porous, the water does not travel through pores, but rather dissolves into the membrane, diffuses across, then dissolves out into the permeate. Any contaminant that can likewise dissolve into the membrane and pass into the permeate will not be rejected by the RO membrane. However, most inorganic contaminants of interest and many organic contaminants are rejected by the membrane and will be retained in the concentrate. RO produces a larger volume of concentrate (reject) solution than membrane filtration processes. The concentrate volume can be as much as 25 to 50 percent of the raw water volume. Drinking water treatment can be accomplished with lower pressure versions of RO (125 to 300 psi), with feasible recoveries of 70 to 85% (AWWA - ASCE 1998).

Removal efficiencies for inorganic contaminants range from 85 to > 99%. Removal for organic contaminants are highly variable depending upon the contaminant and the water quality. Lower molecular weight organic molecules and organic molecules that have an affinity for the membrane may diffuse through the membrane. The degree to which the contaminant passes depends on the contaminant's molecular weight and its chemical nature. Removal efficiencies for organic compounds range from greater than 99% to no removal at all.

An RO membrane can foul if the influent is not pre-treated, depending upon the quality of the raw water (AWWA-ASCE 1998). Influent total organic carbon (TOC) levels can be as high as 20 mg/L without requiring pre-treatment (NRC 1997), but the influent have low turbidity, iron, manganese, and chlorine or pre-treatment is required. Groundwater waters may have low enough TOC levels and turbidity, but may require removal of iron and manganese. Applying disinfection after the membrane process can obviate the need to remove chlorine beforehand.

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[4] Osmotic pressure is defined as the pressure that arises from the natural tendency of a solvent like water to pass from the dilute solution on one side of a semi-permeable non-porous membrane to the concentrated solution on the other side.

Since the permeate has very low mineral content and alkalinity, it can be quite corrosive. The usual practice to reduce corrosivity is to blend, i.e., bypass a pre-determined percentage of the raw water to the permeate. Other possible measures include de-gasification of carbon dioxide and/or hydrogen sulfide (both are acids in water) or pH adjustment through the addition of a chemical base, like sodium hydroxide. Post-treatment disinfection is also a common practice.

Usually, RO systems have automatic backwash features, reducing labor requirements. The skill requirements for the daily operation of common pre-treatment processes are often greater than the membrane process itself. However, periodic cleaning of the membrane surface is required. Care must be taken to avoid contamination of the raw or finished water with the acidic post-wash solution. Also, the membrane should be flushed with permeate to prevent later scaling. If the plant is taken out of operation for days at a time, the membranes should be filled with a disinfection solution to prevent biological growth, which can damage the membrane (NRC 1997).

Electrodialysis (ED) and electrodialysis reversal (EDR)

Electrodialysis (ED) and electrodialysis reversal (EDR) are usually used for de-mineralizing water from brackish water sources. They involve electrochemical separation processes to concentrate salts from the feed water into smaller-volume, higher-concentration solutions within collection channels. ED and EDR systems consist of stacks of alternating anionic and cationic selective membranes. The ionic constituents pass through the membranes in response to an electric current applied perpendicularly to the membrane surfaces. This results in an alternating sequence of de-mineralized water streams and concentrate streams (NRC 1997, AWWA - ASCE 1998). The principal difference between ED and EDR is that EDR involves the additional step of a change in electrode polarity every 15 to 20 minutes, causing a reversal in ion movement. This step minimizes scale buildup on the membranes and thus EDR can operate for longer time periods between cleanings. The majority of plants using ED technology in the United States use EDR (NRC 1997).

ED/R systems require feed water pre-treatment. Cartridge filtration is often the minimum requirement. Turbidity should be less than 2 NTU, free chlorine levels less than 0.5 mg/L, manganese less than 0.3 mg/L, and hydrogen sulfide less than 0.3 mg/L (Conlon 1990). Total dissolved solids up to 4,000 mg/L have been successfully handled by EDR plants (NRC 1997).

Unlike membrane filtration and RO, the product water does not pass through the ED/R membranes, so the potential for organic fouling is reduced. Unfortunately, another consequence is that microbiological, most organic, and colloidal/particulate contaminants are not removed from the product water. Standards for these contaminants must be met through pre-treatment or other means, if necessary. And like other membrane processes, some bypassed water (or other measures) may be required to reduce the corrosivity of the product water. ED/R systems usually operate at 70% recovery (NRC 1997).

A principal disadvantage of ED/R is the high energy consumption. Pumping costs are

similar to costs for ultrafiltration, but process power costs roughly equal pumping costs for ED/R.

More than half of the ED/R systems in operation in North America serve fewer than 3,500 persons, with some serving fewer than 200. Since ED/R plants are amenable to automatic operation, part-time operators may be sufficient, depending upon pre- and post-treatment requirements.

Membrane Process Waste Disposal Considerations

Waste stream disposal is often the most important consideration (NRC 1997). Waste stream disposal can pose a significant problem in some areas, since waste volumes are larger than for conventional treatment . Because membrane filtration processes require little or no chemical addition, the concentrate usually contains only the contaminants found in the source water, and so disposal of the concentrate into the source water may be feasible. Other alternatives include sanitary sewer discharge, deep well injection, dilution, and spray irrigation (Pontius et al. 1996, USEPA 1996). Careful planning may be required to legally and safely dispose of membrane concentrate wastes. A potentially time consuming part of the process involves obtaining regulatory permits. In the vast majority of cases, an acceptable waste disposal method can be successfully implemented and permitted (Pontius et al. 1996).

Disposal of RO and ED/R reject water poses a potentially more serious problem than the membrane filtration processes, because of the large concentrate volumes. Municipal sewer disposal and deep well injection are conventional waste handling strategies. The use of evaporation ponds is another possibility, but is normally used only when conventional means are not possible, because of the high associated costs and land requirements. For areas with very low land costs, this may be a feasible alternative for small systems (EPA 1997a).

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4. AFFORDABLE TECHNOLOGY DETERMINATIONS

Section 4.1: National-Level Affordability Criteria

As discussed in Section 1.3, EPA did evaluate technologies for each small size category against an affordable technology criterion for those regulations where a small system variance could be granted. The size category-dependent affordable technology criteria are collectively referred to as "national-level affordability criteria." This nomenclature has been used to distinguish the national-level affordability criteria from the affordability criteria that States will use for determinations affecting individual systems. EPA published information regarding these "system-level affordability criteria" in February, 1998 (EPA 1998a). This information was required by Section 1415(e)(7)(B) of the SDWA. There are three provisions of the SDWA that refer to these "system-level affordability criteria." Section 1415(e) provides for affordability-based variances, under certain circumstances, for small drinking water systems. Section 1416 allows for exemptions that provide systems facing compelling economic factors additional time to comply with SDWA requirements. Small systems could receive as long as nine additional years to comply. Finally, Section 1452(b) provides that affordability on a per household basis shall be one of the three factors used to prioritize systems for assistance from the new Drinking Water State Revolving Fund (DWSRF). The system-level affordability criteria can be different for different purposes. For example, States can use different affordability criteria to make decisions about whether a system should receive a small system variance and when a system should receive additional subsidization from the DWSRF. In fact, the threshold used for additional assistance for systems meeting a NPDWR would likely be lower than the threshold used to determine when a system would operate at a level that does not provide an equivalent level of protection as meeting the MCL.

The national-level affordability criteria used to determine if there is an affordable variance technology will also be different from the system-level criteria used by the State to determine if a system should receive a small system variance. Technologies determined to be "unaffordable" under the national-level affordability criteria may still be affordable for a specific system within the size category, in which case the system may install that technology if it so chooses. Conversely, if a financially disadvantaged small water system out of compliance with a NPDWR cannot afford any of the compliance technologies that are determined to be "affordable" under the nation-level affordability criteria, one option for that system would be to apply to the State for an exemption. This process is available for regulations promulgated after 1996. Such a system cannot apply for a new exemption for the regulations issued prior to August 6, 1998. Those small systems with existing exemptions for rules in effect on August 6, 1998 may continue to get renewals of their exemptions until the exemption period has run out. That means that a small system can have no more than 9 years after the Section 1412 compliance date to meet the applicable MCL/treatment technique even if the exemption was issued prior to the 1996 SDWA Amendments.

To determine if there are any affordable compliance technologies for a given NPDWR, the

national-level affordability criteria are compared against the cost estimates for the applicable treatment technologies. To make this comparison, there must be a consistent unit of measure for both parameters. The selected approach was to measure user burden as the increase to annual household water bills that would result from installation of treatment. For community water systems, the household was selected as the most sensitive user for cost increases (EPA 1998b). Non-community water systems (NCWSs) were also evaluated by comparing their vulnerability to cost increases with households in community water systems. The conclusion, based on this comparison, was that the categories of NCWS were either not vulnerable to SDWA-related treatment cost increases or were less vulnerable to SDWA-related treatment cost increases than a typical household (EPA 1998c).

A summary of the methodology used to determine the national-level affordability criteria is described below. The household is the focus of the national-level affordability analysis. Treatment technology costs are presumed affordable to the typical household if they can be shown to be within a range (defined as a range of percentages of median household income) that appears reasonable when compared to other household expenditures. This approach is based on the assumption that affordability to the median household served by the CWS can serve as an adequate proxy for the affordability of technologies to the system itself. EPA has chosen to express the water system financial and operational characteristics using their median values, which is a measure of their respective central tendencies. EPA believes that the national-level affordability criteria should describe the characteristics of typical systems and should not address extreme situations where costs might be extremely low or excessively burdensome.

After selecting the impacts on households as the measure for comparing national-level affordability and treatment costs, a consistent set of units was needed to make the comparison. The treatment cost models produce rate increases measured in dollars/thousand gallons ($/kgal). Annual household water consumption is needed to convert the treatment technology costs into the increase in annual household water bills. The water consumption estimates were multiplied by 1.15 to account for lost water due to leaks. Since the water lost to leaks is unbilled, the water bills for the actual water used needed to be adjusted to cover this lost water by increasing the household consumption. Multiplying the rate increase by the adjusted annual household consumption yields the increase to annual household water bills ($/household/year increase).

The national-level affordability criteria have two major components: current annual water bills (baseline) and the affordability threshold. The current annual household water bills were subtracted from the affordability threshold to determine the maximum increase that can be imposed by treatment and still be considered affordable. This difference was compared with the converted treatment costs to make the affordable technology determinations. This difference is called the available expenditure margin.

The baseline costs include existing water quality, water production, and water distribution costs. Water production costs include labor and energy for pump operation to supply water to customers. Water distribution costs include costs of infrastructure repair (mains and service lines)

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and administrative costs (customer billing and meter checking). The existing water quality costs include both treatment and monitoring. The data utilized to determine the baseline were collected in 1995, so treatment costs for many of the regulated contaminants may already be accounted for in the baseline.

The affordability threshold was determined by comparing the cost of public water supply for households with other household expenditures and risk-averting behavior. National expenditure estimates were derived to illustrate the current allocation of household income across a range of general household expenditures. This consumer expenditure data provided a basis for determining the affordability threshold by comparing baseline household water costs to median household income (MHI) to determine the financial impact of increased water costs on households.

There are three parameters needed for each size category to perform the affordable technology analysis. These parameters are: annual household consumption, current annual water bills, and median household income (MHI). The annual household water consumption and the current annual water bills were derived directly from data in the 1995 Community Water System Survey (EPA 1997a, EPA 1997b). The MHI data were derived by linking the CWSS data with data in the 1990 Census using zip codes.

The national-level affordability criteria are based on an affordability threshold of 2.5% of the MHI for each size category (EPA 1998d). For each size category, median values have been used for annual household water consumption, baseline annual water bills, and median household income. The baseline water bills ranged from 0.65% to 0.69% MHI in the three size categories. Thus, the available expenditure margin were approximately 1.8% MHI for each size category. Table 4-1 summarizes the national-level affordability criteria and shows the maximum increase that could occur using these criteria. The numbers in this table are slightly different from the numbers in the Federal Register notice (EPA 1998e). There were some minor changes in the baseline values for current water bills and median household income (EPA 1998d). Most systems would not be expected to actually experience cost increases of this magnitude if a compliance technology was installed. Many compliance technologies impose substantially lower household costs. For example, the screening process examined several technologies that imposed less than $300/household per year increases in all three size categories. Appendix F of the "National-Level Affordability Criteria Under the 1996 Amendments to the Safe Drinking Water Act" report lists mitigating measures that could reduce the impact on households. In addition, the national-level affordability criteria do not consider the impact of financial assistance from State Revolving Fund loans or other sources. This financial assistance could also reduce the impact on households in those systems that qualify for financial assistance. For more detail on the national-level affordability criteria, see the "Variance Technology Findings for Contaminants Regulated Before 1996"(EPA 1998d) and the National-Level Affordability Criteria Under the 1996 Amendments to the Safe Drinking Water Act" (EPA 1998b) documents.

Table 4-1: National-Level Affordability Criteria

System Size	Baseline			Affordability	Available Expenditure
Population Served	MHI ($/yr)	Water Bills ($/hh/yr)	Water Bills (%MHI)	Threshold (2.5% MHI)	Margin ($/hh/year increase)
25 - 500	$30,785	$211	0.69%	$770	$559
501 - 3,300	$27,058	$184	0.68%	$676	$492
3,301 - 10,000	$27,641	$181	0.65%	$691	$474

Section 4.2: Affordable Technology Analysis using National-Level Affordability Criteria

Compliance technologies were evaluated against the national-level affordability criteria for those existing regulations where small system variances or variance technologies are not prohibited by the SDWA. When affordable compliance technologies are identified for these contaminants, technologies that can achieve compliance, but did not meet the affordability criterion will also be identified.

In general, technology cost estimates to treat all of the water were compared against the available expenditure margin for each size category (see Table 4-1). Technology cost estimates were derived for both central treatment options and centrally-managed Point-of-Use and Point-of-Entry device options. The procedures followed for this analysis are described in detail in Chapter 4 of the background document entitled "Variance Technology Findings for Contaminants Regulated Prior to 1996" (EPA 1998d). Based on this analysis, an affordable compliance technology was found for each of the five contaminants for all system sizes and expected source water qualities. For most of the system size/source water quality combinations, there are multiple affordable technologies.

The national-level affordability criteria only played a role in removing some of the options in the smallest size categories. The technologies that did not meet the affordability criteria in the smallest size category are also identified as "other compliance technologies." Since the technology costs were based on treatment of all of the water for this analysis, systems requiring lower removals may find that the "other compliance technologies" would pass the national-level affordability criteria if a lower removal efficiency is required. A portion of the influent water could be treated and blended with an untreated portion and the system could still meet the MCL. Under this approach, both the capital and operating and maintenance costs for the process would be reduced. Systems and States should consider the "other compliance technologies" under those circumstances.

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5. SMALL SYSTEMS COMPLIANCE TECHNOLOGIES FOR INORGANIC CONTAMINANTS, INCLUDING CORROSION BY-PRODUCTS

Section 5.1: Background

Seventeen inorganics are regulated. The interim MCL for arsenic was issued in 1975. A proposal for a new regulation for arsenic is expected by January 2000, and a final rule is expected by January 2001. The final rule for fluoride was promulgated in April 1986. The final rule for the Phase II inorganics (asbestos, cadmium, chromium, mercury, nitrate, nitrite and selenium) was promulgated in January 1991. The lead and copper rule was promulgated in June 1991. The final rule for Phase IIb (barium) was promulgated in July 1991. The final rule for the Phase V inorganics (antimony, beryllium, cyanide and thallium) was promulgated in July 1992.

Issues with compliance technologies for inorganics treatment are discussed in Section 5.2.2. A general description of these technologies can be found in Chapter 3. Corrosion control technologies are relevant for inhibiting lead and copper dissolution in the distribution system. In addition, corrosion control reduces release of other inorganics such as asbestos and cadmium. The corrosion control technologies are described in Section 5.2.1. Section 5.3 lists the compliance technologies for small systems and Section 5.4 describes emerging technologies.

A short description of some of the key inorganics are given below:

Lead and Copper:

In June 1991, EPA promulgated a NPDWR for lead and copper consisting of a treatment technique requirement that includes corrosion control treatment, source water treatment, lead service line replacement and public education. Lead occurs in drinking water from two sources: (1) Lead in raw water supplies and (2) corrosion of plumbing materials in the water distribution system (corrosion by-products). Most lead contamination is from corrosion by-products. The primary source of copper in drinking water is corrosion of copper pipes, which are widely used throughout the United States for interior plumbing of residences and other buildings. In some cases, copper is a component of additives to drinking water used by systems to control the growth of algae (EPA 1991a).

Asbestos:

Asbestos fibers are relatively large particles. Asbestos fibers are generally of two types: chrysotile and amphibole. Chrysotile fibers are more common in water supplies and are usually less than 5 microns in length and approximately 0.1 microns in width. Amphiboles are on the order of 0.4 to 1.7 microns in length and 0.1 to 0.4 microns in width (Logsdon 1979, Kirmeyer 1979a, Kirmeyer 1979b, Black & Veatch 1975). Because of the large size of the particles, the potential for using inexpensive membrane technologies exists. However, further research is required.

Antimony:

Antimony is found in over 100 mineral species; however, it does not occur in abundance. Metallic antimony is blueish white in color, with a metallic luster, and is extremely brittle, with a flaky, crystalline texture. Antimony has valence states in the -3, 0, +3, and +5 forms; antimony does not seem to occur in drinking water in the +3 and +5 states. Though ion exchange (IX) is an affordable, effective treatment technology for most inorganics, IX does not appear to be effective in removing antimony (EPA 1990).

Fluoride:

Fluoride commonly occurs in the earth's crust as fluorspar (CaF_2), cryolite (Na_3AlF_6) and fluorapatite ($Ca_{10}F_2(PO_4)_6$) and ranks thirteenth among the elements in order of abundance. Concentrations as high as 9 to10 mg/l are not uncommon in some ground waters (Benefield 1982). Fluoride has beneficial and detrimental effects. It can help prevent dental cavities when an optimum amount is present in drinking water. However, long-term consumption of water containing excessive amounts of fluoride can lead to fluorosis of the teeth and bones. The MCL for fluoride is 4.0 mg/l, and the secondary maximum contaminant level (SMCL) is 2.0 mg/l. The SMCL was set at 2 mg/l because that level would prevent the majority of cases of water-related cosmetically objectionable dental fluorosis while still allowing for the beneficial effects of fluoride (EPA 1986a).

Nitrate:

Nitrate is a common ion found in most natural waters. It is the end product of the oxidation of ammonia. Because it is an algal nutrient it can promote algal blooms (Benefield 1982). Nitrate is also a potential hazard to infants. Serious and occasionally fatal poisonings in infants have occurred following ingestion of well waters shown to contain nitrate at concentrations greater than 10 mg/l of nitrate (as Nitrogen). Well water, particularly shallow well waters, tend to have higher concentrations of nitrates than surface waters. The major sources of nitrate contamination has been from septic tank discharges, fertilizer in agricultural drainage, animal feedlots, domestic and municipal sewage, and industrial wastes (EPA 1984a).

Arsenic:

Arsenic occurs in two primary forms: organic and inorganic. Inorganic arsenic occurs in two valence states, arsenite (As III) and arsenate (As V). Most natural waters contain the inorganic forms of arsenic. Groundwaters generally contain As (III) and surface waters generally contain As (V). Arsenate is removed more efficiently that arsenite by the treatment technologies listed here. Therefore, if arsenite is the predominant species present, oxidation to arsenate may be required to achieve the desired removal.

Section 5.2 Evaluation of Technologies

Corrosion Control Technologies

There are primarily three different approaches to control for corrosion in the distribution system. One approach is to cause a calcium carbonate precipitate to form inside the distribution system to protect the inside of the pipes. Another approach, referred to as passivation, is to change the water to be less corrosive without causing a precipitate to form. There are two methods of passivation. The first is to change the alkalinity and pH of the water. The second is to add an inhibitor (EPA 1992). The third approach to control for corrosion is to use aeration.

Calcium carbonate precipitation

The principle behind calcium carbonate precipitation is to maintain the concentration of calcium and carbonate high enough in the product water so that calcium carbonate precipitates out in the distribution system. The solids form a protective coating. This approach is only practical if the concentration of the calcium and carbonate are high enough in the influent water. If necessary, calcium can be added in the form of hydrated or quick lime. The carbonate can be adjusted by adding soda ash, sodium bicarbonate or carbon dioxide. The pH can be adjusted, if necessary, by adding these aforementioned chemicals and/or caustic soda, hydrochloric acid or sulfuric acid. Small systems should be aware of the complexities inherent in using lime and soda ash systems. These methods require a high degree of operator attention because the calcium carbonate plugs bins, tanks, pumps and piping. To keep downtime to a minimum the bins have to be kept dry. In addition, the feed systems must be acid cleaned. Small systems should also be aware of complexities in operating a sodium hydroxide system. In addition to avoiding calcium carbonate plugging of the sodium hydroxide feed system, small systems should also be aware that employees may have to handle a strong base; sodium hydroxide is usually delivered as a 50 percent solution (EPA 1992). Stakeholders expressed a concern that this approach may also cause a build-up of precipitate in consumers' hot water heaters.

This control strategy is only appropriate for lead. It is not an effective strategy for copper for several reasons. First, a much larger surface area would need to be coated. Second, a calcium carbonate film may not establish on copper piping. Third, adjusting alkalinity for precipitation may produce a high alkalinity finished water which can be corrosive to copper.

Passivation

The other approach to corrosion control is passivation. In this case, the goal is to produce less corrosive water. A precipitate need not be created.

Alkalinity and pH

One method of passivation is to alter the alkalinity and the pH. This is appropriate when the water is not very hard and low in alkalinity. This essentially involves use of the same chemicals (lime, soda ash, etc.) and feed systems as in calcium carbonate precipitation. An advantage of this approach is that small systems do not have to attempt the difficult task of forming a precipitate throughout the distribution system. Small systems should, however, be aware that employees might have to handle chemicals such as strong bases (EPA 1992).

Limestone contactors

A method of altering the alkalinity and pH that might be particularly applicable to the smaller systems is the use of limestone contactors (EPA 1987). This method would be applicable if the raw water was soft and slightly acidic. With this technology, the water flows through and dissolves a packed bed of crushed limestones. Because the raw water is slightly soft and slightly acidic, the calcium carbonate dissolves. Consequently, the pH, calcium and alkalinity increases. Limestone contactors have low capital and operation and maintenance costs. This technology is primarily recommended for the smallest category (25-500 only). Stakeholders expressed a concern that limestone contactors are presently not widely in use.

Inhibitors

The other approach to passivation for corrosion control is to use inhibitors. These are usually phosphate or silicate based. The principal type of phosphates used are orthophosphates; all are measured as orthophosphate as residual. Polyphosphates have a record of successful corrosion suppression in some waters, but in others they can increase corrosivity. Polyphosphates are primarily used as sequesterants. The chemicals are not dangerous, have a long shelf life, and are highly soluble. Small systems would be able to use small tanks and feed pumps. Systems should be aware, however, that tanks containing a phosphate-rich solution may experience some biological growth. Consequently, routine cleaning would be recommended. Another potential problem with inhibitors is that when first added, previously corroded material may be released (EPA 1992).

Aeration

Aeration removes carbon dioxide, which directly affects pH and dissolved inorganic carbon (DIC), the parameters that most influence lead and copper solubility. As a result, aeration can be an effective corrosion control strategy, presuming the initial pH and DIC are appropriate. A suitable water must have a significant carbon dioxide concentration and a corresponding relatively low pH. Carbon dioxide concentrations less than about 4 to 10 mg/L CO_2 are not suitable for aeration. Mineral precipitation brought about by water quality changes resulting from aeration may present operational constraints under some conditions. Aeration produces consistent water quality and may be advantageous to smaller utilities because of relatively low costs and simple operational and maintenance needs (Lytle et al, 1998).

Compliance Technologies for Inorganics

Activated Alumina

In the application of activated alumina (AA) for treatment of inorganics such as arsenic, fluoride and selenium, the pH must be lowered to the optimal range. When treated with an acid solution, alumina is strongly positively charged and will select highly for fluoride (F^-), selenium species (SeO_4^{2-}, $HSeO_3^{2-}$), and arsenic ($H_2AsO_4^-$). Activated alumina displays a selectivity sequence, which refers to an order in which ions are preferred by the alumina. Table 9.2 in Water Quality and Treatment (AWWA 1990) shows the most preferred ions (i.e. those with the highest separation factors) at the top of the table and the least preferred ions at the bottom. The greatest adsorption capacity for fluoride occurs at pH 5.5. The greatest adsorption capacity for arsenic occurs at approximately between 5.5 to 6.0 (Rosenblum 1984). To lower the pH, systems would have to use acids, which may be problematic for small systems, since some degree of oversight would be required to ensure that the pH adjustment chemicals are added without causing significant water chemistry problems. However, many small systems have only part-time operators. Small systems should also be concerned that it may be necessary to raise the pH after treatment to avoid corrosion problems. In addition, chemicals involved in the regeneration process (sodium hydroxide and sulfuric acid) may be difficult for small system operators to handle. Consequently, small systems will likely need to regenerate the media off-site or dispose of the spent media rather than regenerate it. AA media will likely pass toxicity tests (in the case of arsenic) and therefore will be suitable for landfilling (EPA 1998a). Small systems should also be concerned about highly concentrated waste streams that can be produced. Spent regenerant from arsenic treatment cannot likely be discharged to a sanitary sewer without pre-treatment.

Coagulation/filtration

Coagulation/filtration (C/F) units are available as package plants, however, it may not be advisable to install a C/F unit solely for inorganics removal. It may be a relevant technology if the raw water is also high in turbidity. Stakeholders mentioned that some manufacturers are making C/F units solely for arsenic removal. Stakeholders also expressed concerns about solids handling.

For instance, disposal of arsenic contaminated sludge may be an issue, especially if it is deemed hazardous. Sludges are evaluated by the toxicity characteristic leaching procedure (TCLP) to determine if a sludge should be classified as hazardous. Sludges from four different water treatment plants were evaluated (Bartley 1992) for a variety of inorganic contaminants, including arsenic. One plant had a C/F process, one plant had a C/F and LS process, and two had LS processes. All TCLP extracts were considerably below the current criterion (5 mg/L of arsenic) for being designated a hazardous waste.

Lime softening

Lime softening (LS), like coagulation/filtration, is not advisable solely for inorganics removal. However, if systems have hard water and inorganics problems, LS would be recommended as a compliance technology. Stakeholders agreed with this approach. Arsenic TCLP extracts from the LS sludges (from the study mentioned above) were also well below the criterion for being designated a hazardous waste.

Ion exchange

In considering application of ion exchange (IX) for inorganics removal, it is important to understand what the effect of competing ions will be, and to what extent the brine can be recycled. Similar to activated alumina, ion exchange exhibits a selectivity sequence, which refers to an order in which ions are preferred. Table 9.2 in Water Quality and Treatment (AWWA 1990) shows the most preferred ions (i.e. those with the highest separation factors) at the top of the table and the least preferred ions at the bottom. Barium, lead and copper are highly preferred cations. Sulfate competes with both nitrate and arsenic, but more aggressively with arsenic in anion exchange. The presence of TDS also impairs aresenic removal. Source waters with TDS levels above 500 mg/L and sulfate levels above 120 mg/L are not amenable to IX treatment (EPA 1998a). Spent regenerant is produced during IX bed regeneration and this spent regenerant may have high concentrations of sorbed contaminants and can be expensive to treat and/or dispose. Research has been conducted to minimize this effect: recent research on arsenic removal has shown that the brine can be reused as many as 25 times (Clifford 1998). Though ion exchange (IX) is an affordable, effective treatment technology for most inorganics, IX does not appear to be effective in removing antimony. In a bench scale study of ion exchange a removal of only 40 percent was obtained from an influent antimony concentration of 120 ug/l after processing 700 bed volumes (EPA 1990). The charges on a ion also effect the removal efficiency. For instance, ion exchange will remove arsenic (V), but won't remove arsenic (III), because the predominant species in natural water is uncharged.

Reverse osmosis

A concern with reverse osmosis (RO) for inorganics treatment is that if the full stream is treated, then most of the alkalinity and the hardness would also be removed. In this case, post-treatment may be necessary to avoid corrosion problems. If feasible, a way to avoid this issue is to blend the water rather than treat the full stream. The amount of water that is rejected is also an issue with RO. Discharge concentrate can be between 10 and 50 percent of the influent flow (EPA 1998a). For that reason it may not be an appropriate technology for all parts of the U.S. RO involves passing water through a semi-permeable membrane by forcing the water from the concentrated solution side to the dilute solution side. Any contaminant that cannot dissolve into the membrane and pass into the permeate will be rejected by the RO membrane. Most inorganic contaminants of interest are rejected by the membrane and will be retained in the concentrate. Because of the small pore size, RO can remove both As(III) and As(V). However, as with the other treatment technologies, RO removes As(V) to a greater degree than As(III). Consequently pre-oxidation will improve removal efficiencies. For asbestos removal, RO and ultrafiltration techniques have problems with asbestos fibers accumulating on the membrane surfaces. Conventional flushing techniques may not be effective.

Oxidation

Several oxidants are available for precipitating inorganics from drinking water, including chlorine, ozone, chlorine dioxide and permanganate. In general, inorganics removal by oxidation involves the conversion of the contaminant to a higher valence state which may be less soluble and subject to precipitation. The oxidized inorganic can then be removed by clarification and/or filtration. However, oxidation of cyanide is a physical break-up. Oxidation has been evaluated for cyanide removal and the oxidants which have been evaluated include chlorine and ozone. Bench and pilot evaluations of chlorine oxidation were performed on wastewaters where cyanide concentrations and oxidant dosages were higher than those typically encountered in drinking water treatment. The results indicate that chlorine oxidation could achieve significant cyanide removal. Oxidation with chlorine is not a new technology; it has been frequently applied in small ground water systems. Chlorine oxidation is fairly inexpensive and not difficult to implement. A concern with chlorine, however, is the formation of disinfection by-products, especially since the chlorination should be conducted at a pH greater than or equal to 8.5. The use of chlorine to oxidize cyanide results in the formation of cyanogen chloride. Chronic exposure to cyanogen chloride may be as harmful as chronic exposure to cyanide at and above the MCL. Chlorine quickly and effectively oxidizes cyanide and cyanogen chloride in a process called alkaline chlorination. Alkaline chlorination oxidizes cyanide to harmless bicarbonate and nitrogen gas by using excess chlorine at pH values greater than at least 8.5. The higher the pH the faster the reaction proceeds. Alkaline chlorination is prescribed over simple chlorination because of the need to destroy cyanide and cyanogen chloride as quickly as possible.

Corrosion control

In addition to preventing dissolution of lead and copper, corrosion control is relevant for inorganics removal because asbestos and cadmium can also be released from distribution systems. Corrosion control would minimize this release. Please refer to Section 5.2.1 for information on corrosion control technologies. In some cases where corrosion control is not possible, the only alternative may be to replace the piping.

Direct filtration

Direct filtration is a compliance technology for asbestos removal and can achieve 95% removal. In the application of this technology, proper chemical pretreatment is necessary. The chemical treatment may consist of conditioning the feed water with alum or iron coagulants and addition of polymers prior to filtration. The chemicals, when so added, destabilize the suspended asbestos particles in the water making them easier to remove in the filter. Higher asbestos levels in plant effluents are associated with poor destabilization of particles in the water and filter breakthroughs (EPA 1986b).

Diatomaceous earth filtration

Diatomaceous earth filtration is a compliance technology for asbestos removal and capable of 95% removal. Improved removal of asbestos fibers has been obtained with a two-step pre-coating procedure. A coarse grade of diatomite is first applied. A second pre-coat of a finer grade of diatomite that has been conditioned with alum or an anionic polymer is then applied. Similar conditioning of the diatomite used for body feed, by the continuous addition of a polymer to the raw water, also improves the fiber removal efficiency (EPA 1986b).

Granular activated carbon

Granular Activated Carbon (GAC) is a compliance technology for treatment of mercury. GAC columns are used in water treatment systems primarily for the removal of organics by adsorption and are particularly effective in removing those organics which contribute to taste and odor problems in drinking water. High removal efficiencies of mercury have been obtained with GAC and usually the capacity of GAC for organic mercury is greater than its capacity for inorganic mercury (EPA 1984b).

Electrodialysis reversal

Electrodialysis reversal (EDR) is a compliance technology for barium, selenium and arsenic. In the removal of arsenic, fairly high recoveries can be obtained by using an internal brine recycle system (EPA 1998a). EDR can be quite expensive to run because of the energy it uses. However, because it is generally automated and allows for part-time operation, it may be an appropriate technology for small systems.

POU Reverse Osmosis and Ion Exchange

POU Reverse Osmosis (POU-RO) and/or Ion Exchange (POU-IX) units are affordable compliance technologies for antimony, lead, arsenic, barium, beryllium, cadmium, chromium, copper, fluoride, selenium and thallium. For antimony, the only compliance technology listed for the smallest size category is POU-RO. POU units essentially use the same technology concepts as in centralized treatment, and so the comments regarding the treatment technologies made above also apply for POU treatment. Waste disposal is not likely to be an issue with POU-RO (please refer to Section 6.2). POU-RO units need to be provided with a means of discharging reject water to a drain; the reject water will likely be dilute enough to discharge directly into a drain. The EPA Drinking Water Research Division (DWRD) conducted POU studies in Alaska and Oregon where POU-RO and POU-IX were demonstrated to be viable treatment alternatives. DWRD entered into a cooperative agreement with San Ysidro, New Mexico to study POU-RO removal of arsenic, fluoride and other contaminants. Again, POU units were shown to be effective. Since the conclusion of the San Ysidro study, the village has assumed ownership of the units and is now responsible for operating and maintaining the units (EPA 1998a).

Section 5.3 Small Systems Compliance Technology List

Compliance Technologies for Inorganic Contaminants (IOCS)

Table 5.1 contains the technologies that have been identified as compliance technologies for at least one IOC. The table contains the same structure as other tables with a list of limitations that are contained in the footnotes and operator skill level and raw water quality issues for general operation of the technology.

Table 5.1: Technologies for IOCs

Unit technology	Limitations (see footnotes)	Operator Skill Level Required	Raw Water Quality Range
1. Activated Alumina	(a) (b)	Advanced	Ground waters, Competing anion concentrations will affect run length
2. Ion Exchange (IX)	(c)	Intermediate	Ground waters with low total dissolved solids. Competing ion concentrations will affect run length. Water should be low in solids to avoid fouling the resin.
3. Lime Softening	(d) (e) (f)	Advanced	Hard ground and surface waters. Variable source water quality may make LS too difficult.

4. Coagulation/ Filtration	([g]) ([h])	Advanced	Can treat wide range of water quality
5. Reverse Osmosis (RO)	([i]) ([j]) ([k])	Advanced	Surface water usually require pre-filtration
6. Alkaline Chlorination	([l]) ([m])	Basic	All ground waters
7. Ozone Oxidation		Intermediate	All ground waters
8. Direct Filtration	([n])	Advanced	Needs high raw water quality
9. Diatomaceous earth filtration	([o]) ([p])	Intermediate	Needs very high raw water quality
10. Granular Activated Carbon	([q])	Basic	Surface waters may require prefiltration
11. Electrodialysis Reversal		Advanced	Requires prefiltration for surface water
12. POU - IX	([r])	Basic	Same as Technology #2
13. POU - RO	([r])	Basic	Same as Technology #5
14. Calcium Carbonate Precipitation	([s]) ([t]) ([u])	Basic	Waters with high levels of alkalinity and calcium
15. pH and alkalinity adjustment (chemical feed)	([s])	Basic	All ranges
16. pH and alkalinity adjustment (limestone contactor)	([v])	Basic	Waters that are low in iron and turbidity. Raw water should be soft and slightly acidic.

| 17. Inhibitors | (ʷ) (ˣ) | Basic | All ranges |
| 18. Aeration | (ʸ) | Basic | Waters with moderate to high carbon dioxide content. |

Limitations Footnotes to the Technology Tables for IOCs

ᵃ Chemicals required during regeneration and pH adjustment may be difficult for small systems to handle.

ᵇ May create highly concentrated waste streams.

ᶜ Disposal of regeneration solution containing high concentrations of undesired ions may be problematic.

ᵈ Softening chemistry may be too complex for small systems.

ᵉ Operation and maintenance of lime feeders and lines carrying lime slurry may be too complex for small systems.

ᶠ In LS, there is a potential for precipitation of excess lime in filter beds and formation of calcium carbonate deposits within filters.

ᵍ It may not be advisable to install coagulation/filtration solely for inorganics removal.

ʰ Solids handling may be an issue. For instance, disposal of arsenic contaminated sludge may be an issue, especially if deemed hazardous.

ⁱ If all of the influent water is treated, then most of the alkalinity and hardness would also be removed; post-treatment corrosion control will be necessary.

ʲ Amount of water that is rejected can be substantial. RO may not be appropriate for all parts of the U.S.

ᵏ For asbestos removal, RO has problems with asbestos fibers accumulating on the membrane surfaces. Conventional flushing techniques may not be effective.

ˡ pH must exceed pH 8.5 to ensure complete oxidation without build-up of cyanogen chloride

ᵐ With alkaline chlorine oxidation, there is the potential for formation of disinfection by-products.

ⁿ Conditioning the feed water with alum or iron coagulants and addition of polymers prior to filtration may be necessary for asbestos removal (EPA 1986b).

ᵒ Two-step precoating procedure may be necessary for asbestos removal. A coarse grade is first applied. A second coat conditioned with alum or an anionic polymer may be necessary (EPA 1986b).

ᵖ Continuous addition of a polymer to the raw water may be necessary to improve asbestos fiber removal efficiency (EPA 1986b).

ᑫ Usually, the capacity of GAC for organic mercury removal is greater than its capacity for inorganic mercury removal (EPA 1984b).

ʳ When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance (see Section 1.4).

Section 1.3 indicated that EPA would identify affordable compliance technologies for those existing regulations where small system variances or variance technologies are not prohibited by the SDWA. There are statutory prohibitions against small system variances or variance technologies for 13 of the 17 IOCs. Table 5.2 contains the compliance technologies for the four IOCs where affordability was considered. Affordability only plays a role in removing some of the options in the smallest size category. The technology costs are based on treatment of all of the water. The technologies that did not meet the affordability criteria in the smallest size category are also identified in the next column called other compliance technologies. These technologies may be affordable if the concentration of the contaminant is low enough that a portion of the influent stream can be treated and blended with an untreated portion to still meet the MCL. Systems and States should consider these options under those circumstances. Table 5.3 contains the compliance technologies for the remaining thirteen IOCs where affordability was not considered due to statutory prohibitions (EPA 1998b).

Table 5.2: Compliance Technologies by System Size Category for those IOC NPDWRs where Affordability is Considered

Inorganic Contaminant	Compliance Technologies for System Size Categories (Population Served)			
	25 - 500 (afford)	25 - 500 (other)	501 - 3,300 (afford)	3,301 - 10,000 (afford)
Antimony	13	4, 5	4, 5, 13	4, 5, 13
Asbestos	8, 9, 15, 17	4	4, 8, 9, 15, 17	4, 8, 9, 15, 17
Cyanide	2, 6, 7	5	2, 5, 6, 7	2, 5, 6, 7

Lead	2, 12, 13, 14, 15, 16, 17, 18	3, 4, 5	2, 3, 4, 5, 12, 13, 14, 15, 16, 17, 18	2, 3, 4, 5, 12, 13, 14, 15, 16, 17, 18

Table 5.3: Compliance Technologies by System Size Category for those IOC NPDWRs where Affordability is Not Considered

Inorganic Contaminant	Compliance Technologies for System Size Categories (Population Served)		
	25 - 500	501 - 3,300	3,301 - 10,000
Arsenic	1, 2, 3, 4, 5, 11, 12, 13	1, 2, 3, 4, 5, 11, 12, 13	1, 2, 3, 4, 5, 11, 12, 13
Barium	2, 3, 4, 5, 11, 12, 13	2, 3, 4, 5, 11, 12, 13	2, 3, 4, 5, 11, 12, 13
Beryllium	1, 2, 3, 4, 5, 12, 13	1, 2, 3, 4, 5, 12, 13	1, 2, 3, 4, 5, 12, 13
Cadmium	2, 3, 4, 5, 12, 13	2, 3, 4, 5, 12, 13	2, 3, 4, 5, 12, 13
Chromium	2, 3 [a], 4, 5, 12, 13	2, 3 [a], 4, 5, 12, 13	2, 3 [a], 4, 5, 12, 13
Copper	2, 3, 4, 5, 12, 13, 15, 16, 17, 18	2, 3, 4, 5, 12, 13, 15, 16, 17, 18	2, 3, 4, 5, 12, 13, 15, 16, 17, 18
Fluoride	1, 5, 13	1, 5, 13	1, 5, 13
Mercury	3[b], 4[b], 5[b], 10	3[b], 4[b], 5[b], 10	3[b], 4[b], 5[b], 10
Nitrate	2, 5, 11	2, 5, 11	2, 5, 11
Nitrite	2, 5	2, 5	2, 5
Nitrate + Nitrite	2, 5, 11	2, 5, 11	2, 5, 11
Selenium	1, 2[c], 3, 4[d], 5, 11[d], 13	1, 2[c], 3, 4[d], 5, 11[d], 13	1, 2[c], 3, 4[d], 5, 11[d], 13
Thallium	1, 2, 12	1, 2, 12	1, 2, 12

Footnotes for Table 5.3: Compliance Technologies for IOCs (affordability not considered)
[a] Compliance technology for Chromium III only.
[b] Compliance technologies only when influent mercury concentrations   10 μg/L.
[c] Compliance technology for Selenium VI only.
[d] Compliance technology for Selenium IV only.

Section 5.4: Emerging Technologies

Following is a listing of technologies that EPA did not list as compliance technologies. However, EPA is monitoring the development of these technologies and may list them as compliance technologies in future updates of this guidance.

Biological denitrification

For nitrate removal, another appropriate technology may be biological denitrification. In biological denitrification, micro-organisms are fed some form of carbon, and use the nitrate as an electron acceptor instead of oxygen. The micro-organisms reduce the nitrate to nitrogen. Though this technology has been used in wastewater treatment, its use in the United States in water treatment is limited. The primary reason is that there is concern that since bacteria are being used to treat the water, there is a potential for bacterial contamination of the water supply.

Nanofiltration, ultrafiltration and microfiltration

Asbestos:

The MCL for asbestos is 7 million fibers/liter and refers only to those fibers longer than 10 microns (EPA 1991b). For particles of that size, reverse osmosis, nanofiltration, ultrafiltration and microfiltration would be effective removal technologies. The membrane pore size for microfiltration varies from approximately 0.1 to 1.0 microns (AWWA 1998); therefore, the technology can be expected to remove asbestos fibers larger than 10 microns. For asbestos removal, membrane techniques, however, have problems with asbestos fibers accumulating on the membrane surfaces. Conventional flushing techniques may not be effective. The issue requires further research.

Arsenic:

Nanofiltration (NF) membranes have pore sizes that vary from approximately 0.001 microns to 0.005 microns. Because of the small pore size, NF can remove both As(III) and As(V), but as with the other treatment technologies, NF removes As(V) more effectively. The small pore size, however makes NF membranes more prone to fouling than ultrafiltration or microfiltration membranes. The application of NF for surface water treatment is typically not accomplished without extensive pretreatment for particle removal and possible pretreatment for dissolved constituents to prevent fouling (EPA 1998a). NF can be operated at lower pressures then reverse osmosis, which translates into lower operation and maintenance costs. However, a recent study with arsenic removal revealed that the removal efficiency dropped significantly during pilot-scale tests where the process was operated at more realist recoveries. When the membrane unit was operated at a recovery of 65%, the arsenic removal efficiency dropped to 65% and when the recovery was increased to 90%, the arsenic removal efficiency dropped down to 16% (Chang 1994).

POU Activated Alumina Units

Activated Alumina (AA) units are often used for fluoride removal and are also applicable for arsenic and selenium removal. Since the greatest adsorption capacity occurs at pH 5.5 for fluoride, and between 5.5 and 6.0 for arsenic, and the pH will not be adjusted in a POU unit, the removal efficiency will not be optimum. This implies that the exchange/adsorption capacity of the activated alumina will be reached in a shorter time, and the spent cartridge will need to be replaced more often. If, after investigation, EPA determines that this is not a major issue, POU AA units will be added as compliance technologies in the next update of this list.

POU Ion Exchange and Reverse Osmosis Units for Nitrate

Ion exchange and reverse osmosis are appropriate technologies for nitrate removal. If they are used as POU devices, it is important to educate consumers as to potential health effects. Since POU devices do not treat all the water taps in a house, there is a potential health risk of household residents drinking untreated water. Nitrate, as mentioned previously, is a potential hazard to young infants; serious and occasionally fatal poisonings in infants have occurred following ingestion. Households need to be informed about the importance of meeting replacement schedules for media, cartridges, filters, and modules associated with POU systems. Households also must be careful not to use untreated water to make infant formula. Almost all established cases of water related nitrate-induced methemoglobinemia in the United States have resulted from the ingestion of private well water used to make infant formula. Stakeholders suggested that EPA investigate the feasibility of public awareness projects such as using print, radio and television media and public forums. Public outreach would, however, have significant costs and may offset any savings of using POU devices.

POE Units

POE units are relatively expensive, and not likely an affordable technology for small systems. In addition, waste disposal issues remain with POE units. The disposal of the brine or concentrate stream may be problematic. In addition, EPA needs to investigate if the usage of a limestone contactor after a reverse osmosis unit will be adequate for corrosion control of internal plumbing.

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6. SMALL SYSTEMS COMPLIANCE TECHNOLOGIES FOR RADIONUCLIDES

Section 6.1: Background

The applicability of particular treatment technologies to the removal of radionuclides from drinking water depends significantly on the chemical and physical characteristics of the contaminants involved and the site specific characteristics of the water system, e.g., source water quality and water system size. The considerations that determine feasibility include: high removal efficiency, general geographic availability and applicability (e.g., climate considerations) of the technology, cost, service life, and co-treatment compatibility.

The removal strategies for radium, gross-alpha emitters, and total beta and photon emitters exploit the chemistries of the individual contaminants, as with any removal contaminant removal strategy. The chemical properties of the contaminant to be removed, e.g., speciation, solubility, tendency to sorb, etc., have a deciding influence on the choice of the best treatment strategy. For example, some contaminants occur as either cations or anions depending upon the source water conditions, e.g., pH, the presence of other complexing ions, including dissolved organic compounds, etc. Thus, the choice of cation versus anion exchange treatment may depend upon the site specific situation. As another relevant example, for coagulation/filtration treatment processes to be effective for removing elevated gross alpha levels caused by uranium, uranium must sorb to the floc or precipitate before settling or filtration. Highly efficient removal will only occur for those uranium species that sorb significantly under the site specific conditions of the source water as affected by the treatment process. For reverse osmosis treatment, the water chemistry of the contaminants in question is less important since the removal mechanism tends to remove both cations and anions and does not involve sorption.

Radionuclides occur naturally as trace elements in rocks and soils as the result of the radioactive decay of the uranium-238 (U-238) and thorium-232 (Th-232). Of the U-238 and Th-232 decay series, radon-222, radium-226, radium-228, U-238, and U-234 are the most common in ground water (Zapecza and Szabo 1986). The other naturally occurring radionuclides are not present in significant amounts in ground water, because of their environmental immobility and/or short half-lives. The naturally occurring radionuclides of the uranium-238 decay series (uranium-238, radium-226, and radon-222) are responsible for the majority of radiation exposure associated with drinking water (e.g., Lowry and Lowry 1988, EPA 1991a). Radium-228 can also have significant occurrence.   Of these, only radium-226 and -228 currently have National Primary Drinking Water Regulations. Total beta and photon emitter activity will be discussed only briefly

since most are anthropogenic and their occurrence is very site specific[1]. Although uranium[2] comprises the majority of "true total alpha activity" in surface waters (i.e., total alpha activity without excluding radon-222 and uranium isotopes), it is exclude by definition from gross alpha activity. This being the case, and since radium-226 primarily comprises gross alpha occurrence in ground waters, radium will be the focus of the remainder of this discussion[3].

When planning removal strategies for radionuclides, it is important to understand that different isotopes of the same element (e.g., radium-226 versus radium-228) are chemically indistinguishable from the perspective of treatment (Clifford 1990). In other words, when planning treatment, "radium is radium".

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[1] Beta and photon activity is usually the result of releases from nuclear facilities. Since releases from these facilities are strictly controlled, occurrence is rare. As such, total beta and photon activity is of concern to only a few drinking water supplies.

[2] Uranium was proposed for regulation in 1991. A final NPDWR for uranium is expected in the near future and will include a list of small systems compliance technologies.

[3] A revised Small Systems Compliance Technology list for gross alpha activity will be issued with the future updated NPDWR for radionuclides.

Chemical Behavior of Radium

Radium is primarily a ground water contaminant. Under oxidizing conditions (e.g., surface waters), it is very immobile. The sources of radium to ground water include dissolution of radium-bearing aquifer solids, "alpha-recoil[1]" of radium isotopes from the aquifer solid matrix across the solid/water boundary (Hess et al. 1985), and desorption of radium from aquifer solids surfaces. Since radium itself is not very soluble in water and does not form strong complexes with common solutes found in aquifers, the alpha recoil process is important in that it can significantly increase the radium concentration above that due to dissolution from the aquifer material. The radium "liberated" by the alpha recoil process may then stay in solution or sorb to the aquifer matrix, where the fraction of radium in solution to that sorbed is determined by the local geochemical conditions of the aquifer. For a more detailed discussion of how local geology and geochemical processes control the occurrence of radium in aquifers, see, e.g., Hess et al. 1985, Zapecza and Szabo 1986, and Michel 1991. In general, radium occurs at higher ground water concentrations under reducing conditions with high total dissolved solids content (Tanner 1964, as cited in Zapecza and Szabo 1986, and Michel 1991).

Radium, though much less soluble, behaves in water analogously to calcium and magnesium (all are alkaline earth metals, group IIA), so water softening processes like ion exchange and lime softening tend to remove radium also. Like the other alkaline earth metals, radium remains a divalent cation ($Ra^{2+}_{(aq)}$) up to the higher end of pH values normally found in drinking water sources. In other words, radium does not significantly hydrolyze water (form hydroxides or oxides) at ambient pH levels. This greatly simplifies the water chemistry of radium. One treatment strategy consequence of this is that cation exchange is usually the most appropriate ion exchange type.

It is important to keep in mind that the radium ion is a problem at picogram (pg) per liter levels[2], whereas calcium concentrations of 100 mg/L are not unusual. To put this in perspective, under those conditions, for every radium ion present in solution, there would be 10^{11}, or one hundred billion, calcium ions competing in the chemical processes[3] that are exploited in water

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[1] Alpha-recoil refers to the recoil motion of the daughter product (the radium isotope, in this case) resulting from the high energy ejection of the alpha particle during the alpha-decay of the parent isotope, which was originally embedded in the aquifer solid phase. Analogous to the recoil energy of a gun (Michel 1991), the high speed ejection of the alpha particle results in recoil of the progeny radium isotope, imparting enough energy to eject it across the solid/water interface into the ground water phase. This mechanism results in the enhanced solubility of the radium isotope (Hess et al. 1985).

[2] 1 pCi/L of radium roughly corresponds to 1 pg/L.

[3] For a discussion of competitive sorption, see Snoeyink 1990, p.788. Radium has the largest atomic weight and hydrated ionic radius of the alkaline earth metal cations, which greatly

softening. Fortuitously, radium preferentially sorbs relative to calcium or magnesium during water softening processes to an extent that allows good radium removals. During lime softening, which involves the precipitation of calcium carbonate and magnesium hydroxide, radium co-precipitates efficiently enough to achieve good removals (Clifford 1991). These and other treatment processes will be discussed in more detail later in this chapter.

Another consequence of radium's tendency to strongly sorb is that radium tends to associate with suspended particulate matter. Colloid and micro-particulates in ground water sources can include silica, high molecular weight organic matter, clays, and oxides precipitates of Mn, Fe, and Al. Depending on the local chemical and physical conditions, a variable amount of radium may be removed during the filtration removal of this suspended material. Unfortunately, the average removal efficiency from simple filtration is often too low to be very useful (Clifford 1991).

Section 6.2: Evaluation of Technologies

Based on the properties of radium discussed above and the other criteria affecting treatment technology selection, the treatment technologies evaluated for radium removal were limited to: ion exchange (IE), point-of-use IE, point-of-entry IE, reverse osmosis (RO), point-of-use RO, point-of-entry RO, lime softening (LS), greensand filtration, co-precipitation with barium sulfate, selective sorbents, electrodialysis/electrodialysis reversal (ED/EDR), and pre-formed hydrous manganese oxides (HMOs). For the removal of gross alpha emitters where radium comprises most of the activity, these same technologies would apply. For the removal of gross alpha activity caused by radionuclides other than the radium, which can include a variety of contaminants, technologies should be evaluated on a case-by-case basis. This is also true for total beta and photon emitter activity. However, ion exchange (IE), point-of-use IE, point-of-entry IE, reverse osmosis (RO), point-of-use RO, and point-of-entry RO were determined to be robust enough to merit a general evaluation.

The best available technologies (BATs) from the 1991 radionuclides proposed rule (EPA 1991a) were evaluated as small systems compliance technologies. The table below lists the MCLs and the 1991 proposed BATs for the currently regulated radionuclides.

MCLs and BATs for Regulated Radionuclides		
Contaminant	**MCL (1976)**	**BAT (Proposed 1991)**
combined radium-226 and radium-228	5 pCi/L	Ion exchange (IE), lime softening (LS), reverse osmosis (RO)

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increases its tendency to sorb to ion exchange resins relative to the other alkaline earth cations, including Ca^{2+} and Mg^{2+}.

gross alpha particle activity	15 pCi/L	RO
total beta particle activity and photon activity, average annual concentration	4 millirem/year	IE, RO

Ion Exchange

The ion exchange (IX) process and general small systems concerns regarding the use of ion exchange are discussed in Chapter 3. IX may be used to selectively remove radionuclide ions from drinking water, e.g., the well known application of sodium ion exchange softening for removing radium. As discussed in Chapter 3, IX treatment may be readily adapted for use by small systems (NRC 1997) and may be used in a point-of-use and point-of-entry mode. The effluent must be regularly monitored and/or the resin must be regenerated on a sufficiently frequent basis to ensure that breakthrough has not occurred. However, the units may be controlled automatically, so operator requirements may not be overly time intensive. Determination of regeneration frequency and trouble-shooting do require a skilled operator (Clifford 1990a). It should be noted that disposal can be expensive in the case of concentrated radionuclides.

Wastes generated by IX treatment include rinse and backwash water and, eventually, the resin itself. The rinse and backwash liquid waste includes brine, radium, and any other contaminants removed by the process. The contamination of the exhausted resin depends upon its loading capacity and the degree of use since the last regeneration (EPA 1994). Disposal issues specific to radium are discussed below.

Point-of-entry and point-of-use softening units are common and have been shown to be consistent and effective in removing radium (AWWA-ASCE 1998, Clifford 1991a, Clifford 1991b). The general concerns regarding monitoring and performance that were discussed in Chapter 3 apply here. Disposal of point-of-entry regenerant wastes are issue that remains to be resolved before this technology will be listed as a small systems compliance technology. Point-of-use softeners may be regenerable or disposable. Water systems must take care to ensure that proper radium removal performance is being maintained through monitoring and/or maintenance. If drain disposal of regenerant wastes from point-of-use softeners to sanitary sewers is possible, this technology may be an attractive option for small water systems. If disposal is not an option, non-regenerable resins may be an attractive option.

Cation Exchange

Cation exchange resins are used to remove undesired cations from water by exchanging them with protons (H^+), sodium ions (Na^+), or, in the case of sodium restrictions, potassium ions (K^+). Cation exchange is often used to reduce hardness through the removal of calcium and magnesium cations, and thus is an efficient treatment for radium. Cation exchange is also a treatment of choice for cationic beta and photon emitters.

As discussed in the introduction to this chapter, radium preferentially sorbs relative to calcium and magnesium. Studies indicate that sodium cation exchange can remove 80 - 98% of radium (Brink et al. 1978, as cited in Clifford 1990b, USEPA 1983, USEPA 1992). Significant radium breakthrough was reported only after significant hardness breakthrough occurred (Clifford 1990b). Since treated water is often blended with some raw water (commonly 30 to 50% blending) to reduce corrosivity in the effluent after softening, the radium influent levels must not be so high that the blending process raises the radium effluent levels above the MCL. If the radium influent levels are too high, corrosivity reduction other than blending or a treatment other than softening must be used.

Weak acid cation (WAC) exchange resins may be used to remove radium from ground water. For example, acid WAC resins may be used to exchange hydronium ion (H^+) for radium. The exchange process removes hardness, alkalinity, and total dissolved solids from the influent and is limited by carbonate alkalinity. Acid elution can be used to regenerate the resin. Although acid WAC resin exchangers are more expensive than sodium exchangers, they should be considered when hardness and total dissolved solids reduction is desired along with radium removal.

The liquid waste stream (rinse and backwash) volume produced by cation exchange for radium removal typically ranges between 2 and 10% of the product water volume. The radium concentration in the liquid waste depends upon the radium influent concentration, the volume of regenerant solution used, and the frequency of regeneration. An Iowa case study showed liquid waste radium levels between 110 and 530 pCi/L. Another showed an average and peak waste level of 23 and 160 pCi/L, respectively. At the latter facility, the exhausted resin accumulated a radium level of ca. 9 pCi/g (EPA 1994).

Anion exchange

A few studies have been conducted to specifically assess the effectiveness of anion exchange for "gross alpha" removal, where either uranium is not the dominant source or the speciation was not specified (EPA 1992). Removals between 85 and 95 percent can be achieved, depending on which alpha emitters are present and on the water quality.

Lime Softening

Lime softening (Benefield et al. 1990, EPA 1992, NRC 1997) can be used to remove radium from drinking water with removal efficiencies of 80 to 95%. This process involves inducing precipitation of calcium carbonate and magnesium hydroxide by increasing the pH of the treated water to ca. 10 through the addition of lime or lime-soda ash. The general process is discussed in more detail in Chapter 3.

For surface water systems, lime softening technology is considered most feasible for large systems (those that serve more than 10,000 persons) because of the difficulties resulting from the combination of variable source water quality and the complexity of the chemistry involved. Changing water quality necessitates frequent monitoring and modification of the chemical dosage, creating the need for intensive oversight by a highly qualified operator. This requirement may be too burdensome for small surface water systems.

For ground water systems, the relative uniformity in water quality makes lime softening a more feasible technology, since the required dosages are relatively constant. However, the operation and maintenance of lime feeders and the lines that carry the lime slurry to the treated water are not simple matters, and they may prove too difficult for part-time operators. Since many ground water systems are small, this limits the applicability of lime softening. Fortunately, small package plants with labor saving devices and remote monitoring/control features are becoming more common, making lime softening more accessible to small systems. The National Research Council (1997) has suggested that while lime softening may be appropriate for small ground water systems serving fewer than 3,300 persons, those serving fewer than 500 should only use lime softening if they have a service contract or a satellite operation that would enable a qualified operator to monitor the treatment process on a regular basis. Since radium is typically found at higher levels only in ground waters, lime softening may be an appropriate radium removal option for many small systems.

Wastes generated by lime softening include lime sludge, filter backwash liquid and sludge, and sludge supernatant. Typical radium concentrations in waste products are reported to range from 1,980 pCi/L in the wet lime sludge, 6 to 9 pCi/g in the dried sludge, 6 to 50 pCi/L in the filter backwash liquid, and ca. 20 to 25 pCi/L in the sludge supernatant (EPA 1994).

Reverse Osmosis (RO)

The reverse osmosis process is described in Chapter 3 of this document. Reverse osmosis has been shown to be highly effective for removing inorganic contaminants, including heavy metals and radionuclides such as radium and uranium. RO can remove 87 to 98% of radium in drinking water. Similar removals can be achieved for alpha particle activity and total beta and photon emitter activity (EPA 1992, EPA 1998a).

Historically, RO membranes have required high operating pressure, in excess of 400 psi,

to provide adequate feed water recovery for brackish and fresh water supplies. However, recent advances in membrane technology have led to the development of membranes capable of operating at much lower pressures (100 to 200 psi). Low pressure membranes provide substantial savings in process electric energy.

The performance of an RO system for radionuclide removal depends upon a number of factors including pH, turbidity, iron/manganese content of the raw water, and membrane type. Design of a pretreatment system is dependent upon the quality and quantity of the feed water source and may include one or more of the following: pH adjustment, filtration, iron and manganese reduction, or additives for scale prevention. Existing treatment plants may already provide much of the pretreatment required, for example, coagulation/filtration for highly turbid surface water or iron removal for well waters. RO is adaptable to all systems sizes and can be cost effective for small systems.

RO does not selectively remove dissolved contaminants. Therefore it is very effective for removing multiple contaminants in one step.

RO systems produce very high quality water, removing 90 to >99% total dissolved salts from the feed water, leading to demineralized product water. Demineralized water has low alkalinity and can be corrosive. To reduce corrosivity in the product water, systems may by-pass some of the raw water and blend it with the permeate, raise the pH, or otherwise add alkalinity. The need for blending may be a factor in the selection of a RO system. In fact, the blending process can make an RO process more economical than complete treatment of all raw water. The fraction of the raw water to be treated will depend upon the removal efficiency of the selected RO membrane, the initial concentration of contaminants in the raw water, and the required effluent objective.

The reject water from RO is the only waste generated. However, reject water is continuously generated during operation, so the volumes created are large compared to the amount of water treated. The radium concentration in the reject water depends on the radium concentration in the influent and the percent recovery of the operation. For example, if the RO unit removes 98% of radium and rejects 50% of the influent water, then the reject water will contain roughly two times the concentration of the influent water. Studies report ranges of ca. 8 to 40 pCi/L of radium in the reject water (EPA 1994).

Although point-of-use (POU) RO was not proposed as BAT in 1991 (see Chapter 1), it appears to be a very promising small systems treatment option for inorganic contaminants removal (NRC 1997), including radium, since it is reliable, effective, and simple to use on the small scale (Clifford 1991a, Thomson and O'Grady 1998, EPA 1998c). A typical POU RO configuration for radionuclides removal would include a 5 micron pre-filter to remove particulates, a GAC filter to remove chlorine, taste, and odor, the RO unit itself, and a connection to the sink drain for reject water disposal. The discharge line requires an air gap to prevent a cross-connection between wastewater and drinking water.

Since general POU concerns are described above, this section will focus on reject water disposal concerns. One of the primary advantages of POU RO is that reject water waste disposal is straightforward if drain disposal to a sanitary sewer is possible. Although the total mass or concentration of radionuclide contaminants discharged from the house would not significantly change when RO treatment is installed, the reject water does contain higher radionuclides concentrations than the untreated tap water. The actual degree of concentration depends on the recovery percentage, as described above. Once the reject water sufficiently mixes with the other drainage water, the radionuclide levels will be diluted until they approach those in the untreated water. Since the drain water from a single tap is usually a small part of the drain water budget of the entire household, this dilution should occur very quickly. The table below shows the relationship between the % increase in radium concentration for the total household drainage versus the RO recovery percentage:

Percent Increase in Radium Concentration in Household Drainage versus RO Rejection Percentage		
% Recovery[1]	% [Ra] Increase[2]	Notes
50	5.0	1) "% Recovery" = 100*Volume of Product Water/ Volume of Total Water at Tap).
40	3.3	
30	2.1	2) "% [Ra] Increase" is the percentage increase in the concentration of radium in the total house drainage, i.e., for a recovery of 50% and an untreated water (influent) radium concentration of 10 pCi/L, the total house drainage would have an average concentration of 10.5 pCi/L.
20	1.3	
10	0.6	

The table assumes that drinking and cooking water comprises 5% of the total household water (EPA 1991) and that the rest of the water is returned to the drain. As the table shows, if the drain water is discharged to a sanitary sewer, the concentration of radionuclides reaching the waste water treatment plant should not be significantly affected by the addition of POU RO. Clifford (1991a) reports a 15% recovery for spiral wound POU RO as typical. At this recovery, the reject water is concentrated by a factor of about 1.18 relative to the raw water and, extrapolating from the table, the increase in the average radium concentration in total household drainage is less than one percent.

Stakeholders discussed the possibility of using POU RO with households connected to septic tanks. While the above analysis would indicate that this may be feasible, EPA (1994) does not suggest disposal of water treatment wastes into septic tanks. However, this suggestion is based on centralized treatment assumptions and may not cover POU RO scenarios. This issue deserves attention in the future.

Technologies for Radionuclide Removal Not Proposed as BAT in 1991

Greensand Filtration for Radium Removal

Greensand filtration technology consists of a conventional filter box with the traditional filtration medium replaced by manganese greensand. Manganese greensand has enhanced sorptive abilities that allow it to remove certain dissolved ions in addition to normal filtration. The water is pre-treated with potassium permanganate to oxidize dissolved materials into more insoluble chemical species, which consequently are removed much more efficiently by the greensand filter. This is a continuous process, except when interrupted for filter backwashing. Studies indicate that up to 56% of radium is also removed by greensand filtration. In a pilot plant study, the radium removal efficiency was improved to 90% by passing the potassium permanganate pre-treated water through a detention tank before filtration.

Wastes generated by this process include sludge and supernatant from the filter backwash, and eventually the greensand media must be disposed of. Radium concentrations in the filter backwash have been found to range from ca. 65 to 170 pCi/L. Dry weight concentrations of radium in the greensand medium have been found to vary from ca. 30 to 46 pCi/g at one plant and from 75 to 250 pCi/g at another (EPA 1994).

Pre-formed Hydrous Manganese Oxide (HMO) Filtration

Although no municipal installations are currently reported in the literature, pilot studies have been completed and a full scale demonstration is planned (Clifford 1990a). Pilot studies conducted in Illinois consisted of a pre-formed MnO_2 (HMO) dosage of 2.0 mg/L, followed by a minimum of ten seconds of mixing and post-mixing diatomaceous earth filtration or multi-media filtration to remove the suspended MnO_2 (which contains the sorbed radium). Greater than 96% removals were consistently achieved over the five day run period (Clifford 1990a). Valentine et al. (1992) reported average removals of 83%, 79%, and 71% for HMO dosages of 1.0, 0.5, and 0.2 mg/L (as Mn). Where applicable, costs for HMO treatment were projected to be quite low if filtration is already in place (EPA 1994).

HMO filtration is similar to oxidation/filtration in complexity and operator skill requirements. Proper dosages must be determined, and if water quality is variable, the dosage must be re-calibrated. But, since radium is typically a ground water problem, this is less of a concern for this application. Once the proper dose is determined, dosing is relatively easy, requires simple equipment, and is fairly inexpensive (NRC 1997). Filters must be backwashed, which may require intermediate operator skill. Radium containing wastes include HMO sludge, filter backwash, and sludge supernatant.

Coprecipitation of Radium with Barium Sulfate

Addition of a soluble barium salt such as barium chloride to water contaminated with radium and sulfate will result in the coprecipitation of a highly insoluble radium-containing barium sulfate sludge. This process has been primarily used for wastewater treatment. Mine wastewater treatment data indicates that up to 95% of radium is removed by this process. A full-scale drinking water treatment plant in South Dakota currently uses this process to treat a radium influent level of 16 pCi/L down to < 1 pCi/L.

Radium containing wastes generated by this process include the barium sulfate precipitate sludge, filter backwash, and sludge supernatant.

Other Technologies

Other technologies exist which demonstrate promise for radionuclides removal from drinking water. However, these technologies have not been fully tested in drinking water treatment, or have been used only in industrial or experimental situations. Examples include selective sorbents (e.g., acrylic fibers or resins impregnated with manganese dioxide) and non-sodium cation exchangers (e.g., hydrogen ion and calcium ion exchangers) for radium removal. POE IX and RO are not currently listed as compliance technologies because of unresolved issues regarding waste disposal, post-treatment disinfection and corrosion control, and costs, but are being further considered as small systems compliance technologies.

Radiation Hazards Associated with Treatment

It should be noted that caution is required when choosing treatment technologies for radionuclides removal, since many treatments may create radiation hazards through the concentration of radionuclides within the treatment unit or in wastestreams.

Waste Generation and Disposal Guidelines

Waste generation

In the 1991 proposed radionuclides rule (EPA 1991a), EPA referenced a 1990 EPA report entitled "Suggested Guidelines for the Disposal of Naturally Occurring Radionuclides Generated by Drinking Water Treatment Plants" (EPA 1990). In 1992, the Science Advisory Board (SAB) reviewed the 1990 guidance and offered several recommendations.[1] Among the most important SAB recommendations which EPA has acted upon were: (1) the Agency should integrate quantitative information on radioactivity in water treatment wastes within the document to facilitate decision-making processes; and, (2) the Agency should select and provide rationale for its occupational protection approach to water treatment plant workers.

In response to SAB's first recommendation, EPA has developed a spreadsheet program on floppy disk for computing waste volumes and radioactivity levels for several pertinent water treatment processes, along with a user's guide. This should aid in the planning and pre-engineering stages where managers will need information on the types of waste that may be generated at new facilities. The spreadsheet program was developed by EPA in August 1993 and is entitled "Spreadsheet Program to Ascertain Residuals Radionuclide Concentrations" (SPAARC). The program and user's guide can be obtained by contacting National Technical Information Service (NTIS), 5285 Port Royal Rd., Springfield, VA 22161, (703) 487-4650; and ERIC Clearinghouse, 1929 Kenny Road, Columbus OH 43210, (614) 292-6717.

In response to SAB's second recommendation, the occupational guidance has been revised by the Office of Radiation and Indoor Air. It was determined that the doses that personnel in water treatment facilities would receive would be substantially lower than the upper bounds for workers in radiation facilities. In fact, it appears reasonable to keep treatment plant workers' doses to well within the levels recommended for the general public (100 mrem/yr). Consequently, the guidance recommends 100 mrem/yr as the maximum administrative control level in water treatment facilities. The document also contains more guidance on seeking state assistance and/or approval.

EPA has not yet finalized changes to the guidelines based on the SAB recommendation to reevaluate the criteria for disposal of wastes containing lead-210, a byproduct of using activated carbon for removal of radon, which is currently unregulated. Since this wastestream does not affect disposal options for treatments concerning the currently regulated radionuclides, it will not be discussed further here.

Other revisions include: (1) a new section on mixed (or hazardous) wastes, (2) updates reflecting U.S. Nuclear Regulatory Commission (NRC) and other federal regulations, and (3) a new section on suggested wastestream sampling procedures.

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[1]Letter from Dr. R.C. Loehr and Dr. O.F. Nygaard, Science Advisory Board, to W.K. Reilly, EPA, September 30, 1992.

The report was updated in 1994 with the abovementioned revisions and is entitled "Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity" (EPA 1994). The updated guidelines are summarized in the following two figures and table; for details, please refer to the guidelines. Summaries of the guidelines (e.g., EPA 1996) and relevant background materials (e.g., Reid et al. 1983) may be obtained from EPA or the literature.

The table below summarizes estimated waste volumes, radioactivity levels and types of waste generated by several of the above mentioned drinking water treatment processes. These estimates are based on standard engineering assumptions and an assumed average daily water production of 1.0 million gallons per day (MGD).

Characteristics of Selected Water Treatment Wastes (Computed Levels)

Treatment Method	Raw/ Finished Conc. (pCi/L)	Waste Characteristics: Vol. and Radioactivity	Types of waste generated
Coagulation/ Filtration	50/10 (Uranium)	U Sludge volume: 10 kgpd U sludge: 4,000 pCi/g	Iron or alum sludges from the contact and settling basins and from the filter backwash. Supernatant from this sludge is a liquid waste. Additional liquid waste is generated when the sludge is concentrated prior to disposal.
Lime Softening	25/12.5 (Radium)	Ra Sludge volume: 22 kgpd Ra sludge: 557 pCi/L	Settling tank sludge, which is precipitated during the softening process. Filter backwash (both solids and supernatant) and the sludge supernatant are other wastes.
Ion Exchange	25/5 (Radium)	Ra waste flow: 97 kgpd Ra wastes: 207 pCi/L	Liquid waste containing brine, rinse and backwash water, and contaminants stripped off the resin. In addition, the resin itself is a solid waste containing the contaminant exchanged.
Reverse Osmosis	50/15 (U)	U waste flow: 130 kgpd U wastes: 320 pCi/L	Reject streams which are continuously generated during the treatment process.

Figure 1 is a flowchart summarizing the guidelines for disposal of radioactive liquids. The Clean Water Act requires that dischargers of pollutants to navigable waters obtain a National Pollutant Discharge Elimination Permit (NPDES), which contains, at a minimum, technology-based effluent limitations. Sufficient flow and channel geometry must be available to prevent a buildup of radionuclides in the surface water or sediments to within limits set by the regulator. Pretreatment regulations prohibit discharge into sanitary sewers that would cause a municipal wastewater treatment plant to violate a NPDES permit. The U.S. Nuclear Regulatory Commission (NRC) limits the discharge of wastes containing radioactive materials into sanitary

sewers. A drinking water treatment plant owner interested in disposing of wastes containing radionuclides into an injection well in a Primacy State should consult with the appropriate State Agency first. State regulations may be more stringent than the Federal requirements and may ban such practice. The plant owner in other States should consult with the appropriate Underground Injection Control (UIC) Regional Branch office of the USEPA before deciding to dispose of wastes containing radionuclides into an injection well.

Figure 1. Disposal of Liquid Wastes

```
                    ┌─────────────────────┐
                    │  Water Treatment    │
                    │  Liquid Wastes      │
                    └─────────────────────┘
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Ra 226 < 60	Ra 226 < 600	Ra 226 < 60
Ra 228 < 60	Ra 228 < 600	Ra 228 < 60
U < 300	U < 3000	U < 300

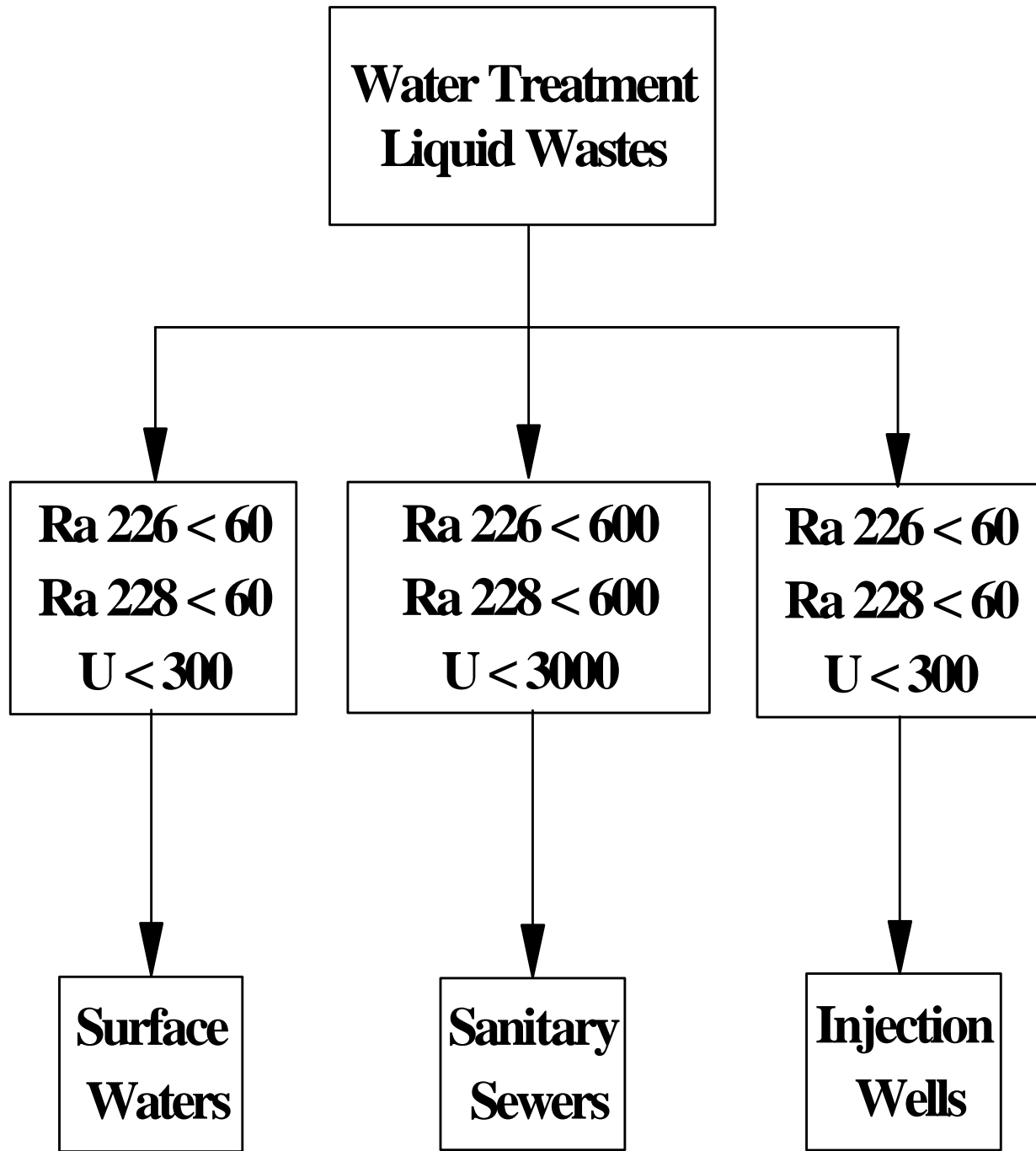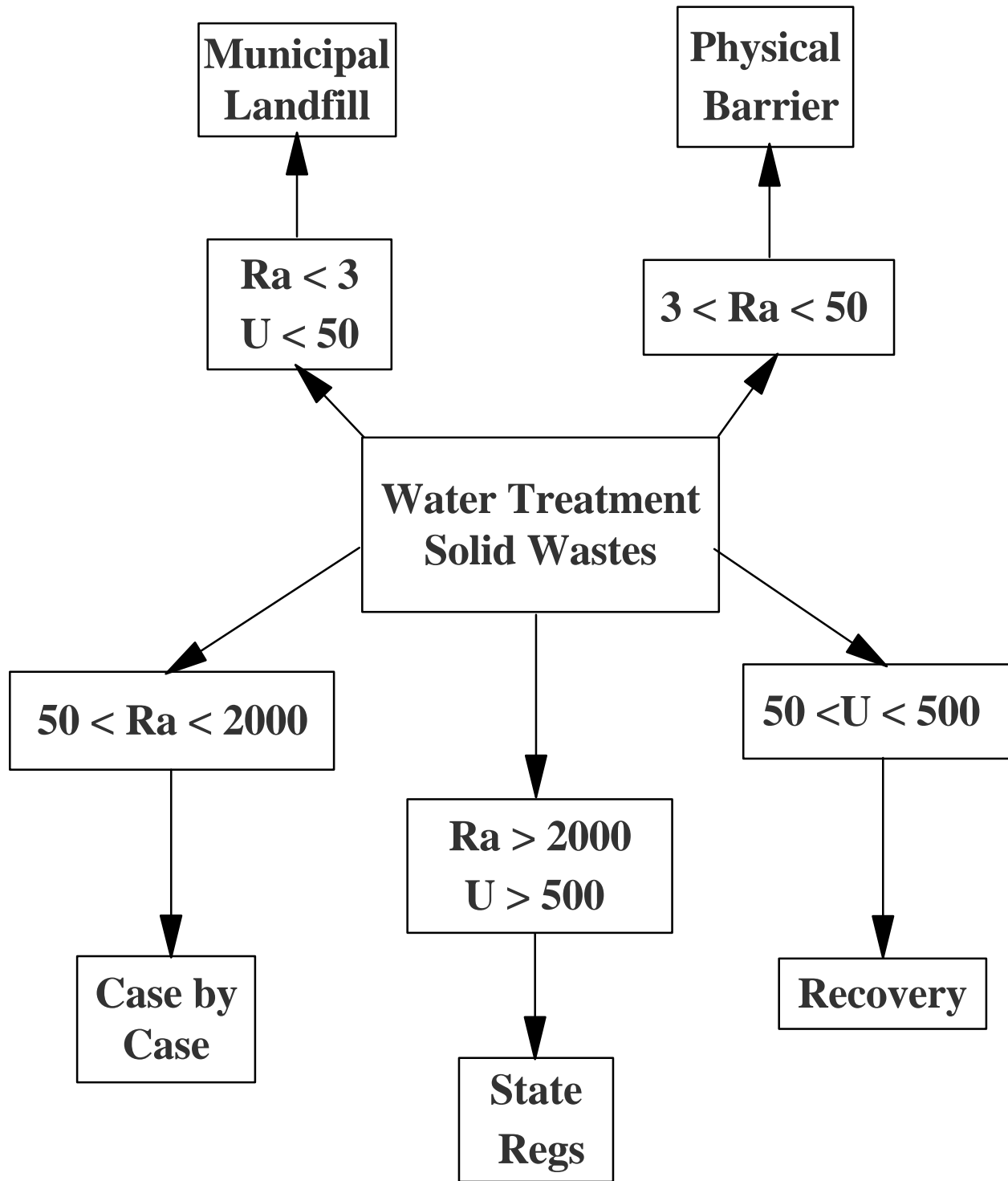| **Surface Waters** | **Sanitary Sewers** | **Injection Wells** |

Figure 2 is a flowchart summarizing the guidelines for radioactive solids/sludges. Wastes containing less than 3 pCi/g (dry) of radium and less than 50 ug/g (dry) of uranium may be disposed of without the need for long-term institutional controls in a municipal landfill if the wastes are first dewatered and then spread and mixed with other materials when emplaced. Solids/sludges containing 3 to 50 pCi/g (dry) of radium should be disposed of with a physical barrier that would protect against radon release and isolate the wastes, and provided with institutional controls designed to avoid inappropriate uses of the disposal site. The disposal method for solids/sludges containing 50 to 2,000 pCi/g (dry) of radium should be determined on a case by case basis. Recovery of the uranium resource may be considered for solids containing 50 to 500 ug/g (dry) of uranium. Wastes containing more than 2000 pCi/g (dry) of radium or more than 500 ug/g (dry) of uranium should be disposed of only as permitted by State regulations.

Figure 2. Disposal of Solid Wastes

Municipal Landfill		Physical Barrier

$$Ra < 3$$
$$U < 50$$

$$3 < Ra < 50$$

Water Treatment Solid Wastes

$$50 < Ra < 2000$$

$$Ra > 2000$$
$$U > 500$$

$$50 < U < 500$$

Case by Case

State Regs

Recovery

Section 6.3: Small Systems Compliance Technologies List

Based on the evaluation of the technologies described in Section 6.2, the following table lists the Small Systems Compliance Technologies for radionuclides (EPA 1998b).

Table 6.1: Technologies for Radionuclides			
Unit Technologies	**Limitations (see footnotes)**	**Operator Skill Level Required[1]**	**Raw Water Quality Range & Considerations[1]**
1. Ion Exchange (IX)	([a])	Intermediate	All ground waters
2. Point of Use (POU) IX	([b])	Basic	All ground waters
3. Reverse Osmosis (RO)	([c])	Advanced	Surface waters usually require pre-filtration
4. POU RO	([b])	Basic	May require pre-filtration
5. Lime Softening	([d])	Advanced	All waters
6. Green Sand Filtration	([e])	Basic	
7. Co-precipitation with Barium Sulfate	([f])	Intermediate to Advanced	Ground waters with suitable water quality
8. Electrodialysis/ Electrodialysis Reversal		Basic to Intermediate	All ground waters
9. Pre-formed Hydrous Manganese Oxide Filtration	([g])	Intermediate	All ground waters

[1] National Research Council (NRC). *Safe Water from Every Tap: Improving Water Service to Small Communities*. National Academy Press. Washington, D.C. 1997.

Limitations Footnotes to Table: Technologies for Radionuclides:

[a] The regeneration solution contains high concentrations of the contaminant ions. Disposal options should be carefully considered before choosing this technology.
[b] When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance (see Section 1.4).

c Reject water disposal options should be carefully considered before choosing this technology. See other RO limitations described in Chapter 3 and Section 6.2.

d The combination of variable source water quality and the complexity of the chemistry involved in lime softening may make this technology too complex for small surface water systems.

e Removal efficiencies can vary depending on water quality.

f This technology may be very limited in application to small systems. Since the process requires static mixing, detention basins, and filtration, it is most applicable to systems with sufficiently high sulfate levels that already have a suitable filtration treatment train in place

g This technology is most applicable to small systems that already have filtration in place.

Chapter 1 indicated that EPA would identify affordable compliance technologies for those existing regulations where small system variances or variance technologies are not prohibited by the SDWA. There are statutory prohibitions against small system variances for all three radionuclides, therefore affordability cannot be considered in listing these technologies. The following table contains the compliance technologies the three radionuclides. The statutory prohibitions on variance technologies and small system variances are discussed in detail in Chapter 1 of this document and Section IV of the "Small Systems Compliance Technology Lists for Existing National Primary Drinking Water Regulations" (EPA 1998b).

Table 6.2: Compliance Technologies by System Size Category for Radionuclide NPDWRs, Affordability is Not Considered			
	Compliance Technologies[1] for System Size Categories (Population Served)		
Contaminant	25 - 500	501 - 3,300	3,300 - 10,000
combined radium-226 and radium-228	1, 2, 3, 4, 5, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9
gross alpha particle activity	3, 4	3, 4	3, 4
total beta particle activity and photon activity, average annual concentration	1, 2, 3, 4	1, 2, 3, 4	1, 2, 3, 4
Note: 1) Numbers correspond to those assigned to technologies found in the Compliance Technologies Table for Radionuclides.			

Section 6.4: Emerging Technologies

POE ion exchange and POE reverse osmosis have been determined to require further evaluation. They have not been listed as compliance technologies since issues regarding ion exchange regeneration, other maintenance, waste disposal, post-treatment disinfection, post-treatment corrosion control, etc. remain. EPA will evaluate information regarding these technologies in the near future and will include them in future updates, if deemed appropriate.

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7. SMALL SYSTEMS COMPLIANCE TECHNOLOGIES FOR VOLATILE ORGANIC CONTAMINANTS

Section 7.1: Background

Volatile organic contaminants (VOCs) are composed of a form of a carbon-based molecule. These compounds dissipate or vaporize easily into air at room temperature. Volatile organic compounds are usually used as solvents, degreasers, and fumigants. Table 2.11 lists the National Primary Drinking Water Standards for regulated VOCs.

VOCs typically are found in greater amounts in groundwater supplies than surface water because exposure to air helps them dissipate from surface supplies. In groundwater supplies, the compounds are very mobile and percolate into wells and aquifers. The compounds do not degrade readily in the groundwater and, as known or suspected carcinogens, are a potentially serious threat to drinking water safety.

The technologies considered for the small systems compliance list are commonly used in the drinking water industry. The BATs for removal of VOCs from drinking water are granular activated carbon and packed tower aeration. The technologies listed for treatment of VOCs include diffused aeration, multiple tray aeration, spray aeration, and mechanical aeration.   The other technologies that were considered are listed as emerging technologies due to lack of performance data. These technologies include powdered activated carbon, gas permeable membrane aeration, advanced oxidation processes, and point-of-entry technologies.

Point-Of-Use (POU)/Point-Of-Entry (POE) Technologies

POU technologies were not be considered for compliance technologies for VOCs because POU units are attached only to the tap. Because of the volatile nature of VOCs, the indoor use of VOC contaminated water can lead to significant human exposure through non-ingestion routes such as inhalation following volatilization (e.g., while showering) or from direct contact with the contaminated water. Stakeholders agreed that POU technologies should not be listed for treatment of VOCs.

POE technologies were not considered for compliance technologies for VOCs. The potential for off-gas emissions from POE units is more likely to be a problem because these POE units would be located near homes. Off-gases may have to be treated using a scrubber, thereby increasing the complexity and the cost of the aeration units. Also, there is the potential for water quality deterioration from airborne particulates, oxidized inorganics, instability resulting in corrosion, and biological growth in the aeration device. Post-treatment disinfection may be needed after treatment with POE aeration units.

Section 7.2: Evaluation of Technologies

Packed Tower Aeration

Packed tower aeration has been proven to effectively remove several VOCs from drinking water. Packed tower aeration is considered a BAT for VOCs removal. The removal efficiency for VOCs is primarily dependant on the air-to-water ratio, packing height, and available area for mass transfer.   The minimum air-to-water ratio needed to efficiently remove VOCs depends upon Henry's Law Coefficient. . The sizes of packing materials determine the available area for mass transfer. Smaller materials may provide greater areas of mass transfer, however, an increased pressure drop may occur if the materials are too small.

Field tests performed in Brewster, NY, Wausau, WI, and Baldwin Park, CA resulted in >96% removal efficiencies for VOCs such as tetrachloroethylene, trichloroethylene, cis-dichloroethylene, and toluene. The influent concentrations were as great as 600 ug/L, using air to water ratios of ~30:1 and tower heights ranging from 5.5-7.5 m packed with plastic saddles (Ram et al. 1990).

Some of the concerns with PTA units are that repressurization equipment and blowers draw large amounts of electricity, therefore, electrical costs are high. If the unit is not adequately ventilated, the contaminant removal efficiency will decrease due to mass transfer constraints. These systems may be limited for use in residential areas due to fan noise, and depending on the location these systems may be subject to freezing.

As with most aeration technologies, air quality regulations in certain localities may prevent the implementation of these units since large quantities of a contaminant are vented into the air. Also, pretreatment for the removal of microorganisms, iron, manganese, and excessive particulate matter may be needed. Post-treatment disinfection may have to be used to ensure no microbial growth.

Diffused Aeration

Similar to PTAs, the efficiency of diffused aerators is dependant upon factors including diffuser type, air-to-water ratio, depth of the water in the contact chamber, detention time, and air and water temperature. Diffused aeration is considered an accepted technology for treatment of VOCs (NRC 1997).

Several performance studies have been conducted using diffused aerators.   Studies conducted in Glen Cove, New York (1984) showed that diffused aerators can efficiently treat VOCs with influent concentrations ranging from 50-250 mg/l using air-to-water ratios of 15:1 (EPA 1985). The removal rates ranged from 50-90+% for 1,2-dichloropropane, cis-1,2-dichloroethylene, trans-1,2-dichloroethylene, toluene, ethylbenzene, chlorobenzene, xylenes, o-dichlorobenzene, and ethylene dibromide. For the most part, the percent removals were higher

for VOCs with the higher Henry's Law Coefficients.

Diffused aeration units may not be as efficient as other aeration methods because it does not provide for convective movement of the water thus limiting air-water contact. It is generally used to adapt existing plant equipment such as storage tanks or basins. The removal efficiency of these systems depends upon the gas to liquid mass transfer rate. The diffused aerator has less interfacial area for mass transfer than the PTA; a longer contact time may be needed to achieve sufficient removal of the VOCs. On the other hand, increased basin depth, contact basin geometry, and turbines to reduce the air bubble size and increase bubble holdup can improve gas transfer, thus improving the efficiency of the system.

With diffused aerators, increased energy costs may be incurred due to post-treatment repressurization. Also, post-treatment disinfection may have to be used to ensure no microbial growth.

Multiple Staged Bubble Aerators (MSBA)

MSBAs are variations to the traditional diffused aerator. These systems are typically packaged plant commercial units that are more efficient than the traditional diffused aerator. MSBAs further reduce energy costs by optimizing the air to water ratio, contact time, and mass transfer area.

MSBA units are highly efficient, however the efficiency depends upon the air-to-water-ratio. These units have the same limitations as the diffused aerator.

Multiple Tray Aeration

Multiple tray aeration is considered a conventional technology for the removal of VOCs from drinking water (NRC 1997). Multiple tray aerators consist of a series of trays with slats, perforations, or wire mesh bottoms over which water falls and eventually collects at the base of the unit. The thin film of water formed as the water flows over the media provides a large surface area for mass transfer of the VOCs from water to air. Coke, coal, stone, or ceramic balls can be placed in the trays to increase efficiency.

Multiple tray aeration has been effective in removing 20 to 90 percent of VOCs from drinking water (Robeck and Love 1983, Hess et al 1981). In studies performed in Smyrna, Delaware reported removal efficiencies ranging from 50 to 90% of trichloroethylene and other VOCs. In Camden, New Jersey (1979) conducted studies to determine the efficiency of the aeration unit by testing trichloroethylene, tetrachloroethylene, carbon tetrachloride, and 1,2-dichlorethane (EPA 1985). Preliminary results indicated that the aerator efficiency could be improved by increasing the air-to-water ratio.

The performance of tray aerators will be impaired in a poorly ventilated building.

Artificial ventilation will be a requirement and may be provided by enclosure and provision of a forced draft. The addition of the forced draft may increase the cost of the unit. Post-treatment disinfection may be necessary because slime and algae growth can be a problem. Chemicals such as copper sulfate or chlorine may have to be used to control the growth.

Shallow Tray Aeration (STA)

STAs involve the use of shallow trays, and are more efficient to multiple tray aerators. STAs increase the available area of mass transfer; thereby increasing the removal efficiency of most VOCs. However, because of the high air-to-water ratio (100-900 m^3/m^3), greater energy costs may be incurred.

Spray Aeration

Spray aeration is an accepted technology where the contaminated water is sprayed through nozzles. The small droplets produced expose a large interfacial surface area through which VOCs can migrate from the liquid (water) phase to the gaseous (air) phase. Spray aerators have been used to effectively treat VOCs (Wood 1982). Case studies (Florida) demonstrated that > 99% of VOCs were removed from an influent total VOC concentration between 100-200 mg/l. The primary VOCs treated were 1,1-dichloroethane, and trichloroethylene, tetrachloroethylene, vinyl chloride, and 1,1,1-trichloroethane (EPA 1985).

Although spray aerators are capable of achieving efficient removal of VOCs, this type of aerator is for use only when low removal levels of VOCs are needed to reach an MCL. These systems may not be as energy efficient as other aeration methods. Also, the spray aerator needs a large operational area, which will increase building construction costs and may also increase operating problems during cold weather when the temperature is below freezing.

Mechanical Aeration

Mechanical aerators are considered accepted technologies for the removal of VOCs from drinking water (NRC 1997). Mechanical aerators introduce air into the water by rapidly agitating the water surface with a mechanical mixer. They are not as efficient as other aeration systems at removing VOCS. The contacting system between the air and water is not as effective for volatilizing the contaminants. These systems often require large basins, long residence times, and high energy inputs. However, these systems can be cost-effective because they are adaptable to existing basins, and are often installed as a system retrofit.

Mechanical aerators will probably not achieve VOC removals that are sufficient to attain desired water qualities if influent levels are extremely high. Mechanical aerators should be used when only low level removals are needed to reach the MCL.

Granular Activated Carbon

For the purposes of determining best available technologies (BATs) for removing SOCs from drinking water, the Safe Drinking Water Act (§ 1412.b.4.D) explicitly states that any BAT listed by EPA must be at least as effective as granular activated carbon (GAC). The various BATs listed for the Phase II and V SOCs are GAC, packed tower aeration (PTA), and, in the case of gylphosate, oxidation by chlorination or ozonation (EPA, 1991a, 1991b, and 1992b). However, for the purposes of determining the list of compliance technologies for small systems of a given size category, the Safe Drinking Water Act (§ 1412.b.4.E) states that any listed technology must be affordable and able to achieve compliance with the maximum contaminant level. To emphasize the point, the listed small systems compliance technologies do not have to be as effective as GAC in controlling SOCs.

Granular activated carbon (GAC) is most often used to treat VOCs in drinking water. GAC is listed as a BAT for removal of VOCs. It is packed into columns through which the raw water flows. Packing the carbon in columns allows more complete contact between the water and activated carbon, greater adsorption efficiency, and greater process control than is possible for powdered activated carbon (Snoeyink 1990). In many cases GAC has been used to treat several VOCs to the maximum contaminant levels with influent concentrations ranging up to 500 mg/l (Ram et al. 1990).

Although the adsorption characteristics of individual VOCs vary, they are amenable to removal by activated carbon adsorption for a period of time or gallons of water treated. The amount of water treated depends on the influent contaminant concentration, the amount of carbon in the treatment unit, and the time the contaminant is in contact with the carbon. The removal efficiency of the carbon system will deteriorate with use, and eventually breakthrough will occur.

Section 7.3: Small System Compliance Technologies List

Table 7.1 contains the technologies that have been identified as compliance technologies for at least one VOC. The table contains the same structure as other tables with a list of limitations that are contained in the footnotes and operator skill level and raw water quality issues.

Table 7.1: Technologies for VOCs

Unit technology	Limitations (see footnotes)	Operator Skill Level Required[1]	Raw Water Quality Range[1]
1. Packed Tower Aeration (PTA)	([a])	Intermediate	All ground waters
2. Diffused Aeration	([a, b])	Basic	All ground waters
3. Multi-Stage Bubble Aerators	([a, c])	Basic	All ground waters

4. Tray Aeration	(a, d)	Basic	All ground waters
5. Shallow Tray Aeration	(a, e)	Basic	All ground waters
6. Spray Aeration	(a, f)	Basic	All ground waters
7. Mechanical Aeration	(a, g)	Basic	All ground waters
8. Granular Activated Carbon (GAC)	(h)	Basic	All ground waters

[1] National Research Council (NRC). *Safe Water from Every Tap: Improving Water Service to Small Communities*. National Academy Press. Washington, DC. 1997

Limitations Footnotes to the Technology Tables for VOCs

[a] Pretreatment for the removal of microorganisms, iron, manganese, and excessive particulate matter may be needed. Post-treatment disinfection may have to be used.

[b] May not be as efficient as other aeration methods because it does not provide for convective movement of the water thus limiting air-water contact. It is generally used only to adapt existing plant equipment.

[c] This units are highly efficient, however the efficiency depends upon the air-to-water ratio.

[d] Costs may increase if a forced draft is used. Slime and algae growth can be a problem, but can be controlled with chemicals such a copper sulfate or chlorine.

[e] These units require high air/water ratios (100-900 m^3/m^3)

[f] For use only when a low removal levels are needed to reach an MCL because these systems may not be as energy efficient as other aeration methods because of the contacting system.

[g] For use only when a low removal levels are needed to reach an MCL because these systems may not be as energy efficient as other aeration methods because of the contacting system. The units often require large basins, long residence times, and high energy inputs which may increase costs.

[h] See the SOCs compliance technology table for limitation regarding these technologies.

Chapter 1 indicated that EPA would identify affordable compliance technologies for those existing regulations where small system variances or variance technologies are not prohibited by the SDWA. There are statutory prohibitions against small system variances or variance technologies for 2 of the 21 VOCs. Table 7.2 contains the compliance technologies for the 19 VOCs where affordability was considered. Affordability only plays a role in removing options in the smallest size category. The technology costs are based on treatment of all of the water. The

technologies that did not meet the affordability criteria in the smallest size category are also identified in the next column called "other compliance technologies." These technologies may be affordable if the concentration of the contaminant is low enough that a portion of the influent stream can be treated and blended with an untreated portion to still meet the MCL. This blending would reduce both the capital and operating and maintenance costs of the process. Systems and States should consider these options under those circumstances. Table 7.3 contains the compliance technologies for the remaining two VOCs where affordability was not considered due to statutory prohibitions (EPA 1998).

Table 7.2: Compliance Technologies by System Size Category for those VOC NPDWRs where Affordability is Considered

Volatile Organic Contaminant	Compliance Technologies for System Size Categories (Population Served)			
	25 - 500 (afford)	25 - 500 (other)	501 - 3,300 (afford)	3,301 - 10,000 (afford)
Benzene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
Carbon Tetrachloride	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
Chlorobenzene	1, 2, 3, 4, 5, 6, 7	8	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 3, 4, 5, 6, 7, 8
cis-1,2-Dichloroethylene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
1, 2 - Dichloroethane	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
1,1-Dichloroethylene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
Dichloromethane	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
1, 2 - Dichloropropane	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
Ethylbenzene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
o-Dichlorobenzene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
p-Dichlorobenzene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
Tetrachloroethylene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8

Toluene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
trans-1, 2-Dichloroethylene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
1, 2, 4-Trichlorobenzene	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
1, 1, 1-Trichloroethane	1, 2, 3, 4, 5, 6	8	1, 2, 3, 4, 5, 6, 8	1, 2, 3, 4, 5, 6, 8
1, 1, 2-Trichloroethane	1, 2, 3, 4, 5,	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
Trichloroethylene	1, 2, 3, 4, 5, 6, 7	8	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 3, 4, 5, 6, 7, 8
Xylenes (total)	1, 2, 3, 4, 5	8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8

Table 7.3: Compliance Technologies by System Size Category for those VOC NPDWRs where Affordability is Not Considered

Volatile Organic Contaminant	Compliance Technologies for System Size Categories (Population Served)		
	25 - 500	**501 - 3,300**	**3,301 - 10,000**
Styrene	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8
Vinyl Chloride	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8	1, 2, 3, 4, 5, 8

Section 7.4: Emerging Technologies

Powdered Activated Carbon

PAC is generally less than 50 mm in diameter and is added to the raw water line or to a mixing basin. In order to treat VOCs effectively, PAC must contact all of the incoming water. Following adsorption, the carbon containing the organic compounds is settled or filter from the water and disposed of with the plant sludge. In some cases no modifications other than the addition of PAC dosing equipment need to be made to an existing plant because the normal contact time used for other elements of water treatment is sufficient for contaminant adsorption onto PAC. However, the contact time has to be determined prior to the design of the process. The dose of PAC added to the system has to be adapted to deal with varying source water quality.

The removal efficiencies of VOCs depend upon sufficient contact time, proper mixing, effects of chlorine and other chemicals, and the removal method of spent PAC. However, PAC requires coagulation/sedimentation facilities such as feed equipment, mixing chambers, clarifiers, and filtration. If these facilities are in place, PAC is simple to employ on a small scale. PAC is considered an emerging technology because long-term performance for treatment of VOCs has not been evaluated.

Gas-Permeable Membrane Aeration

Gas-permeable membrane aeration is an emerging technology (NRC 1997). In gas permeable membrane systems, water flows through the interior of hollow membrane tubes constructed of a material that allows gases but not liquids to pass through. The large surface area for air-water contact allows for removal of VOCs (Semmens et al. 1989). Some studies have shown that when compared with other aeration systems, gas-permeable membrane systems offer the highest removal efficiencies of all contacting devices (NRC 1997). However, this technology has to be considered emerging because long-term performance has not been evaluated.

Advanced Oxidation Processes

Advanced oxidation is considered an emerging technology. The majority of advanced oxidation research as focused on treatment of chlorinated organics present in groundwater. Advanced oxidation processes can oxidize some volatile organic compounds such as trichloroethylene and tetrachloroethylene to completion. An added benefit is that advanced oxidation processes may used for disinfection. However, AOPs have only been used in one drinking water system on the pilot level. Therefore, this technology is considered emerging because long-term performance has not been evaluated.

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8. SMALL SYSTEMS COMPLIANCE TECHNOLOGIES FOR OTHER SYNTHETIC ORGANIC CONTAMINANTS

Section 8.1: Background

The Phase II and V SOCs are a diverse group of chemicals in terms of properties, although most of them are used as pesticides and find their way into drinking water through this common use. They vary widely with regard to chemical structure, make-up, and charge, which causes them to exhibit a range of environmental behaviors. For the same reasons, the removal of these compounds in drinking water treatment processes also varies. For example, Miltner et al. (1989) demonstrated that water softening removed a significant percentage of carbofuran, but for the other seven pesticides studied, softening was not effective. Miltner et al. (1989) also demonstrated that clarification, filtration, and chlorination were not effective for any of the eight pesticides studied. In general, less conventional treatment like activated carbon, membranes, air stripping, ozonation, or advanced oxidation is required (Clark et al., 1990).

The physical and chemical properties (Schwarzenbach et al. 1993, Kamrin 1997) that determine the behavior of SOCs in the environment and during treatment processes include volatility (tendency to evaporate), water solubility, and resistance to chemical degradation. Volatile SOCs can enter the atmosphere and, if chemically persistent, travel great distances before being deposited. Modes of atmospheric deposition of pollutants include dry-fall, or deposition of the pollutant directly from the air or when attached to settling dust, etc. and wet-fall, or deposition of the pollutant through rainfall, snow, or other precipitation (Schnoor 1996). Through atmospheric deposition, contaminants can reach surface waters and soils that are otherwise pristine. For example, waters and soils that do not receive agricultural run-off can become contaminated with pesticides because of atmospheric deposition. Water solubility is another very important property that affects the environmental mobility and treatability of SOCs. If an SOC is very water soluble, it can be readily transported in run-off (Larson et al. 1997), through ground water (Barbash and Resek 1996), and is more difficult to remove with granular activated carbon (GAC) (Snoeyink 1990, p. 786). If the SOC is relatively insoluble, it tends to sorb to the soil matrix in the case of ground water. In the case of surface water, insoluble SOCs may sorb to suspended particles, some of which will settle out, or directly to the sediment matrix. In general, the less soluble an SOC, the greater its tendency to sorb to GAC (Snoeyink 1990, Schwarzenbach et al. 1993).

Ten technologies for the removal of the Phase II and Phase V synthetic organic chemicals (SOCs) have been evaluated as potential compliance technologies for small systems: GAC, PAC, aeration, oxidation, advanced oxidation, ultrafiltration, nanofiltration, and reverse osmosis. For the purposes of determining best available technologies (BATs) for removing SOCs from drinking water, the Safe Drinking Water Act (§1412.b.4.D) explicitly states that any BAT listed by EPA must be at least as effective as granular activated carbon (GAC). The various BATs listed for the Phase II and V SOCs are GAC, packed tower aeration (PTA), and, in the case of gylphosate, oxidation by chlorination or ozonation (EPA 1991a, 1991b and 1992a). However, for the

purposes of determining the list of compliance technologies for small systems of a given size category, the Safe Drinking Water Act ((§1412.b.4.E) states that any listed technology must be affordable and able to achieve compliance with the maximum contaminant level. To emphasize the point, the listed small systems compliance technologies do not have to be as effective as GAC in controlling SOCs.

Section 8.2: Evaluation of Technologies

Granular activated carbon (GAC) and powdered activated carbon (PAC)

The activated carbon processes are described in Chapter 3 of this document and in detail in terms of SOCs removal in the "technologies and costs" regulatory support documents for the Phase II and Phase V final rules (USEPA 1990 and 1992b). Based on past research and pilot scale work, GAC is considered to be the best available broad spectrum removal process for SOCs. PAC, when applied properly, works well for many of the SOCs. However, both technologies exhibit a wide range of removal efficiencies, depending upon site specific conditions and the identify of the SOC in question. Site specific conditions that may affect percent removal include the presence of other "competing" contaminants, including natural organic matter, biofilm development on the carbon surface, temperature, pH, variable influent concentrations (leading to desorption), activated carbon particle size and specific surface area, and hydraulic loading rate (AWWA - ASCE 1998).   Due to the potential for variability in removal efficiencies, some degree of source water-specific testing is needed to ensure adequate removal. In cases in which the raw water has a low concentration of natural organic matter, such as most ground waters, inexpensive bench-scale tests may be adequate to predict performance (NRC 1997). For surface water systems, pilot tests may be required.

Discussions of models to predict full-scale performance that also discuss basic activated carbon principles in the context of drinking water regulations are found in numerous sources (e.g., Sontheimer 1988, Snoeyink 1990, Speth 1990, Speth and Adams 1993). Design parameters are discussed in a variety of text books (e.g., AWWA - ASCE 1998), journal articles (e.g., AWWA 1989), and EPA regulatory support documents (USEPA 1990 and 1992b).

POE and POU GAC are both potentially useful for small systems applications. However, issues regarding cost-effectiveness and backwash waste disposal for POE GAC preclude its being listed this year. POE GAC will continue to be evaluated as an emerging technology. POU GAC is currently commonly used to remove taste and odor compounds and other organic contaminants in a non-regulatory manner and is a potentially cost-effective way for small systems to remove regulated SOCs. Regulatory issues regarding POU use were described in Chapters 1 and 3. The performance and GAC bed life depend on the amount of GAC used in the device, the contact time, and the nature of the contaminants being removed. A proper monitoring and unit replacement schedule must be maintained to ensure that good removals are maintained (NRC 1997).

Packed Tower Aeration (PTA)

Packed tower aeration (PTA) is BAT for several of the more volatile Phase II and Phase V SOCs, namely dibromochloropropane, ethylene dibromide, di(2-ethylhexyl) adipate, and hexachlorocyclopentadiene. The PTA process is described in Chapter 3. The issues and caveats that apply to PTA treatment for VOCs removal, as described in chapter 7.

Other Aeration Technologies

Chapters 3 and 7 describe other aeration technologies relevant to the removal of the volatile Phase II and V SOCs.

Oxidation

Oxidation by chlorination or ozonation is BAT for glyphosate. Other oxidation processes are potentially applicable, but sufficient published data is not available. Issues and caveats regarding chlorination and ozonation use by small drinking water systems are described elsewhere (EPA 1997, EPA 1998b).

Section 8.3: Small Systems Compliance Technologies List

Based on the evaluation of the technologies described in Section 8.2, the following table lists the Small Systems Compliance Technologies for at least one Phase II or V SOC (EPA 1998a). The table contains the same structure as other tables with a list of limitations that are contained in the footnotes and operator skill level and raw water quality issues.

Table 8.1: Technologies for SOCs			
Unit Technology	**Limitations (see footnotes)**	**Operator Skill Level Required[1]**	**Raw Water Quality Range and Considerations[1]**
1. Granular Activated Carbon (GAC)		Basic	Surface water may require pre-filtration
2. Point of Use (POU) GAC	([a])	Basic	Surface water may require pre-filtration
3. Powdered Activated Carbon	([b])	Intermediate	All waters
4. Chlorination	([c])	Basic	Better with high quality water

5. Ozonation	([c])	Basic	Better with high quality waters
6. Packed Tower Aeration (PTA)	([d])	Intermediate	All ground waters
7. Diffused Aeration	([d, e])	Basic	All ground waters
8. Multi-Stage Bubble Aerators	([d, f])	Basic	All ground waters
9. Tray Aeration	([d, g])	Basic	All ground waters
10. Shallow Tray Aeration	([d, f])	Basic	All ground waters

[1]   National Research Council (NRC). *Safe Water from Every Tap: Improving Water Service to Small Communities*. National Academy Press. Washington, DC. 1997.

Limitations footnotes for Table 10: Technologies for SOCs

[a] When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance.
[b] Most applicable to small systems that already have a process train including basins mixing, precipitation or sedimentation, and filtration. Site specific design should be based on studies conducted on the system's particular water.
[c] See the SWTR compliance technology tables for limitations associated with this technology.
[d] Pretreatment for the removal of microorganisms, iron, manganese, and excessive particulate matter may be needed. Post-treatment disinfection may have to be used.
[e] May not be as efficient as other aeration methods because it does not provide for convective movement of the water thus limiting air-water contact. It is generally used only to adapt existing plant equipment.
[f] This units are highly efficient, however the efficiency depends upon the air-to-water ratio.
[g] Costs may increase if a forced draft is used.

Chapter 1 indicated that EPA would identify affordable compliance technologies for those existing regulations where small system variances or variance technologies are not prohibited by the SDWA. There are statutory prohibitions against small system variances or variance technologies for 14 of the 32 SOCs. The following table contains the compliance technologies for the 18 SOCs where affordability was considered. Affordability only plays a role in removing options in the smallest size category. The technology costs are based on treatment of all of the water. The technologies that did not meet the affordability criteria in the smallest size category are also identified in the next column called "other compliance technologies." These technologies

may be affordable if the concentration of the contaminant is low enough that a portion of the influent stream can be treated and blended with an untreated portion to still meet the MCL. This blending would reduce both the capital and operating and maintenance costs of the process. Systems and States should consider these options under those circumstances. The subsequent table contains the compliance technologies for the remaining fourteen SOCs where affordability was not considered due to statutory prohibitions. The statutory prohibitions on variance technologies and small system variances are discussed in detail in the Variance Technologies Findings Document (EPA 1998c).

Table 8.2: Compliance Technologies by System Size Category for those SOC NPDWRs where Affordability is Considered				
Contaminant	**Compliance Technologies for System Size Categories (Population Served)**			
	25 - 500 (afford)	**25 - 500 (other)**	**501 - 3,300 (afford)**	**3,301 - 10,000 (afford)**
Alachlor	2, 3[1]	1	1, 2, 3	1, 2, 3
Atrazine	2, 3	1	1, 2, 3	1, 2, 3
Carbofuran	2, 3	1	1, 2, 3	1, 2, 3
Dibromochloropropane	2, 3, 6, 7, 8, 9, 10	1	1, 2, 3, 6, 7, 8, 9, 10	1, 2, 3, 6, 7, 8, 9, 10
2,4-D	2, 3	1	1, 2, 3	1, 2, 3
Lindane	2, 3	1	1, 2, 3	1, 2, 3
Methoxychlor	2, 3	1	1, 2, 3	1, 2, 3
Pentachlorophenol	2, 3	1	1, 2, 3	1, 2, 3
Dalapon	2, 3	1	1, 2, 3	1, 2, 3
Di(2-ethylhexyl) adipate	2, 3, 6, 7, 8, 9, 10	1	1, 2, 3, 6, 7, 8, 9, 10	1, 2, 3, 6, 7, 8, 9, 10
Di(2-ethylhexyl) phthalate	2, 3	1	1, 2, 3	1, 2, 3
Dinoseb	2, 3	1	1, 2, 3	1, 2, 3

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[1] This affordability determination assumes that the small system already has the appropriate treatment train in place for mixing, contact, and filtration.

Table 8.2: Compliance Technologies by System Size Category for those SOC NPDWRs where Affordability is Considered				
Contaminant	**Compliance Technologies for System Size Categories (Population Served)**			
	25 - 500 (afford)	**25 - 500 (other)**	**501 - 3,300 (afford)**	**3,301 - 10,000 (afford)**
Diquat	2, 3	1	1, 2, 3	1, 2, 3
Endothall	2, 3	1	1, 2, 3	1, 2, 3
Glyphosate	4, 5		4, 5	4, 5
Hexachlorocyclopentadiene	2, 3, 6, 7, 8, 9, 10	1	1, 2, 3, 6, 7, 8, 9, 10	1, 2, 3, 6, 7, 8, 9, 10
Picloram	2, 3	1	1, 2, 3	1, 2, 3
Simazine	2, 3	1	1, 2, 3	1, 2, 3

Table 8.3: Compliance Technologies by System Size Category for those SOC NPDWRs where Affordability is Not Considered			
Contaminant	**Compliance Technologies for System Size Categories (Population Served)**		
	25 - 500	**501 - 3,300**	**3,300 - 10,000**
Chlordane	1, 2, 3	1, 2, 3	1, 2, 3
Ethylene Dibromide	1, 2, 3, 6, 7, 8, 9, 10	1, 2, 3, 6, 7, 8, 9, 10	1, 2, 3, 6, 7, 8, 9, 10
Heptachlor	1, 2, 3	1, 2, 3	1, 2, 3
Heptachlor Epoxide	1, 2, 3	1, 2, 3	1, 2, 3
Polychlorinated Biphenyls	1, 2, 3	1, 2, 3	1, 2, 3
Toxaphene	1, 2, 3	1, 2, 3	1, 2, 3
2,4,5-TP	1, 2, 3	1, 2, 3	1, 2, 3

Table 8.3: Compliance Technologies by System Size Category for those SOC NPDWRs where Affordability is Not Considered			
Contaminant	**Compliance Technologies for System Size Categories (Population Served)**		
	25 - 500	**501 - 3,300**	**3,300 - 10,000**
Benzo(a)pyrene	1, 2, 3	1, 2, 3	1, 2, 3
Endrin	1, 2, 3	1, 2, 3	1, 2, 3
Hexachlorobenzene	1, 2, 3	1, 2, 3	1, 2, 3
Oxamyl	1, 2, 3	1, 2, 3	1, 2, 3
2,3,7,8-TCDD (Dioxin)	1, 2, 3	1, 2, 3	1, 2, 3
Acrylamide	N/A (treatment technique)	N/A (treatment technique)	N/A (treatment technique)
Epichlorohydrin	N/A	N/A	N/A

Section 8.4: Emerging Technologies

Membrane Processes

Reverse osmosis, including POE and POU RO, and nanofiltration show promise as compliance technologies for SOCs. However, efficient rejection of a SOC depends upon the specific membrane (surface charge, pore size and distribution, etc.), the source water quality, and the environmental conditions of the test (AWWA - ASCE 1998). Very importantly, rejection of SOCs must be confirmed through bench or pilot-scale testing. Because data on SOCs removal via membranes are limited and because there are so many variables that affect membrane removal efficiencies for SOCs, EPA will evaluate them further before listing any membrane technologies as small systems compliance technologies.

POE GAC

As described above, POE GAC shows promise and will continue to be evaluated as a potential small systems compliance technology.

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APPENDIX A

RELEVANT PARTS OF SECTIONS 1412 OF THE REVISED (1996) SDWA

SEC. 105. TREATMENT TECHNOLOGIES FOR SMALL SYSTEMS.

Section 1412(b)(4)(E) (42 U.S.C. 300g-1(b)(4)(E)) is amended by adding at the end the following:

> ``(ii) List of technologies for small systems.--The Administrator shall include in the list any technology, treatment technique, or other means that is affordable, as determined by the Administrator in consultation with the States, for small public water systems serving--
>
> > ``(I) a population of 10,000 or fewer but more than 3,300;
> > ``(II) a population of 3,300 or fewer but more than 500; and
> > ``(III) a population of 500 or fewer but more than 25;
>
> and that achieves compliance with the maximum contaminant level or treatment technique,
>
> > including packaged or modular systems and point-of-entry or point-of-use treatment units. Point-of-entry and point-of-use treatment units shall be owned, controlled and maintained by the public water system or by a person under contract with the public water system to ensure proper operation and maintenance and compliance with the maximum contaminant level or treatment technique and equipped with mechanical warnings to ensure that customers are automatically notified of operational problems. The Administrator shall not include in the list any point-of-use treatment technology, treatment technique, or other means to achieve compliance with a maximum contaminant level or treatment technique requirement for a microbial contaminant (or an indicator of a microbial contaminant). If the American National Standards Institute

> has issued product standards applicable to a specific type of point-of-entry or point-of-use treatment unit, individual units of that type shall not be accepted for compliance with a

maximum contaminant level or treatment technique requirement unless they are independently certified in accordance with such standards. In listing any technology, treatment technique, or other means pursuant to this clause, the Administrator shall consider the quality of the source water to be treated.

``(iii) List of technologies that achieve compliance.--Except as provided in clause (v), not later than 2 years after the date of enactment of this clause and after consultation with the States, the Administrator shall issue a list of technologies that achieve compliance with the maximum contaminant level or treatment technique for each category of public water systems described in subclauses (I), (II), and (III) of clause (ii) for each national primary drinking water regulation promulgated prior to the date of enactment of this paragraph.

``(iv) Additional technologies.--The Administrator may, at any time after a national primary drinking water regulation has been promulgated, supplement the list of technologies describing additional or new or innovative treatment technologies that meet the requirements of this paragraph for categories of small public water systems described in subclauses (I), (II), and (III) of clause (ii) that are subject to the regulation.

``(v) <<NOTE: Records.>> Technologies that meet surface water treatment rule.--Within one year after the date of enactment of this clause, the Administrator shall list technologies that meet the Surface Water Treatment Rule for each category of public water systems described in subclauses (I), (II), and (III) of clause (ii).''.