Enclosure 8

PWR Secondary Water Chemistry Guidelines:

Draft Revision 6

Non-Proprietary Version

PWR Secondary Water Chemistry Guidelines – Revision 6

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NON-PROPRIETARY DRAFT REPORT, JUNE 2004

EPRI Project Manager
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REPORT SUMMARY

State-of-the-art water chemistry programs reduce equipment corrosion and enhance steam generator reliability. These revised PWR secondary water chemistry guidelines—prepared by a committee of industry experts—represent the latest field and laboratory data on secondary system corrosion and performance issues. PWR operators can use these guidelines to update their secondary water chemistry programs.

Background
Industry water chemistry guidelines are updated periodically as new information becomes available. Previous versions of these PWR secondary water chemistry guidelines identified a detailed water chemistry program deemed to be consistent with the then-current understanding of research and field information. Each revision discussed the impact of these guidelines on plant operation, noting that utilities may wish to revise the presented program following a plant-specific evaluation for implementation. Utility feedback since publication of Revision 5 in May 2000 revealed that some utility chemistry personnel required further details regarding how to best integrate these guidelines into the plant-specific optimization process while still ensuring compliance with NEI 97-06 and NEI 03-08.

Objective
- To update the PWR Secondary Water Chemistry Guidelines—Revision 5.

Approach
A committee of industry experts—including utility specialists, nuclear steam supply system vendor representatives, Institute of Nuclear Power Operations representatives, consultants, and EPRI staff—collaborated in reviewing the available data on secondary water chemistry and secondary cycle corrosion. From these data, the committee generated water chemistry guidelines that should be adopted at all PWR nuclear plants. Recognizing that each nuclear plant owner has a unique set of design, operating, and corporate concerns, the guidelines committee developed a methodology for plant-specific optimization.

Results
Revision 6 of the *PWR Secondary Water Chemistry Guidelines*—which provides recommendations for PWR secondary systems of all manufacture and design—includes the following chapters:

- Chapter 1 contains a list of management responsibilities. This chapter also addresses the requirements for a secondary water chemistry program to be in compliance with NEI 97-06, SG Program Guidelines, and identifies the parts of *Guidelines* that are mandatory, "shall" requirements, and recommendations.

- Chapter 2 presents a compilation of corrosion data for steam generator tubing and, to a lesser extent, balance-of-plant materials. This information serves as the technical bases for the specific parameters and programs detailed in the document.
- Chapter 3 discusses the role of the concentration processes in local regions of the steam generator and the chemistry programs available for minimizing the impact of impurity concentration. It briefly identifies the supporting aspects and considerations in adopting these chemistry regimes.
- Chapter 4 presents a detailed method for performing the plant-specific optimization, including development of a modified chemistry program.
- Chapters 5 and 6 present water chemistry programs for the recirculating steam generator (RSG) and once-through steam generator (OTSG), respectively. These are the chapters most frequently referred to by chemistry personnel. The tables in these chapters provide the boundaries for the plant-specific optimization procedures described in Chapter 4.
- Chapter 7 provides information on data collection, evaluation, and management. This chapter describes methods of using **EPRI chemWORKS** ™ modules for evaluating plant data and predicting high-temperature chemistry environments throughout the cycle.
- Appendix A provides examples of methodologies for implementing integrated exposure programs.
- Appendix B provides the results of a recent review of PWR steam chemistry considerations.

EPRI Perspective
This sixth revision of the *PWR Secondary Water Chemistry Guidelines*, endorsed by the utility executives of the EPRI Steam Generator Management Project, represents another step in maintaining proactive chemistry programs to limit or control steam generator degradation, with consideration given to corporate resources and plant-specific design/operating concerns. Each utility should examine its plant-specific situation to determine which recommendations should be implemented.

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EPRI FORWARD

Industry water chemistry guidelines are updated periodically as new information becomes available. Previous revisions of these guidelines have identified a detailed water chemistry program that was deemed to be consistent with the then current understanding of research and field information. Each revision, however, has recognized the impact of these *Guidelines* on plant operation and has noted that utilities should optimize their program based on a plant-specific evaluation prior to implementation. To assist in such plant-specific evaluations, Revisions 4 and 5, issued in 1996 and 2000, respectively, provided an increased depth of detail regarding the corrosion mechanisms affecting steam generators and the balance of plant, and provided additional guidance on how to integrate these and other concerns into the plant-specific optimization process. Revision 6 retains the format of Revisions 4 and 5, and adds to the detailed information contained in these revisions. The chapters of Revision 6 cover the following:

- Chapter 1 identifies Management Responsibilities. It also describes which elements of the *Guidelines* are mandatory and "shall" requirements under NEI 97-06, Steam Generator Program Guidelines, (consistent with NEI 03-08) and which are recommendations.
- Chapter 2 presents a compilation of corrosion data for steam generator tubing and, to a lesser extent, balance-of-plant materials. It is not intended to relate operational bulk water chemistry to the corrosion phenomena, which is covered in Chapter 3. The corrosion data presented in Chapter 2 serve as the technical bases for each of the specific parameters and programs detailed in the balance of the document.
- Chapter 3 discusses the role of the concentration processes in the various locations of the steam generator and the chemistry "tools" available for modifying the resulting chemistry within these concentrating regions. It briefly identifies the supporting aspects of and the considerations for adopting these chemistry regimes. It refers the reader to more detailed documents for application of the chemistry strategies.
- Chapter 4 presents a detailed methodology for performing the plant-specific optimization that can be used to develop a modified chemistry program that satisfies site-specific concerns. Chapter 4 also presents example startup and operating chemistry parameters and limits that can be used as a starting point for site-specific evaluations.
- Chapters 5 and 6 present water chemistry programs for RSGs and OTSGs, respectively. These are the chapters most frequently referred to by chemistry personnel. The tables contained within these chapters provide boundaries of the envelope within which plant-specific optimization should occur.
- Chapter 7 provides information on data collection, evaluation, and management. This chapter covers use of **EPRI chem*WORKS*™** modules for evaluating plant data and predicting high-temperature chemistry environments throughout the cycle.

- Appendix A provides detailed guidance with regard to use of the integrated exposure concept.
- Appendix B provides a review of PWR steam chemistry considerations.

These *Guidelines* were produced by the Committee with support from an industry Technical Review Team and the technical committees of the Steam Generator Management Program. Key technical changes in this revision include:

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Chairman

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The objective of this document is to provide guidance on determining and implementing a set of plant-specific water chemistry requirements for the secondary cycle of PWRs. Accordingly, this document presents the corrosion data that provide the technical bases for water chemistry control (Chapter 2), the various water chemistry control strategies that are available (Chapter 3), a recommended methodology for plant-specific optimization (Chapter 4), generic water chemistry guidelines for RSGs and OTSGs (Chapters 5 and 6, respectively), and suggested data collection, evaluation, and management techniques (Chapter 7).

In addition, the US nuclear power industry established a framework for increasing the reliability of steam generators by adopting NEI 97-06, *Steam Generator Program Guidelines* (1, 2). This initiative references EPRI's Water Chemistry Guidelines, including this document, as the basis for an industry consensus approach to chemistry programs. Specifically, the initiative requires that US utilities meet the intent of the *EPRI PWR Secondary Water Chemistry Guidelines.* The focus of the NEI initiative is steam generator integrity. These *Guidelines* are a support document under NEI 97-06. These *Guidelines* include control parameters and monitoring requirements which must be incorporated into a plant's water chemistry program in order to meet the intent of these *Guidelines*.

1.2 Water Chemistry Management Philosophy

1.3 Generic Management Considerations

This section lists and discusses the considerations which are common to most utilities, including the elements of organizations which are needed to carry out the water chemistry program effectively. Actions are identified without specifying responsibility for completing them. Utility-specific implementation policies and procedures should assign the responsibilities to specific positions within the organization. One major element of these *Guidelines* is the need for every level of management to understand the importance of the action levels presented in Chapters 5 and 6 and their potential impact on, and benefits to, the utility company. In addition, there is a need for management to support a data collection, evaluation, and management system similar to the approach discussed in Chapter 7.

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Corrosion of steam generator tubes has been the major issue affecting selection of secondary water chemistry parameters. However, corrosion and flow-accelerated corrosion (FAC) of steam generator internals and other secondary system components are also important concerns. The objective of this chapter is to review the causes of this corrosion and FAC and to provide the technical bases for measures to control these concerns.

2.2 Introduction

This chapter of the secondary water chemistry guidelines discusses corrosion issues affecting PWR steam generators and balance of plant components, with the objective of providing bases for selecting secondary water chemistry parameters that minimize problems due to corrosion.

The objective of secondary side water chemistry control is to minimize corrosion damage and performance losses for all secondary system components and to thereby maximize the reliability and economic performance of the secondary system. To achieve this objective, the water chemistry has to be compatible with all parts of the system including steam generators, turbines, condensers, feedwater heaters, moisture separator reheaters (MSRs), and piping. The variety of materials used in the many components in typical secondary systems, and the range of temperatures, pressures, phases, and velocities place constraints on the selection of water chemistries for secondary systems.

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These guidelines reflect current understanding of the role of chemical transport, impurity concentrations, material selection, corrosion behavior, chemical analysis methods, and industry practices on the operation and integrity of steam generator systems.

The guidelines included in this chapter represent a condensation of the technical bases from Chapter 2, chemical control strategies from Chapter 3, and optimization issues from Chapter 4 into a generic program for recirculating steam generators (RSG).

5.2 Control and Diagnostic Parameters

The tables presented in this chapter include chemistry monitoring requirements and recommendations.

5.3 Action Levels

Action Level 1

Action Level 2

Action Level 3

5.4 Corrective Actions

Typical corrective actions for various plant status modes are also presented. These corrective actions are not meant to be all-inclusive or universally applicable but should be considered. It should be noted that impurities may originate from within the system (weld repair, plant modification, component replacement, etc.) or from without (condenser cooling water leak, makeup water contamination, etc.). Corrective actions vary accordingly.

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WATER CHEMISTRY GUIDELINES ONCE-THROUGH STEAM GENERATORS

6.1 Introduction

The guidelines presented in this chapter reflect the current understanding of the roles of chemical transport, impurity concentrations, and materials on the operation and integrity of once-through steam generator (OTSG) systems. They also reflect the technical bases of Chapter 2, the chemical control strategies of Chapter 3 and the optimization issues of Chapter 4.

6.2 Control and Diagnostic Parameters

6.3 Action Responses

Action Level 1

Action Level 2

Action Level 3

6.4 Status Modes

6.5 Guidelines

6.5.1 Cooldown/Hot Soaks

6.5.2 Cold Shutdown/Wet Layup

6.5.2.1 Guidelines/Technical Justifications

Table 6-1
Full Wet Layup (RCS ≤200°F) (Technical Specification Modes 5 and 6)
Steam Generator Sample

Table 6-2
Once Through Steam Generator Fill Water

6.5.2.2 Parameter Justifications

6.5.2.3 Corrective Actions

6.5.3 Startup, Hot Standby, and Reactor Critical at <15% Reactor Power (RCS >200°F, <15% Reactor Power) – Modes 1, 2, 3 and 4 of STS

6.5.3.1 Guidelines/Technical Justifications

Table 6-3
Once Through Steam Generator Startup/Hot Standby/Reactor Critical at <15% Reactor Power (Technical Specification Modes 1, 2, 3 and 4) Feedwater Sample

Table 6-4
Once Through Steam Generator Startup/Hot Standby/Reactor Critical at <15% Reactor Power (Technical Specification Modes 1, 2 and 3 and Mode 4 During Startup) Blowdown Sample[a]

6.5.3.2 Parameter Justifications

6.5.3.2.1 Feedwater

6.5.3.2.2 Steam Generator Bulk Water

6.5.3.3 Corrective Actions

6.5.4 Power Operation (≥15% Reactor Power)

6.5.4.1 Guidelines/Technical Justifications

Feedwater chemistry guidelines for power operation are given in Table 6-5. Chemistry guidelines for condensate samples are given in Table 6-6. For normal operation, these values represent limits below which little impurity-related corrosion of steam generator or turbines has been noted by the industry. Out-of-guideline conditions should be corrected to normal values within the time specified. Higher water quality should be maintained whenever possible.

Table 6-5
Once-Through Steam Generator Power Operation (≥15% Reactor Power)
Feedwater Sample

Table 6-6
Once-Through Steam Generator Power Operation (>15% Reactor Power) Condensate Sample

Table 6-7
Once-Through Steam Generator Power Operation (>15% Reactor Power) Mode 1 of Standard Technical Specifications Moisture Separator Drain Sample

6.5.4.2 Parameter Justifications

6.5.4.3 Corrective Action Guidelines - Power Operation

6.6 References

7

DATA: COLLECTION, EVALUATION, AND MANAGEMENT

7.1 Introduction

Table 7-1
Continuous Instrumentation Suggestions for Recirculating Steam Generators

Table 7-2
Continuous Instrumentation Suggestions for Once-Through Steam Generators

7.2 QA/QC Considerations

7.2.1 Basis for Generating Chemistry Data of Known Quality

7.2.2 Data Management

7.2.3 QC Considerations for Secondary Chemistry Control

7.3 Sampling Considerations

7.3.1 General Considerations

Efforts should be made to assure that a sample is representative of the process stream or vessel of interest. Chemistry results are no better than the validity of samples under analysis. Long sample lines and improper sample conditioning can lead to results which have little to do with the process stream being analyzed. Non-representative samples can result from:

7.3.2 Special Sampling Considerations

The sampling of feedwater, condensate, and blowdown for metal oxides can present significant challenges. The system is two phase and, although the solids may be uniformly distributed in the flowing stream, the sampling lines present the greatest challenge for maintaining representative sampling. Consider the following:

Figure 7-1
Example of Feedwater Sample Line Configuration for Oxygen Sampling

Figure 7-2
Example of Feedwater Sample Line Configuration for Metal Oxide Sampling

Figure 7-3
Suggested Feedwater Sample Line Configuration for Oxygen and Metal Oxide Sampling

Figure 7-4
Example of a Sample Tee Configuration

Table 7-3
Example Calculation of Oxygen Reduction in a Feedwater Sample Line

7.3.3 Sampling for Lead

7.4 Data Collection

7.5 Data Evaluation Tools

7.5.1 Introduction

7.5.2 EPRI chemWORKS™ Software

7.5.3 Calculated Cation Conductivity

Table 7-4
Equivalent Conductivities for Some Ions: [Ref MULTEQ Database]

7.5.4 Steam Generator Corrosion Evaluations

7.5.4.1 Source Term Evaluation

Table 7-5
Typical Source and Removal Terms in PWR Secondary Systems

Table 7-6
Source and Removal Term percentages

7.5.4.2 Source Term Contribution From Total Organic Carbon

7.5.4.3 Integrated Exposure Evaluation (for Recirculating Steam Generators)

7.5.4.3.1 Integrated Exposure Method A: (ppb*days)

Figure 7-5
Spreadsheet Used to Calculate IE by Simple Integration Method

Figure 7-6
Sample Sodium IE Calculation for Plant with High Impurity Exposures During Startup

Figure 7-7
Plant Exposure at Normal Operation vs. Reference Plant Exposure

7.5.4.3.2 Integrated Exposure Method B: Tube Exposure Factor

Figure 7-8
Three Cases with Similar Cumulative Mass Accumulation over the Cycle Length

Figure 7-9
Relative Tube Surface Area Wetted for Three Different Cases where Cumulative Mass Accumulation at the End of the Cycle is the Same

Figure 7-10
Drilled Hole Crevice Geometry

Figure 7-11
Relationship between Surface Area Wetted vs. Volume Filled for an Eccentric Crevice

Figure 7-12
Relative Tube Exposure Factor Illustrating Differences in Exposure for Cases where Total Cumulative Mass Accumulation over the Cycle Length is the Same

Figure 7-13
Sample Spreadsheet Used to Calculate Tube Exposure Factors

Figure 7-14
Example Relative Tube Exposure Factor for an Actual Operating Cycle Showing the Effect of the Startup Transient

7.5.4.3.3 Integrated Exposure Method C: CREV-SIM

7.5.4.4 Hideout Return Evaluations

7.5.4.5 Deposit Chemistry Evaluation

7.5.4.6 Sludge Analysis and Monitoring

7.6 Balance of Plant Corrosion Concerns

7.6.1 pH Control and Corrosion Product Transport

Table 7-7
pH Control Program Data Trends

Table 7-8
Example Calculation for Iron and Copper Transport

7.6.2 Integrated Corrosion Product Loading

Table 7-9
Example Data on Steam Generator Deposit Loading

7.7 Technical Assessments

7.7.1 Contaminant Ingress Control (Ionic Contaminants)

7.7.2 Contaminant Ingress Monitoring (Oxidants)

7.7.3 Corrosion Product Transport

7.7.4 Steam Generator Corrosion

7.7.5 System/Component Observations

7.7.6 Demineralizer/Filter Performance

7.7.7 Process Instrument Performance and Reliability

7.7.8 Hideout Return

7.8 References

A
INTEGRATED EXPOSURE EVALUATIONS

1.0 Introduction

This appendix was created to demonstrate how some plants use integrated exposure in practice. Three plant documents (or summaries of plant documents) are presented, which describe different methodologies for use of integrated exposure.

2.0 Integrated Exposure Example 1

PWR Secondary Chemistry Operating Guideline

I. Introduction

II. Purpose

III. Operating Philosophy

IV. Basis

V. Operating Methodology

3.0 Integrated Exposure Example 2

Utilization of Integrated Exposure Limits to Control Molar Ratio

4.0 Integrated Exposure Example 3

5.0 References

B
PWR STEAM CHEMISTRY CONSIDERATIONS

1.0 Introduction

2.0 PWR Steam Chemistry Considerations –

Introduction to Paper

This paper reviews the key issues associated with steam chemistry in PWR's. Over the past several years, EPRI and other international organizations have sponsored a research program focused on steam chemistry within power plant steam cycles.

Recommendations

Discussion

Deposition Processes in Turbines

Figure B-1
Location of Salt Concentration in LP Turbines

Steam Chemistry Guidelines

The ideal approach to establishing steam chemistry limits would follow the following step wise approach:

Table B-1
Reheat Steam Limits in Drum Units

Figure B-2
Steam Expansion Path for Fossil and Nuclear Steam Cycles

3.0 References