



U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.56

MAINTENANCE OF WATER PURITY IN BOILING WATER REACTORS

A. INTRODUCTION

General Design Criteria 14, "Reactor Coolant Pressure Boundary," and 31, "Fracture Prevention of Reactor Coolant Pressure Boundary," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," require assurance that the reactor coolant pressure boundary will have minimal probability of gross rupture or rapidly propagating failure.

General Design Criterion 15, "Reactor Coolant System Design," requires that the reactor coolant system and associated auxiliary, control, and protection systems be designed with sufficient margin to ensure that the design conditions of the reactor coolant pressure boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences. Failure of the reactor coolant pressure boundary may be postulated where the mechanisms of general corrosion and stress-corrosion cracking induced by impurities in the reactor coolant are present.

Furthermore, General Design Criterion 13, "Instrumentation and Control," requires that instrumentation be provided to monitor variables and systems that can affect the reactor coolant pressure boundary over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions as appropriate to ensure adequate safety.

This guide describes a method acceptable to the NRC staff for implementing the criteria with regard to minimizing the probability of corrosion-induced failure of the reactor coolant pressure boundary in

boiling water reactors (BWRs) by maintaining acceptable purity levels in the reactor coolant. It further describes instrumentation acceptable to the NRC staff for determining the condition of the reactor coolant and coolant purification systems in BWRs.

B. DISCUSSION

Water quality control starts during construction when extensive efforts are necessary to ensure that components and piping are clean. Concern with proper water quality must start even before the plant operates and continue through all operations until final shutdown. Maintenance of high water quality is important during all operations since water is often transferred from one part of the plant to another during outages and this water can easily find its way to the hotwell and from there to the reactor.

In a typical BWR direct or single cycle reactor system (see Fig. 1 in the appendix), water is boiled by means of a nuclear fission heat source. The steam and water mixture produced in the core area passes through steam separators where much of the water is removed. Wet steam passes from the separators to the steam dryers to produce relatively dry steam (less than 1/10 of a percent moisture). The steam at approximately 1000 psi and 550°F (288°C) enters the main steam lines and passes through the turbine to the main condenser. Condensed steam is collected in the hotwell located below the cooling tubes of the condenser. Leaks in the condenser tubes can result in circulating water entering the hotwell and introducing impurities. When the circulating water in the condensers is seawater, the consequences of tube leaks may be quite significant; therefore, special precautions are required in seawater-cooled plants.

De-aeration in the condenser reduces the oxygen content of the water. The condensate then passes

* The substantial number of changes in this revision has made it impractical to indicate the changes with lines in the margin.

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through full-flow demineralizers in order to obtain the purest possible feedwater. The condensate demineralizers remove insoluble corrosion products by filtration and remove dissolved ionic materials, i.e., metals and salts, by ion exchange. They also afford limited protection from large condenser tube leaks until corrective action is initiated. The feedwater passes through the feedwater heaters and enters the reactor at about 385°F (196°C). Since there is no "blowdown," the reactor water concentrates all the soluble and insoluble materials that enter via the feedwater. In BWRs, the reactor water cleanup system performs the blowdown function by removing soluble and insoluble impurities from the reactor water. Thus, extremely pure feedwater is provided by the equipment as necessary.

In BWRs, the various heat exchangers of auxiliary systems are barriers between high-purity reactor water and cooling water that may be contaminated with dissolved or suspended solids.

Main condenser leakage is a potential source of such contaminants. Such leakage should be minimized by proper condenser design and by providing for reliable detection of leakage. The rate of condenser leakage may be estimated from measurements of the electrical conductivity of the water in the condenser hotwell or in the line between the hotwell and the demineralizer. A meter with sufficient range to measure all water conductivity levels at least up to the limiting conditions of the technical specifications that require immediate shutdown of the reactor should be provided.

The condensate demineralizer system is provided between the condenser and the reactor vessel to reduce impurities from condenser leakage and other sources to an acceptable level. A typical condensate demineralizer consists of several parallel ion exchange units, the resins in which serving both to remove ionic impurities and to filter out suspended solids.

Depending on the flow rate, type of resin, cleanliness of resin of BWR full-flow demineralizer systems, and type of ions in the coolant, total capacity may not be available for ionic impurity removal in the condensate treatment system before decontamination factors become unacceptably low during condenser leakage. Demineralizer capacity reduction should be considered in the design so that there is adequate capacity margin available to permit orderly shutdown of the reactor in case of a serious condenser leak.

There are no instruments that will directly measure the capacity of a demineralizer unit. The capacity may be determined indirectly, however, from the initial capacity of the unit and the calculated flows of ions through the unit. Subtraction of the total ion

flow from the initial capacity gives the remaining capacity.

Operation of a demineralizer unit after its ion-exchange capacity has been depleted results in the direct passthrough of ions into the reactor vessel. Depending on the nature of these ions, stress-corrosion cracking or other forms of corrosion might be accelerated, crud buildup on fuel and on other components might be promoted, and plant radiation levels might be increased.

The conductivity of the inlet and outlet water of the demineralizer should be measured to monitor demineralizer performance. The monitoring instrument, which should be set to trigger alarms in the control room, should be capable of quickly detecting demineralizer breakthrough and should have sufficient range to measure all conductivity levels up to and including the limiting conditions of the plant technical specifications that require immediate shutdown of the reactor.

Even with highly efficient condensate demineralizers, some contaminants, at very low concentrations, pass into the reactor vessel. Chloride ions and high or low pH conditions, which may promote stress-corrosion cracking of austenitic stainless steel components and structures, are of particular concern.

To control contaminants within limiting conditions, the conductivity of the coolant at the inlet and outlet of the reactor water cleanup system should be continuously monitored. The chloride content and pH of the reactor water should be determined periodically. The reactor should not be operated for extended periods of time with the reactor water cleanup system out of service.

Limits on chloride concentration and pH in the reactor vessel water of BWRs that have been found acceptable to the NRC staff are presented in the appendix to this guide. Also presented in the appendix are representative limits for the electrical conductivity of the water at several other locations in the BWR water cycle.

C. REGULATORY POSITION

Condensate demineralizers in boiling water reactors should be designed and operated so as to permit an orderly shutdown of the reactor in case of serious leakage in the condenser or in other heat exchangers without contaminating the reactor coolant pressure boundary or core structural components with potentially harmful constituents of the condenser cooling water. Sufficient instrumentation should be provided so that (1) the electrical conductivity of the condensate is known, (2) the available capacity of the condensate demineralizers can be determined at all times, and (3) the conductivity of the reactor coolant water at the inlet and outlet of each demineralizer is

known. Additional protection to the pressure vessel and core structural components should be provided in the form of a functioning reactor water cleanup system and instrumentation to measure reactor water conductivity. An acceptable approach is as follows:

1. The licensee should establish appropriate limits for the electrical conductivity of purified condensate to the reactor vessel (the electrical conductivity of the BWR feedwater cycle and that of the reactor water cleanup cycle). Separate limits may be required for such operating conditions as startup, hot standby, low power, high power, and at temperatures $\leq 212^{\circ}\text{F}$ (100°C).

Chemical analyses for dissolved and suspended impurities should be performed as called for in the plant technical specifications. A conductivity meter should be provided at each condenser hotwell or in the line between the hotwell and the condensate demineralizer with sufficient range to measure at least all levels of conductivity up to and including the limiting conditions of the technical specifications that require immediate shutdown of the reactor. The recording conductivity meters recommended in regulatory position 4.a may be used for this purpose.

2. The licensee should establish the sequential resin regeneration frequency or resin replacement frequency required to maintain adequate capacity margin in the condensate treatment system for postulated condenser cooling water leakage. The capacity required and corresponding resin regeneration or replacement frequency will depend on several parameters, including condenser cooling water composition, chloride concentration, flow rate in each demineralizer unit, type and quantity of resin, cation/anion resin ratio, postulated condenser leakage, and time for orderly reactor shutdown.

3. The initial total capacity of the new anion and cation demineralizer resins should be measured. Anion exchange capacity may be determined by a procedure recommended by the resin manufacturer. The total exchange capacity of the cation resin may be measured by a procedure recommended by the resin manufacturer or by paragraphs 41 through 49 of ASTM D2187-71, "Standard Methods of Test of Physical and Chemical Properties of Ion-Exchange Resins."* For resins that are to be regenerated, these determinations should be repeated at least semiannually. The resins should be discarded and replaced when their capacity following regeneration falls below 60 percent of the initial value. More frequent determinations should be made at plants using seawater or other water containing large amounts of dissolved or suspended matter as coolant in their heat exchangers. For resins that are not regenerated but

are instead replaced periodically with material of the same type, measurements of initial capacity should be made on a sample of new material at least once a year (when the time between replacements is less than 1 year) or at each replacement (when the time between replacements exceeds 1 year). When the type of anion or cation resin is changed, a measurement of total capacity of the replacement resin should be made prior to use in the demineralizer.

4. The licensee should verify that the minimum residual demineralizer capacity in the most depleted demineralizer unit established in accordance with the recommendations of regulatory position 2 is maintained. The following is an example of an acceptable method for determining the condition of the demineralizer units so that the ion exchange resin can be replaced or regenerated before an unacceptable level of depletion is reached.

a. Recording conductivity meters should be installed at the inlet and outlet of both the condensate treatment system and reactor water cleanup system. The range of these instruments should be sufficient to measure all levels of potential water conductivity specified in the plant technical specifications. For the condensate treatment system, the conductivity meter readings should be calibrated so that estimates of condenser leakage can be made based on cooling water conductivity, condensate conductivity, and flow rate. The chemical composition of the cooling water and its relation to specific conductance should be established and periodically confirmed so that estimates of residual demineralizer capacity can be made.

b. A recording flowmeter should be used to measure the rate of flow through each demineralizer.

c. The quantity of the principal ion(s) likely to cause demineralizer breakthrough should be calculated by:

- (1) Converting the conductivity readings of the water entering the demineralizer to weight fraction (e.g., ppm or ppb) of the principal ion(s) and
- (2) Integrating over time the product of concentration of this ion(s) and demineralizer flow.

The input quantity of ion(s) to the demineralizers should be determined at a frequency adequate to ensure sufficient residual ion exchange capacity in the event of a major condenser leakage to prevent exceeding reactor coolant limits.

d. Each demineralizer unit should be replaced or regenerated when the remaining capacity (calculated by subtracting the total utilization determined from conductivity and flow measurements in accordance with regulatory position 4.c from the initial capacity

* Copies may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

determined in accordance with regulatory position 3) approaches the minimum residual demineralizer capacity determined in accordance with regulatory position 2. The accuracy of the above calculation should be checked by measurements made on resin samples taken when demineralizer units are removed from service for regeneration or resin cleaning. Measurements on samples from each unit should be made at each of the first two such removals from service and at every fifth such removal from service thereafter. If appropriate, the actual measurements may be used to adjust the calculated value of residual demineralizer capacity. Such adjustment and its justification should be reported to the NRC in the annual operating report.

5. The conductivity meter(s) located at the inlet and outlet of the demineralizer(s) of the condensate treatment system and the reactor water cleanup system should be set to trigger alarms in the control room when, as a minimum, either of the following conductivity levels is reached (values of which should be determined by the licensee):

a. The level that indicates marginal performance of the demineralizer systems.

b. The level that indicates noticeable breakthrough of one or more demineralizers.

6. The chloride content in the reactor vessel water should be maintained as low as practical. The ionic equilibria of the reactor vessel water should be con-

trolled to ensure a neutral pH. The licensee should establish limits for conductivity, pH, and chlorides in the reactor vessel water and should specify procedures to be used for their determination. Acceptable reactor water chemistry limits are given in Table 1 of the appendix to this guide. If the limiting values of the conductivity, pH, or chloride content are exceeded, appropriate corrective actions as defined in the plant technical specifications should be taken.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

With the exception of the commendation of regulatory position 4.a on additional conductivity meters as applied to operating plants, this guide reflects current NRC staff practice. Therefore, except in those cases in which the applicant or licensee proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein is being and will continue to be used in the evaluation of submittals in connection with operating license or construction permit applications until this guide is revised as a result of suggestions from the public or additional staff review. Regulatory position 4.a will be used in the evaluation of the performance of operating plant licensees on a case-by-case basis.

APPENDIX

The data presented in this appendix illustrate the water quality levels acceptable to the NRC staff for the BWR reactor vessel and condensate system. Table 1 provides conductivity, pH, and chloride limits for BWR reactor water during various plant operating conditions, including maximum acceptable levels for short durations and special conditions. The relationships among conductivity, pH, and chloride concentration in water at 77°F (25°C) are presented in Figure 2 of this appendix. (Reference "Chloride Con-

trol in BWR Coolants," General Electric Report NEDO-10899, 73NED59, Class 1, June 1973.) This relationship is acceptable in establishing appropriate conductivity/pH limits and alarm setpoints.

Table 2 provides conductivity limits for the condensate treatment system to ensure maintenance of reactor water quality limitations. The limits indicated establish action points for the corrective actions required to maintain reactor water quality limits.

142 284

TABLE 1
ACCEPTABLE REACTOR WATER CHEMISTRY LIMITS

PARAMETER	LIMIT	MAXIMUM LIMIT
<i>Specific Conductance at 77°F (25°C)</i>		
1. Power Operation Steaming rates greater than 1% of rated steamflow	1 $\mu\text{mho/cm}^a$	10 $\mu\text{mho/cm}^b$
2. Startup/Hot Standby and Power Operation Steaming rates less than 1% of rated steamflow	2 $\mu\text{mho/cm}^c$	--
3. Cold Shutdown Reactor is not pressurized [i.e., at or below 212°F (100°C)]		10 $\mu\text{mho/cm}$
<i>Chloride</i>		
1. Power Operation Steaming rates greater than 1% of rated steamflow	0.2 ppm ^a	0.5 ppm ^b
2. Startup/Hot Standby and Power Operation Steaming rates less than 1% of rated steamflow	0.1 ppm	--
3. Cold Shutdown Reactor is not pressurized [i.e., at or below 212°F (100°C)]		0.5 ppm
<i>pH at 77°F (25°C)</i>		
1. Steaming rates greater than 1% of rated steamflow	pH not less than 5.6 nor greater than 8.6 ^d	--
2. Reactor is not pressurized [i.e., at or below 212°F (100°C)]	pH not less than 5.3 nor greater than 8.6	

^a Time above 1 $\mu\text{mho/cm}$ at 77°F (25°C) and 0.2 ppm chloride not to exceed 72 hours for any single incident, but the total time for all incidents should not exceed 2 weeks per year. When the time limits are exceeded, an orderly shutdown should be initiated within 4 hours.

^b When the maximum conductivity or chloride concentration limits are exceeded, an orderly shutdown should be initiated immediately, and the reactor should be brought to the cold standby condition as rapidly as cooldown rate permits.

^c Time above 2 $\mu\text{mho/cm}$ at 77°F (25°C) and 0.1 ppm chloride not to exceed 48 hours for any single occurrence. When the time limits are exceeded, the reactor should be brought to the hot shutdown condition until the limits are restored.

^d The reactor should be shut down if pH is <5.6 or >8.6 for a period of 72 hours.

TABLE 2
ACCEPTABLE CONDUCTIVITY LIMIT OF CONDENSATE SYSTEM WATER
SPECIFIC CONDUCTANCE AT 77°F (25°C)
($\mu\text{mho/cm}$)

Location	Limit ^a	Maximum Limit ^b
<i>Condensate</i>		
Inlet to Demineralizer	0.5	10
<i>Treated Condensate</i>		
Combined Demineralizer Outlet	0.1	0.2
Individual Demineralizer Outlet	0.2	0.5

^a Indicating condenser leakage or marginal demineralizer performance requiring corrective action to be taken as defined in plant technical specifications.

^b Indicating orderly reactor shutdown and/or corrective actions to be taken immediately.

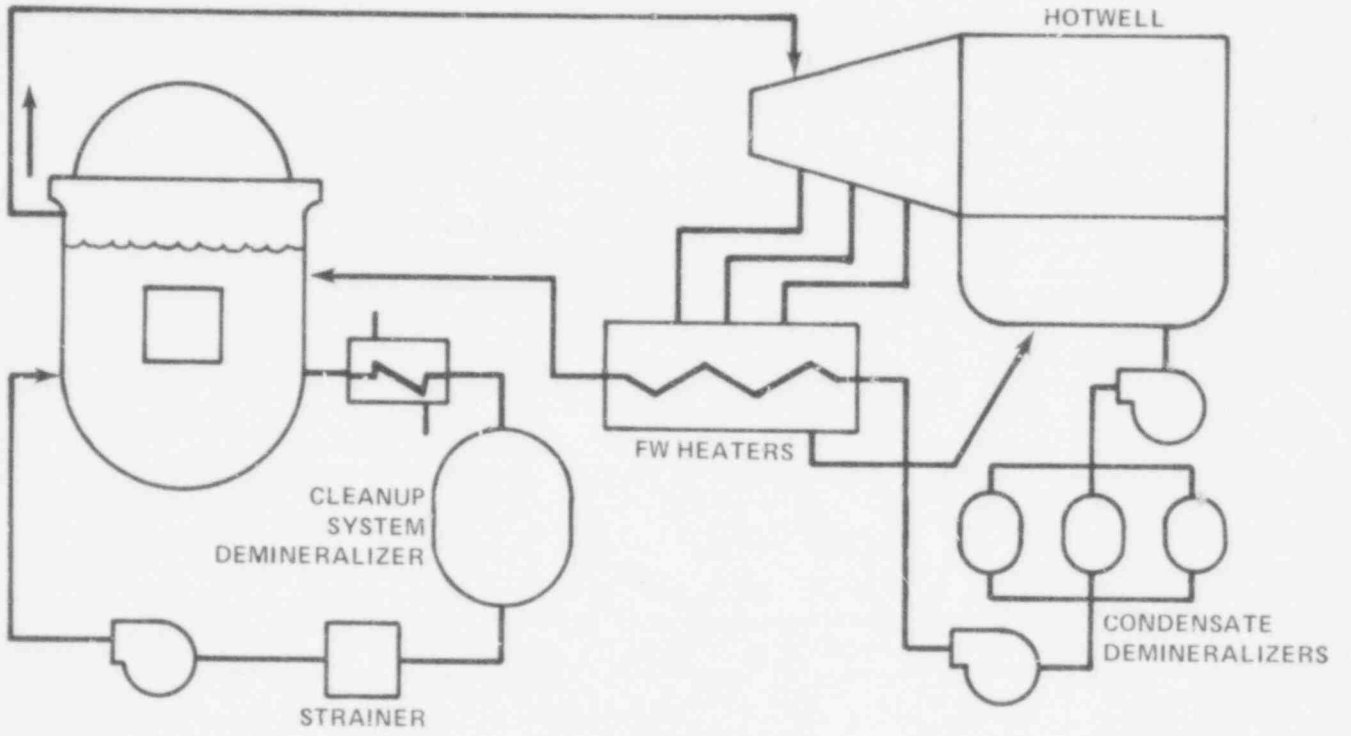


Figure 1
BWR WATER CYCLE

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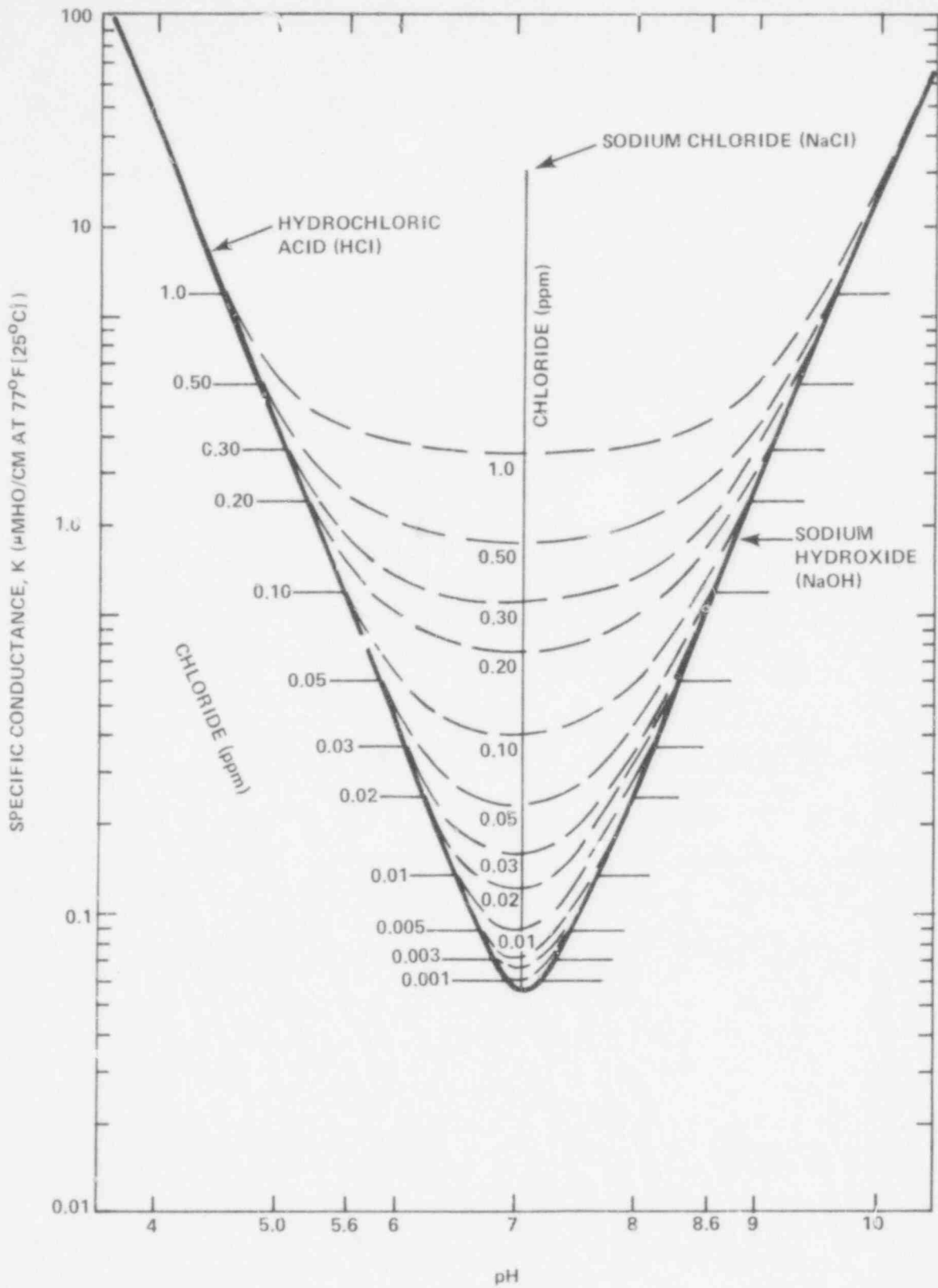


Figure 2
 CONDUCTIVITY, $\mu\text{MHO/CM}$ VS. CHLORIDE
 CONCENTRATION OF AQUEOUS SOLUTIONS
 AT 77°F (25°C)

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