

Westinghouse Non-Proprietary Class 3



WCAP-14542

Evaluation of the Radiological
Consequences from a
Loss of Coolant Accident at
Indian Point Nuclear
Generating Station Unit No. 2
Using NUREG-1465
Source Term Methodology

Westinghouse Energy Systems



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USING NUREG-1465 SOURCE TERM METHODOLOGY

JULY 1996

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CONTAINMENT AND RADIOLOGICAL ANALYSIS

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1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

The current FSAR analysis of the LBLOCA radiological consequences uses the TID-14844 ⁽¹⁾ source term methodology. In order to meet the 10 CFR 100 offsite dose guidelines, radioiodine concentrations in the containment atmosphere (and, thus, the activity releases to the environment) are reduced by containment sprays that are adjusted to a high pH by sodium hydroxide and by a containment atmosphere filtration system. With the application of the NUREG-1465 ⁽²⁾ source term methodology, alkaline sprays and containment filtration are no longer needed to meet the offsite and control room dose guidelines. To this end, representative design basis LBLOCA offsite and control room dose calculations were performed utilizing a source term based on NUREG-1465.

The spray additive tank (SAT), which contains the sodium hydroxide; the additive delivery system; the emergency filtration system charcoal absorbers, charcoal dousing system, and HEPA filters (ECFS); and the related testing and maintenance required by the Technical Specifications can all be eliminated. The handling of concentrated sodium hydroxide solution requires special precautions due to its hazardous nature and, with the removal of the SAT, this will no longer be a concern.

This report describes the analyses and evaluations that were performed to demonstrate that elimination of the SAT and ECFS from Indian Point Unit 2, in combination with implementation of the source term methodology from NUREG-1465, results in radiological consequences for a postulated design basis large-break LOCA that are within the defined dose guidelines. The results of the analysis include traditional thyroid and gamma-body doses due to releases of iodines and noble gases and the Total Effective Dose Equivalent (TEDE) dose due to a broad spectrum of fission products in keeping with the NUREG-1465 source term model.

1.2 Background

The Containment Spray System design for Indian Point Unit 2 (IP2) currently utilizes caustic containment spray (weak boric acid solution adjusted with sodium hydroxide to a pH of 8.5 to 10.5) to assure rapid removal of radioactive elemental iodine from the containment atmosphere following a postulated large break LOCA. The removal of airborne iodine is necessary to minimize its release to the environment due to containment leakage and thus assure that offsite doses are within the guidelines of 10 CFR 100.

The specification of an elevated containment spray pH for fission product control was based on the following assumptions:

- Gaseous elemental iodine is the dominant iodine chemical species released from the reactor core
- Elemental iodine removal capability of unadjusted boric acid spray is low (pH of 4.5 to 5)
- Elemental iodine removal capability of the spray increases with increasing pH

The inclusion of charcoal filters in the ECFS was based on the following assumptions:

- Organic iodine compounds, which are not readily removed by sprays, are present in the containment atmosphere in substantial quantity
- Uncertainty, at the time the plant was licensed, in the effectiveness of sprays in removing elemental iodine

During the past 30 years since IP2 was licensed, the results of many studies of iodine behavior in the post-LOCA containment environment have conclusively demonstrated that only a small fraction of the iodine is in the elemental form (most exists as cesium iodide in a particulate form), that the formation of organic iodine compounds is not significant, and that boric acid sprays are highly effective in removing both elemental and particulate iodine without requiring adjustment of the spray to alkaline conditions.

Removal of the spray additive does not eliminate the need to adjust the pH of the recirculating Emergency Core Cooling (ECC) solution. The long-term pH of the ECC solution should be no less than 7.0 to assure that iodine removed by sprays is retained in solution and minimize formation of organic iodine compounds, to prevent chloride-induced stress corrosion cracking of austenitic stainless steel components, and to minimize the hydrogen produced by the corrosion of galvanized surfaces and zinc-based paints. Since the initial pH of the boric acid ECC solution, without spray additive, will be approximately 4.5 to 5.0, a chemical additive must be utilized to raise the pH of the solution in the containment sump.

1.3 Limits of Application of the NUREG-1465 Source Term Methodology

Although the source term methodology from NUREG-1465 is being used to support the removal of spray additive and the emergency filtration system charcoal absorbers and HEPA filters, and is the basis for a revised calculation of offsite and control room doses for the postulated LOCA, the remaining plant features and analyses are not being revised as part of this report.

1.4 References

1. USAEC Technical Information Document, TID-14844, "Calculation of Distance Factors for Power and Test Reactors," March 1962.
2. "Accident Source Terms for Light-Water Nuclear Power Plants," USNRC NUREG-1465, Feb. 1995.

2.0 BENEFITS

Removal of the spray additive and the emergency filters will provide significant benefits to plant operations. The major benefits include simplification of plant design, elimination of hardware, elimination of Technical Specification requirements, and reduction in hazardous chemical exposure. Other benefits are summarized as follows:

1. **Reduction in Testing and Maintenance** - Removal of the additive will eliminate testing and maintenance of the eductors, additive tank discharge valves and associated instrumentation. Elimination of testing and maintenance reduces the operator exposure to sodium hydroxide. Indian Point Unit 2 will retain the eductors and associated spray additive system loop piping as a mini-flow line for the containment spray pumps. Additionally, removal of the charcoal and HEPA filters will provide a significant reduction in costs associated with testing and filter replacement.
2. **Elimination of Active Components** - When the additive tank is removed or decommissioned, the discharge valves will be either removed or locked closed.

Elimination of the charcoal and HEPA filters permits the elimination of ten EQ motor operator valves, two per each containment fan cooler, as well as the ability to remove or retire other active components, such as the butterfly valves, solenoid and limit switches, associated with operation of the charcoal and HEPA filters.

3. **Elimination of Refueling Water Contamination** - Spray additive system testing can result in sodium hydroxide contamination of the refueling water. This necessitates replacement of the spent fuel pool cleanup system ion exchange resins used to remove the sodium contamination. Eliminating the potential for this contamination eliminates the associated resin replacement, waste water processing costs, and radiation exposure.
4. **Elimination of Caustic Cleanup** - Inadvertent actuation of the containment spray system can result in time consuming containment cleanup and personnel radiation exposures. Removal of the hydroxide from the spray will reduce the cleanup effort and personnel exposure to both radiation and sodium hydroxide.

5. **Elimination of High pH environment - Elimination of the spray additive reduces the pH of the post-LOCA environment from a range of 8.5 -10.5 to a range of 7.0 - 9.5. Components qualified at the higher pH may have longer post-accident service life when subjected to a less caustic environment.**
6. **Elimination of Replacement Costs - Elimination of the additive subsystem and the filters will eliminate costs for replacement valves and instrumentation.**
7. **Flexible Spray Operation - Removal of the additive adds flexibility to the operation of the containment spray and emergency core cooling (ECC) systems. With the additive system, the spray injection phase is generally continued beyond the ECC injection phase in order that sufficient sodium hydroxide be added to the sump solution. Without spray additive, the duration of spray injection is not controlled by additive flow and pH restrictions.**
8. **Improved Mixing and Increased Heat Removal - Elimination of the charcoal and HEPA filters allows for a reduction in pressure drop in the containment fan cooler units thereby increasing air flow from 65,000 cfm to 72,000 cfm. This will allow approximately 500,000 BTU/hr additional cooling capability with the containment fan cooler units and permit better mixing within containment.**
9. **Elimination of Fire Hazard - Elimination of the charcoal filters will eliminate the fire hazard associated with the charcoal.**
10. **Reduction in Solid Waste Generation - Elimination of the charcoal and HEPA filters will provide a reduction in the amount of radiological waste shipping associated with the periodic disposal HEPA and charcoal filters.**

3.0 COMPARISON OF NUREG-1465 SOURCE TERM METHODOLOGY TO TID-14844

The reanalysis of LBLOCA offsite and control room doses for Indian Point Unit 2 uses the following NUREG-1465 source term characteristics in place of those identified in TID-14844:

- Iodine chemical species
- Fission product release timing
- Fission product release phases through early in-vessel
- Fission product release fractions
- Fission product groups

A comparison of NUREG-1465 to TID-14844 is provided below in tables 3-1 through 3-4.

Table 3-1

Iodine Chemical Species, %

	TID	NUREG
elemental	91	4.85
organic	4	0.15
particulate	5	95

Table 3-2

Fission Product Release Timing

Release Phase	Duration (TID-14844)	Duration (NUREG-1465) ⁽¹⁾
coolant activity	instantaneous release	10 to 30 sec.
gap activity	instantaneous release	0.5 hr
early in-vessel	instantaneous release	1.3 hr
ex-vessel	not defined ⁽²⁾	2 hr ⁽³⁾
late in-vessel	not defined ⁽²⁾	10 hr ⁽³⁾

- (1) Releases are sequential with the exception of the ex-vessel and the late in-vessel phases which both begin at the end of the early in-vessel release phase.
- (2) Ex-vessel and late in-vessel release not defined in TID-14844.
- (3) Per SECY-94-302 (Reference 1), ex-vessel and late in-vessel releases are not applicable to design basis analyses.

Table 3-3

Core Fission Product Release Fractions

	Gap Release ⁽¹⁾		Early In-Vessel	
	TID	NUREG	TID	NUREG
Noble gases	n/a ⁽²⁾	0.05 ⁽³⁾	1.0	0.95
Halogens	n/a ⁽²⁾	0.05 ⁽³⁾	0.5 ⁽⁴⁾	0.35
Alkali Metals	n/a	0.05 ⁽³⁾	0.01 ⁽⁵⁾	0.25
Tellurium group	n/a	0	0.01 ⁽⁵⁾	0.05
Barium, Strontium	n/a	0	0.01 ⁽⁵⁾	0.02
Noble Metals (Ruthenium group)	n/a	0	0.01 ⁽⁵⁾	0.0025
Cerium group	n/a	0	0.01 ⁽⁵⁾	0.0005
Lanthanides	n/a	0	0.01 ⁽⁵⁾	0.0002

- (1) The TID-14844 methodology does not specifically address the gap release. The NUREG-1465 methodology assumes that gap and early in-vessel (core melt) releases are sequential. Specifically, the TID-14844 source term model assumes the instantaneous release of 50% of core iodine, with no distinction made between gap activity release and early in-vessel release. The NUREG source term assumes a release of gap activity (5% of core) followed by 35% in-vessel release for a total release of 40% of core.
- (2) Gap fraction is not defined by TID-14844.
- (3) 3% immediate release followed by 2% over 0.5 hours
- (4) Per TID-14844, half of this is assumed to plate out instantaneously.
- (5) Referred to in TID-14844 as "other fission products" but not typically included in dose analyses.

Table 3-4**NUREG-1465 Nuclide Groups**

GROUP	TITLE	ELEMENTS IN GROUP
1	Noble Gases	Xe, Kr
2	Halogens	I, Br
3	Alkali Metals	Cs, Rb
4	Tellurium group	Te, Sb, Se
5	Barium, Strontium	Ba, Sr
6	Noble Metals	Ru, Rh, Pd, Mo, Tc, Co
7	Lanthanides	La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm, Am
8	Cerium group	Ce, Pu, Np

3.1 References - Section 3

1. SECY-94-302, "Source Term-Related Technical and Licensing Issues Pertaining to Evolutionary and Passive Light-Water-Reactor Designs," 12/19/94

4.0 PLANT SPECIFIC PARAMETERS AND ASSUMPTIONS

4.1 Reactor Coolant Activity

NUREG-1465 recommends releasing coolant activity within 10 to 30 seconds. In this analysis, coolant activity is assumed to be instantaneously released; i.e., it is modeled as initial containment activity. The coolant activity is set, somewhat arbitrarily, at 0.00002% of the core inventory.

4.2 Gap Activity

The total gap activity fraction is assumed to be 0.05 of the core. Three percent is assumed to be instantaneously released and the remaining 2% is assumed to be released over 0 to 30 min. The gap release applies to only noble gases, halogens (I and Br) and alkali metals (Cs and Rb). This modeling is consistent with NUREG-1465.

4.3 Core Activity

The core fission product activity was specifically calculated for IP2 with the ORIGEN II code. The resulting values are presented in Table 4-1.

4.4 Containment Parameters

4.4.1 Volume

The containment is modeled as 2 discrete volumes: sprayed and unsprayed. The volumes are conservatively assumed to be mixed only by the emergency fan coolers. The IP2 FSAR specifies a total containment volume of 2.61E6 cu ft and sprayed fraction of only 54 percent of the total. Other plants with containments of similar size have sprayed volumes in the range of about 70 to 85 percent. A more realistic value for the IP2 sprayed volume fraction is 0.80 or 2.09E6 cubic feet. Subtracting the sprayed volume from the total, the unsprayed volume is 5.2E5 cubic feet. This volume is assumed to apply during both the injection and the recirculation spray phases.

Table 4-1
Core Fission Product Activity

GROUP	NUCLIDE	ACTIVITY	GROUP	NUCLIDE	ACTIVITY	
Halogens	I-131	8.63E7 Ci	Lanthanides	Y-90	9.02E6 Ci	
	I-132	1.25E8		Y-91	1.07E8	
	I-133	1.76E8		Y-92	1.12E8	
	I-134	1.93E8		Y-93	1.29E8	
	I-135	1.65E8		Nb-95	1.46E8	
Noble Gases	Kr-85m	1.25E7		Zr-95	1.45E8	
	Kr-85	1.09E6		Zr-97	1.45E8	
	Kr-87	4.32E7		La-140	1.58E8	
	Kr-88	6.08E7		La-141	1.43E8	
	Xe-131m	9.63E5		La-142	1.38E8	
	Xe-133m	5.46E6		Nd-147	5.75E7	
	Xe-133	1.73E8		Pr-143	1.30E8	
	Xe-135m	3.45E7		Am-241	1.53E4	
	Xe-135	4.27E7		Cm-242	4.41E6	
	Xe-138	1.45E8		Cm-244	3.97E5	
Tellurium	Te-127	9.14E6		Cerium	Ce-141	1.44E8
	Te-127m	1.21E6			Ce-143	1.33E8
	Te-129m	4.06E6			Ce-144	1.13E8
	Te-129	2.73E7			Pu-238	3.47E5
	Te-131m	1.25E7	Pu-239		2.97E4	
	Te-132	1.23E8	Pu-240		4.56E4	
	Sb-127	9.23E6	Pu-241		1.24E7	
	Sb-129	2.77E7	Np-239		1.67E9	
Barium, Strontium	Sr-89	8.25E7	Noble Metals		Ru-103	1.33E8
	Sr-90	8.63E6		Ru-105	9.13E7	
	Sr-91	1.03E8		Ru-106	4.84E7	
	Sr-92	1.11E8		Rh-105	8.40E7	
	Ba-139	1.57E8		Mo-99	1.58E8	
	Ba-140	1.51E8		Tc-99m	1.38E8	
Alkali Metals	Cs-134	1.95E7				
	Cs-136	5.00E6				
	Cs-137	1.19E7				
	Rb-86	2.04E5				

4.4.2 Leak Rate

0-24 hours	0.1% / day
>24 hours	0.05% / day

The value of 0.05% /day shown above is consistent with Regulatory Guide 1.4 which specifies a long term leak rate equal to one half the initial rate.

4.4.3 Spray System

Table 4-2 lists the containment spray flow rates and durations which were assumed in the analysis. As shown below, two cases were modeled to evaluate a reduction in the duration of the injection spray. The results of each evaluation are included in Section 6.3.

Sprays are modeled without sodium hydroxide additive. The pH of the sump solution is assumed to be raised into the range of 7 to 9.5 by dissolution of trisodium phosphate ($\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$) stored in baskets located inside containment.

Table 4-2

Containment Spray Flow Rates

Description	flow rate, gpm	Duration	
		Case 1	Case 2
spray start delay	0	80 sec	80 sec
injection spray	2200	50 min	20 min
switchover to recirculation, spray stopped	n/a	0	0
recirculation spray	1300	to 24 hours	to 24 hours
recirc. spray stopped to establish hotleg switchover	0	10 min	10 min
restart recirculation spray	1300	indefinite	indefinite

4.4.4 Fan Coolers

Cooler start delay - 35 sec.

Flow rate - 3 units operating - 72,000 cfm per unit - 216,000 cfm total

No charcoal or HEPA filters are assumed.

4.5 Control Room (pressurized control room operation)

Volume - 102,400 ft³

Intake air flow rate - 1400 cfm

Recirculation air flow rate - 600 cfm

Filter efficiencies (for intake and recirculation)

Elemental iodine	95%
------------------	-----

Organic iodine	90%
----------------	-----

Particulates	99%
--------------	-----

Unfiltered inleakage - 30 cfm

4.6 Atmospheric Dispersion Factors

Site Boundary (0 - 2 hours) $7.5 \times 10^{-4} \text{ sec/m}^3$

Low Population Zone Outer Boundary

0 - 8 hours	$3.5 \times 10^{-4} \text{ sec/m}^3$
-------------	--------------------------------------

8 - 24 hours	$1.2 \times 10^{-4} \text{ sec/m}^3$
--------------	--------------------------------------

24 - 96 hours	$4.2 \times 10^{-5} \text{ sec/m}^3$
---------------	--------------------------------------

96 - 720 hours	$9.3 \times 10^{-6} \text{ sec/m}^3$
----------------	--------------------------------------

Control Room

0 - 2 hours	$2.3 \times 10^{-3} \text{ sec/m}^3$
-------------	--------------------------------------

2 - 24 hours	$1.15 \times 10^{-3} \text{ sec/m}^3$
--------------	---------------------------------------

24 - 720 hours	$5.5 \times 10^{-4} \text{ sec/m}^3$
----------------	--------------------------------------

5.0 ACTIVITY REMOVAL COEFFICIENTS AND DECONTAMINATION FACTORS

Other than the noble gases, the activity released to the containment due to a large break LOCA is primarily in the form of particulates. A small fraction of the iodine is assumed to be in the elemental form and an even smaller fraction of the iodine is assumed to be in the organic form. The particulates and the elemental iodine are removed from the containment atmosphere by the action of the containment sprays and by deposition (although no credit is taken in this analysis for deposition removal processes). The organic form of iodine is not easily removed from the atmosphere and is assumed to be removed only by radioactive decay.

5.1 Elemental Iodine Removal by Spray

The current FSAR analysis takes credit for spray removal of elemental iodine assuming enhanced spray removal effectiveness due to the alkaline nature of the spray. With the deletion of spray additive, the spray will not be alkaline but will have a pH of about 4.5.

Although it has been generally held in the past that the iodine removal capability of boric acid spray is very low (Reference 1), a number of spray experiments using either service water or standard grade boric acid solution (containing trace levels of impurities) have shown elemental iodine removal rates comparable to those observed for sprays with either sodium hydroxide or sodium thiosulfate added to bring the spray pH to approximately 9 (References 2,3,4,5). The results of these experiments indicate that the iodine removal rate for sprays is sensitive to both iodine concentration and pH, and that concentration is the more influential parameter.

Reference 5 investigated the effects of both pH and gas phase iodine concentration on the gas-liquid partition coefficient for iodine. The partition coefficient was found to be controlled by iodine concentration rather than by pH and, "the washout removal rate for iodine by city water spray is higher than those predicted from the partition rule due to some impurities in the water" (Reference 5). The results of these experiments are presented in Figure 5-1 which is taken directly from Reference 5.

The PSICO 10 experiments (Reference 4) indicate that, "The elemental iodine removal half-times obtained by spraying service water do not differ greatly from those found by spraying thiosulfate solution." Additionally, the results of the NSPP spray program (Reference 3) indicate that, "boric acid is much more effective than expected".

A review of the CSE (Reference 2) and PSICO data by Brookhaven (Reference 6) indicates that, " ... when the spray solution is fresh, all solutions appeared to effectively reduce the airborne iodine concentration, regardless of the presence or absence of an active spray additive". The reports further indicate that, "when spray solution is fresh, the removal of iodine from the containment atmosphere is dominated by gas phase mass transport and is effectively independent of the equilibrium iodine partition coefficient of the solution, and primarily controlled by the amount of available surface to which iodine may be transported".

The current Standard Review Plan (Reference 7) identifies a methodology for the determination of spray removal of elemental iodine independent of the use of spray additive. The removal rate constant is determined by:

$$\lambda_s = \frac{6K_g TF}{VD}$$

where λ_s = Removal rate constant due to spray removal, hr^{-1}

K_g = Gas phase mass transfer coefficient, ft/min

T = Time of fall of the spray drops, min

F = Volume flow rate of sprays, ft^3/hr

V = Containment sprayed volume, ft^3 (Reference 7 specifies that the full containment volume be used but this is not justified)

D = Mass-mean diameter of the spray drops, ft

Parameters for IP2 are:

K_g = 9.84 ft/min

T = 0.178 min

F = 17,648 ft^3/hr (2200 gpm - spray injection phase)

V = $2.09 \times 10^6 \text{ ft}^3$

D = $3.94 \times 10^{-3} \text{ ft}$

With these parameters the spray removal rate is calculated to be 22.5 hr^{-1} which is reduced to 20 hr^{-1} since this is the upper limit specified by this model.

When sprays are operating in the recirculation phase, the spray flow is only 1300 gpm and the spray removal rate is 13.3 hr^{-1} .

5.2 Particulate Removal by Spray

The current FSAR analysis does not include modeling of particulate removal. With implementation of the NUREG-1465 source term, particulates are the most significant portion of the activity in the containment atmosphere. Particulate spray removal is determined using the model described in Reference 7.

The first order spray removal rate constant for particulates may be written as follows:

$$\lambda_p = \frac{3hFE}{2Vd}$$

where

- h = Drop Fall Height
- F = Spray Flow Rate
- V = Volume Sprayed
- E = Single Drop Collection Efficiency
- d = Drop Diameter

Values for h, F, and V are:

- h = 118.5 ft
- F = 17,648 ft³/hr (2200 gpm - injection phase)
- V = 2.09 x 10⁶ ft³

The E/d term depends upon the particle size distribution and spray drop size. The lower bound for particle washout by sprays is derived from the Containment Systems Experiment (CSE) cesium washout tests (References 2 and 8). The following E/d values were estimated by Postma (Reference 9) from the CSE data.

$$\frac{E}{d} = 0.1 \text{ cm}^{-1} \text{ for } C_o/C_t \leq 100$$

$$\frac{E}{d} = 0.01 \text{ cm}^{-1} \text{ for } C_o/C_t > 100$$

where C_o/C_t = Ratio of the initial aerosol concentration to the concentration at time t (this is also referred to as the decontamination factor or DF)

The model presented in Reference 7, conservatively uses

$$\frac{E}{d} = 0.1 \text{ cm}^{-1} \text{ for } C_o/C_t \leq 50$$

$$\frac{E}{d} = 0.01 \text{ cm}^{-1} \text{ for } C_o/C_t > 50$$

Using the Reference 7 model, the particulate removal constant for the spray injection phase is determined to be:

$$\lambda_p = 4.6 \text{ hr}^{-1} \text{ for } C_o/C_t \leq 50$$

For operation in the recirculation spray mode (spray flow of 1300 gpm) the particulate removal constant is:

$$\lambda_p = 2.7 \text{ hr}^{-1} \text{ for } C_o/C_t \leq 50$$

and:

$$\lambda_p = 0.27 \text{ hr}^{-1} \text{ for } C_o/C_t > 50$$

With the NUREG-1465 source term methodology, there is not an initial concentration defined. In determining the decontamination factor (C_o/C_t), C_o is assumed to be the total inventory that is released to the containment atmosphere over the duration of gap and in-vessel release phases.

5.3 Iodine Retention in Sump

The elemental iodine decontamination factor (DF) described below is a measure of the loading capacity of the sump solution. The DF can be expressed in terms of the containment liquid and gas volumes and the iodine partition coefficient.

$$DF = 1 + \frac{V_s (IPC)}{V_c}$$

where DF = Ratio of the total iodine in the sump liquid and containment atmosphere to that in the containment atmosphere.

IPC = Equilibrium iodine partition coefficient (see Figure 5-2 which is taken from Reference 10)

V_s = Volume of liquid in containment sump and sump overflow
(5.34×10^4 ft³ used for this analysis)

V_c = Containment net free volume less V_s
(2.56×10^6 ft³ used for this analysis)

Lin (Reference 11) observed that the radiolytic I_2 yield decreased substantially with pH above 4 and showed little additional decrease for pH greater than approximately 6.5 (see Figure 5-3 taken from Lin). Beahm (Reference 12) observed that the radiolytic conversion of I^- to I_2 is more than a factor of 100 greater at pH 3 than at pH 6. Thus, radiolytic production of volatile iodine is minimized at pH 6.5.

As discussed in Section 7.2.1, an equilibrium sump solution pH of ≥ 7.0 is required to assure resistance to chloride induced stress corrosion cracking of stainless steel. The NRC has also specified a pH of ≥ 7.0 to assure continued retention of iodine in solution (Reference 7). Based on a pH of 7.0, a value of about 15,000 for the short term (1000 seconds) IPC is seen to be appropriate from Figure 5-2. The longer term (say 1 hour) IPC corresponding to a pH of 7.0 would be much greater; over 50,000 (from Figure 5-2).

Utilizing the above values for the Indian Point 2 and an IPC of 10,000 for conservatism, the DF is calculated to be 210. Consistent with Reference 7, the DF is assumed to be limited to no more than 200. With a DF of 200 the sump solution has the capacity to retain 99.5 percent of the elemental iodine released to the containment.

5.4 References - Section 5

1. "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", NUREG-0800, Section 6.5.2, Rev. 1.
2. Halyard, R. K., et al., "Removal of Iodine and Particles from Containment Atmospheres by Sprays - Containment Systems Experiment Interim Report", BNWL-1244, February 1970.
3. Parsly, L. F., "Spray Program at the Nuclear Safety Pilot Plant", Nuclear Technology, Vol. 10, April 1971.
4. Barsali, L., et al., "Removal of Iodine by Sprays in the PSICO 10 Model Containment Vessel", Nuclear Technology, Vol 23, 1974.

5. Nishizawa, Y., et al., "Removal of Iodine From Atmosphere by Sprays", Nuclear Technology, Vol 10, April 1971.
6. Davis, R. E., Nourbakhsh, H. P., and Khatib - Rahbar, M., "Fission Product Removal Effectiveness of Chemical Additives in PWR Containment Sprays", Brookhaven National Laboratory, Technical Report A-3788, August 12, 1986.
7. "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", NUREG-0800, Section 6.5.2, Rev. 2, December 1988.
8. Halyard, R. K., and Postma, A. K., "The Effect of Spray Flow Rate on the Washout of Gases and Particulates in the Containment Systems Experiment", BNWL-1591, 1971.
9. Postma, A. K., et al, "Technological Bases for Models of Spray Washout of Airborne Contaminants in Containment Vessels", NUREG/CR-0009, October 1978.
10. Bell, J. T., Lietzke, M. H., and Palmer, D. A., "Predicted Rates of Formation of Iodine Hydrolysis Species at pH Levels, Concentrations, and Temperatures Anticipated in LWR Accidents", NUREG/CR-2900, November 1982.
11. Lin, C. C., "Chemical Effects of Gamma Radiation in Aqueous Solutions", Journal of Inorganic Nuclear Chemistry 42, pp 1101-1107, 1980.
12. Beahm, E. C., et al, "Chemistry and Transport of Iodine in Containment", NUREG/CR-4697, October 1986.

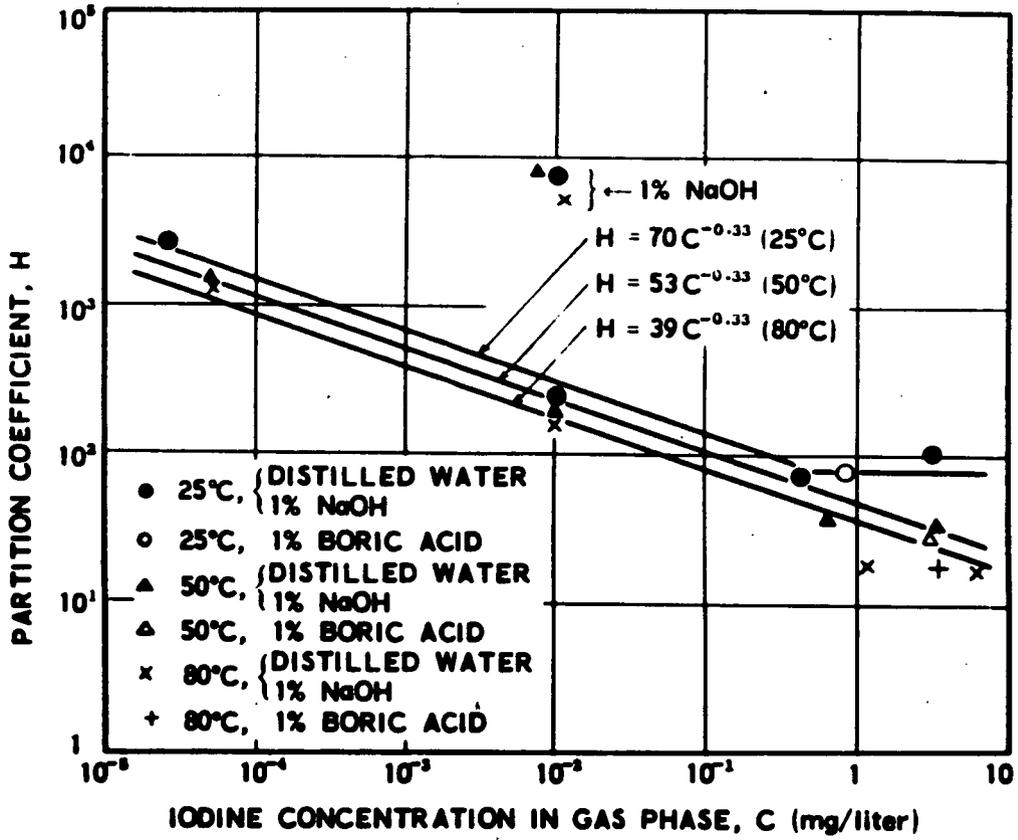


Figure 5-1. Partition coefficient vs Iodine Concentration in Gas Phase (Ref 5)

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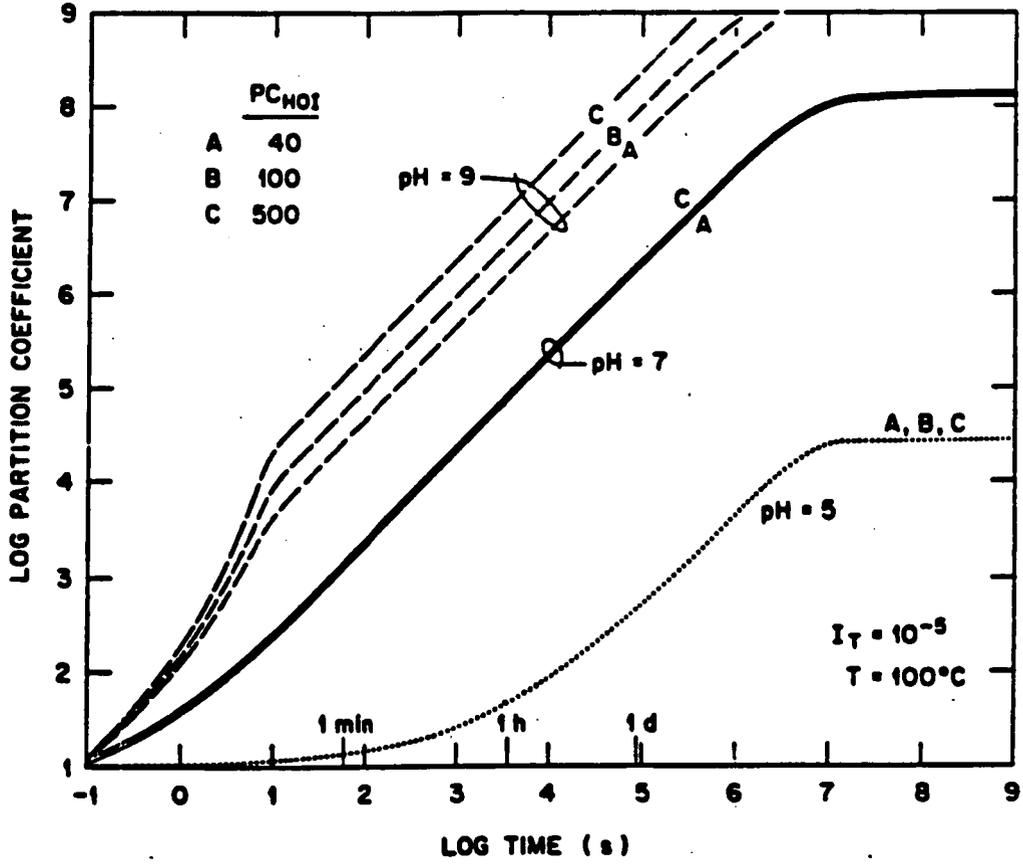


Figure 5-2. Equilibrium Iodine Partition Coefficient (Ref 10)

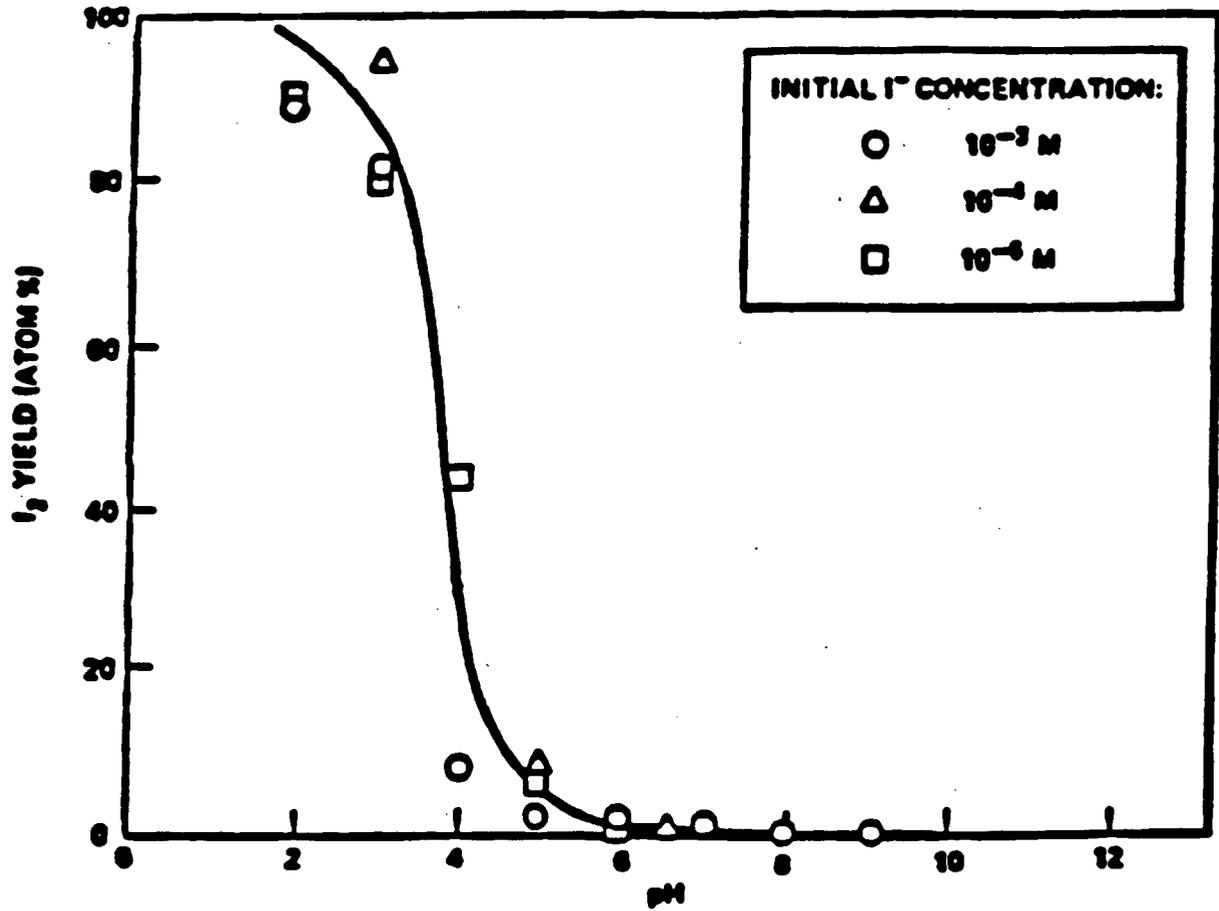


Figure 5-3. The Effect of pH on the I₂ Yield In an Irradiated Solution (Ref 11)

6.0 RADIOLOGICAL CONSEQUENCES

With the revised source term, the deletion of containment atmosphere filtration post-accident, and the deletion of additive from the containment spray solution, the potential doses due to containment leakage during a postulated Loss-of-Coolant Accident (LOCA) need to be recalculated.

6.1 LOCA Doses Currently Reported in the FSAR

The LOCA doses currently in the Indian Point 2 FSAR were determined with spray additive to enhance the spray removal of elemental iodine and with credit for charcoal filters on the fan cooler units. The FSAR thyroid doses are

Site Boundary 116 rem

LPZ Boundary 248 rem

These doses are based on the following assumptions:

Iodine form - 90% elemental, 10% organic, 0% particulate

Elemental iodine spray removal coefficient - 32 hr^{-1}

Elemental iodine filter removal coefficient - no credit taken

Organic iodine filter removal coefficient - 0.028 hr^{-1} (equivalent to 3 fan coolers operating, each with 8000 cfm flow through the charcoal filter and 5% filter efficiency)

Thyroid dose conversion factors are those from TID-14844 (Reference 1)

6.2 LOCA Doses Reported by the NRC in the Safety Evaluation Report

The staff's analysis of the LOCA used the following assumptions that differed from the FSAR analyses:

Iodine form - 85% elemental, 10% organic, 5% particulate

Elemental iodine spray removal coefficient - 4.5 hr^{-1}

Elemental iodine filter removal coefficient - 0.49 hr^{-1} (equivalent to 3 fan coolers operating, each with 8000 cfm flow through the charcoal filter and 90% filter efficiency)

Organic iodine filter removal coefficient - 0.048 hr^{-1} (equivalent to 3 fan coolers operating, each with 8000 cfm flow through the charcoal filter and 9% filter efficiency)

Particulate iodine filter removal coefficient - 4.4 hr^{-1} (value not stated in the SER but derived based on 3 fan coolers operating, each with 65,000 cfm flow through a HEPA filter having 99% removal efficiency)

Using these assumptions the SER reports a Site Boundary dose of 180 rem thyroid and a Low Population Zone boundary dose of 270 rem thyroid.

6.3 LOCA Doses with NUREG-1465 Source Term Methodology and Removal of Spray Additive and In-Containment Filters

The analytical assumptions associated with the subject changes are significantly different than those currently assumed in the FSAR or the SER. The NUREG-1465 source term methodology is discussed in Section 3. The activity removal coefficients associated with the design changes to remove spray additive and filtration of the containment atmosphere post-LOCA are discussed in Section 5. The major changes in the analytical assumptions are listed below:

- Reduction in Organic Iodine - The implementation of the NUREG-1465 source term model results in a iodine existing primarily as cesium iodide aerosol with a small fraction of iodine in the elemental form and a very small fraction in the organic form. The very low level of organic iodine (0.15% instead of the 10% previously assumed) means that 99.85% of the iodine is subject to removal by the sprays.
- Increase in Particulate Iodine - With 95% of the iodine as aerosol there is a reduction in the rate that sprays can remove airborne activity. As demonstrated in Section 5, the ability of sprays to remove aerosols is lower than their ability to remove elemental iodine.

- Gradual Release of Activity from the Core to the Containment Atmosphere - The NUREG-1465 source term model has core activity released over a 1.8 hour time period instead of instantaneously being released to the containment. This reduces the peak containment activity concentration since the sprays and radioactive decay can act to remove inventory before all of the activity is released from the core. It also results in extending the period of time over which there is an elevated level of activity in the containment atmosphere because there is a production term as well as a removal term.
- Plateout of iodine - The current FSAR and SER analyses assume instantaneous plateout of 50% of the iodine released from the core. With the gradual release of activity from the core this is no longer assumed. While deposition removal of elemental iodine and particulates would occur, no credit is being taken in the IP2 analysis.
- Elimination of Containment Atmosphere Filtration Post-LOCA - With the removal of the filters the ability to remove organic iodine from the atmosphere is eliminated; however, since there is such a small fraction in the organic form, this is not significant. There is also no filtration removal of elemental and particulate forms of iodine but removal of these forms of iodine is readily accomplished by the containment sprays.
- Elimination of Spray Additive - The spray additive had been used to justify a high rate of removal of elemental iodine by the sprays. Not only is there less elemental iodine with the NUREG-1465 model (4.85% instead of the 85 to 90% previously assumed) but the spray removal model defined in Section 6.5.2 of the SRP (Reference 2) determines a high removal rate for elemental iodine without adjusting the sprays to alkaline conditions (See Section 5.1).
- Thyroid Dose Conversion Factors - The thyroid dose conversion factors (DCFs) from ICRP Publication 30 (Reference 3) are used instead of those from TID-14844 (Reference 1). The TID-14844 DCFs have been superseded by those in Reference 3.

Some of the changes in analytical assumptions will tend to decrease doses and others tend to increase them. Addendum A to this report provides the results of a benchmark study. This study was performed using the revised source term methodology and removal of the spray additive while retaining filtration through the containment fan coolers. This provides a direct means of measuring the removal the charcoal and HEPA filters from the containment fan

cooler units on the radiological consequences.

As discussed in section 4.4.3, two cases were modeled to evaluate a reduction in the duration of the injection spray. Case 2, with a 20 minute duration of the injection spray, resulted in slightly higher offsite and control room radiological doses; however, in both cases the doses were within acceptable guideline limits. The overall results of the dose analysis using the revised source term and the removal of spray additive and post-accident filtration are shown below for each case.

CASE 1 (Injection spray duration of 50 minutes)

Site Boundary Doses

Thyroid	211 rem
Gamma Body	1.9 rem

LPZ boundary Doses

Thyroid	140 rem
Gamma Body	2.6 rem

Control Room (pressurized control room operation)

Thyroid	23 rem
Gamma Body	0.4 rem
Beta skin	15 rem

CASE 2 (Injection spray duration of 20 minutes)

Site Boundary Doses

Thyroid	224 rem
Gamma Body	1.9 rem

LPZ boundary Doses

Thyroid	147 rem
Gamma Body	2.7 rem

Control Room (pressurized control room operation)

Thyroid	24 rem
Gamma Body	0.4 rem
Beta skin	15 rem

The offsite doses are below the 10 CFR Part 100 dose guideline values of 300 rem thyroid and 25 rem gamma body. The control room doses are within the dose guideline values in Section 6.4 of the SRP (Reference 4) of 30 rem thyroid, 5 rem gamma body, and 30 rem beta skin.

The source term methodology of NUREG-1465 includes significant releases of other nuclide groups in addition to iodines and noble gases. The Total Effective Dose Equivalent (TEDE) dose approach is used to evaluate the dose impact of the full spectrum of nuclides. The TEDE doses for each case are:

	CASE 1	CASE 2
Site Boundary	12.7 rem	13.4 rem
LPZ Boundary	9.9 rem	10.2 rem
Control Room	1.5 rem	1.5 rem

The offsite doses are below 25 rem which is the currently proposed dose limit for TEDE doses (Reference 5). The Control Room dose is well below the 5 rem limit specified in GDC 19 (10 CFR Part 50, Appendix A) for dose to the whole body or its equivalent to any part of the body.

6.4 References - Section 6

1. "Calculation of Distance Factors for Power and Test Reactor Sites," TID-14844, March 1962.
2. "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", NUREG-0800, Section 6.5.2, Revision 2, December 1988.
3. International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," ICRP Publication 30, Supplement to Part 1, 1979
4. "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", NUREG-0800, Section 6.4, Revision 2, July 1981.
5. SECY-94-194, "Proposed Revisions to 10 CFR Part 100 and 10 CFR Part 50, and New Appendix S to 10 CFR Part 50," 7/27/94

7.0 EFFECTS ON HYDROGEN GENERATION AND EQUIPMENT QUALIFICATION

7.1 Hydrogen Production due to Aluminum and Zinc Corrosion

Following a large-break LOCA, hydrogen will be produced by the reaction of the zircaloy fuel clad and steam, by radiolytic decomposition of the core cooling solution and by the corrosion of aluminum and zinc metals and zinc bearing primers. Figure 7-1 shows the relative hydrogen contribution due to the various sources for Indian Point Nuclear Generating Station No. 2. Of these hydrogen sources, only aluminum and zinc corrosion will be affected by spray additive elimination.

The corrosion rates of aluminum and zinc are pH dependent. Elimination of the spray additive decreases the pH of the injection sprays from a maximum of 11 to approximately 4.5. The addition of caustic to raise the equilibrium pH to ≥ 7.0 is necessary to support retention of iodine in the water (see Section 5.4) and to prevent chloride induced stress corrosion cracking of stainless steel (Section 7.2.1). This pH of 7.0 is a decrease from the current minimum equilibrium pH of 8.2 that is reported in the FSAR for the recirculating solution. A discussion of aluminum and zinc corrosion, relative to additive elimination, follows.

7.1.1 Aluminum Corrosion

The corrosion rate of aluminum decreases monotonically with decreasing pH (Reference 1). Aluminum corrosion versus pH (taken from Reference 1) is presented in Figure 7-2. Corrosion in solutions with pH in the range of 4 to 5 appears to be insignificant. Thus, the reduction in injection spray pH and in equilibrium sump solution pH would have the effect of reducing the rate of hydrogen production due to aluminum corrosion.

7.1.2 Zinc (Galvanized Steel) Corrosion

The corrosion of zinc is a function of pH and temperature, with temperature being the more influential parameter. The hydrogen production rate constant can be predicted with the following equation (Reference 2):

$$k = \exp(-8.07 - 2.84 X_3 - 0.229 X_1 X_3 - 0.177 X_1 X_2 X_3)$$

where:

$$X_1 = (\text{pH}-7)/3; \text{ for } 4 \leq \text{pH} \leq 10$$

$$X_2 = (\text{ppm Boron} - 3000)/1000; \text{ for } 2000 \leq \text{ppm B} \leq 4000$$

$$X_3 = [(1/T) - 0.0027]/0.0004$$

T = Absolute Temperature

and k = scm/m² - hr

The rate constants for the spray injection period (approximately 250-300°F) were evaluated with spray additive (pH 10, 2100 ppm B) and without spray additive (pH 5, 2100 ppm B). The results of this evaluation are presented in Figure 7-3. Although the graph shows a 10 percent rate decrease at 300°F and approximately an 8 percent increase at 150°F, only the high temperature portion is applicable to the spray injection period.

The rate constants for the spray recirculation period (approximately 150-250°F) were also evaluated. The rate constants with spray additive (pH 7.5 to 9.5, 2100 ppm B) and without additive (assumes solution pH will be raised into the range of 7-9.5) are presented in Figure 7-4. A maximum rate increase of 4 percent occurs at 150°F.

7.1.3 Zinc Enriched Paint Corrosion

The corrosion of zinc based paints, like galvanized steel, is a strong function of temperature and exhibits little pH effect. Hydrogen production rates, for zinc paint corrosion, were obtained from a recent Sandia study (Reference 3).

Using a standard multiple regression technique, the following equation was developed to fit the "vapor/spray" test data:

$$k = \exp (-11.6738 + X_1 + X_2)$$

where:

$$X_1 = (4.1497 \times 10^{-2}) T; \quad \text{for } 200 \leq T^{\circ}\text{C} \leq 350$$

$$X_2 = (3.6345 \times 10^{-3}) \text{pH}; \quad \text{for } 7 \leq \text{pH} \leq 9$$

Note that, because of data limitations, the pH range is restricted. The results of this evaluation are presented in Figure 7-5.

The maximum rate variation, over the specified pH range, is less than 1 percent.

In acidic solutions, zinc based paint is expected to exhibit the same low temperature rate increase/high temperature rate decrease that was observed for galvanized steel.

7.1.4 Hydrogen Production - Conclusion

Elimination of the spray additive will have little net effect on hydrogen generation due to the corrosion of aluminum and zinc in the post-LOCA containment environment. Changes to the present hardware or to the current hydrogen generation analysis are not necessary for the purposes of this study.

7.2 Equipment Protection

7.2.1 Protection of Stainless Steel

To minimize the occurrence of chloride induced stress corrosion cracking (CISCC), Branch Technical Position MTEB 6-1 (Reference 4) recommends that the minimum pH of the sump solution should be 7 and that the higher the pH, in the range of 7 to 9.5, the greater the assurance that no stress corrosion cracking will occur. This recommendation is based primarily on the results of Westinghouse tests (Reference 5) which showed that at pH 7, 100 ppm Cl, sensitized and nonsensitized samples of 304 stainless steel cracked in approximately 7.5 and 10 months, respectively.

Westinghouse corrosion tests (Reference 5) indicate that the minimum time to crack (100% crack, 304 SS welded single U bend) in a pH 4.5, 100 ppm Cl solution is 3 days. No cracking of any of the test materials was observed before 8 hours. Thus, crack initiation occurred between 8 hours and three days.

The pH adjustment must occur prior to the initiation of cracking. Hence, based on the Westinghouse results, it is necessary that the pH of the sump solution be raised into the caustic range within 8 hours.

It is important to note that chlorides are not expected to instantaneously appear in solution in

concentrations sufficient to initiate cracking. The initial spray and safety injection solution is drawn from the refueling water storage tank where the chloride concentration is limited to 0.15 ppm. The spray injection phase lasts for 20 to 50 minutes. The Westinghouse tests (Reference 5) indicate that crack initiation in boric acid with 0.4 ppm chloride and pH of approximately 4 requires extended exposure times (12 months in one example). Hence, cracking will not occur during spray and safety injection. It is only during recirculation operation that potentially contaminated core cooling solution will contact vital equipment.

As the solution washes over the containment structures and components, chlorides and other contaminants will be removed from the surfaces and dissolved in-solution. Concrete, which is a significant potential chloride source, is painted with a nuclear qualified coating which is expected to greatly impede chloride leaching. To provide perspective, approximately 600 pounds of salt (NaCl) would have to be leached for a 100 ppm Cl concentration. Thus, it appears that the time to reach a 100 ppm chloride concentration may be days rather than hours.

Despite the expectation that buildup of chloride concentration to a critical level would require an extended time period, it is recommended that the pH of the sump solution be adjusted to ≥ 7.0 within 8 hours of the accident initiation. Based on the above discussion, 8 hours is considered a conservatively short time period in which to make the adjustment. The time required to adjust sump solution pH using TSP is far less than 8 hours (see Section 8.2).

7.2.2 Protection of Electrical Components

Safety related electrical equipment is tested to confirm the ability of the seals to exclude the containment environment from the interior of the component. To maximize the challenge to seal materials, high pH sprays (pH 8 to 11) and temperature (250 to 300°F) and extended time periods (approximately 1 year) have traditionally been used as the basis for testing to simulate the post-LOCA containment environment. As such, materials qualified for long term exposure at high pH will not be adversely affected by short term exposure to low pH solution. The ingress of chemical spray and/or steam (which will condense), regardless of the chemical composition, will result in electrical shorting and subsequent failure of the component to perform its safety related function.

Following a LOCA, equipment and surfaces within the containment will initially be covered with boric acid spray solution of pH in the range of approximately 8.5 to 10.5, or spilled reactor coolant of pH in the range of approximately 6 to 9, depending on the concentration of boron

and lithium hydroxide in the coolant. With the elimination of the sodium hydroxide spray additive, the pH of the containment spray solution (weak boric acid solution from the RWST with ≥ 2000 ppm boron) is reduced to approximately 4.5. Equipment in-containment will be exposed to this low pH solution for less than one hour, during the spray injection phase. During this time, trisodium phosphate (TSP), stored in baskets located in-containment, will begin to dissolve and raise the pH of the recirculating core cooling solution into the range of 7.0 to 8.0 (see Section 8.2 for discussion of TSP dissolution time). Spraying of recirculated fluid is anticipated to continue for an extended period of time. Thus, all surfaces will eventually be resprayed with alkaline solution. It is important to note that with the elimination of the spray additive only the pH of the short duration injection spray is significantly different from that specified with spray additive. The long term pH of the recirculation solution is essentially unchanged.

The interactions between components and the containment spray and sump solutions can be categorized into physical effects and chemical effects that are dependent on the chemical composition of the solution. In general, short term physical effects include polymer softening, due to elevated temperatures, and subsequent failure of the softened seal due to elevated containment pressure. Longer term chemical effects, due to the ionic strength of the solution rather than the pH, include osmotic swelling of polymers and short circuiting. To reiterate, elimination of the spray additive only affects the pH of the injection spray which will operate for less than one hour.

To summarize, seal materials are tested at high temperature and pH and for time periods simulating approximately one year of exposure. Hence, exposures to low pH solution for time periods less than one hour will have no adverse effect on the ability of the seal material to perform its intended function in the long term.

7.2.3 Protection of Containment Coatings

Coatings are used in the containment to provide corrosion protection for metals and to aid in decontamination of surfaces during normal operation. Coatings that delaminate may clog the emergency sump screens, core, and heat exchanger flow paths and foul heat transfer surfaces.

Like electrical equipment, coatings are also tested with a high pH solution for long time periods, to maximize the potential deterioration of the coating. And, like seal materials coatings will not be adversely affected by short term exposure to low pH spray solution. In

general, coating failures tend to be thermally related (Reference 3) rather than chemical. In fact, one Westinghouse study (Reference 6) indicated that some coatings showed better resistance to mild acid solutions (pH 4 to 5) than to alkaline solutions.

7.3 References - Section 7

1. "Corrosion Study for Determining Hydrogen Generation from Aluminum and Zinc During Post-Accident Conditions", WCAP-8776, (Non-Proprietary) April 1976.
2. "The Relative Importance of Temperature, pH and Boric Acid Concentration on Rates of H₂ Production From Galvanized Steel Corrosion", NUREG/CR-2812, January 1984.
3. "The Effects of Post-LOCA Conditions on a Protective Coating (Paint) for the Nuclear Power Industry", NUREG/CR-3803, March 1985.
4. NRC Branch Technical Position MTEB 6-1, "pH for Emergency Coolant Water for PWR's"
5. "Behavior of Austenitic Stainless Steel in Post Hypothetical Loss of Coolant Environment", WCAP-7798-L (Proprietary), November 1971, WCAP-7803 (Non-Proprietary), December 1971.
6. "Evaluation of Protective Coatings for Use in Reactor Containment", WCAP-7198-L (Proprietary), November 1971.

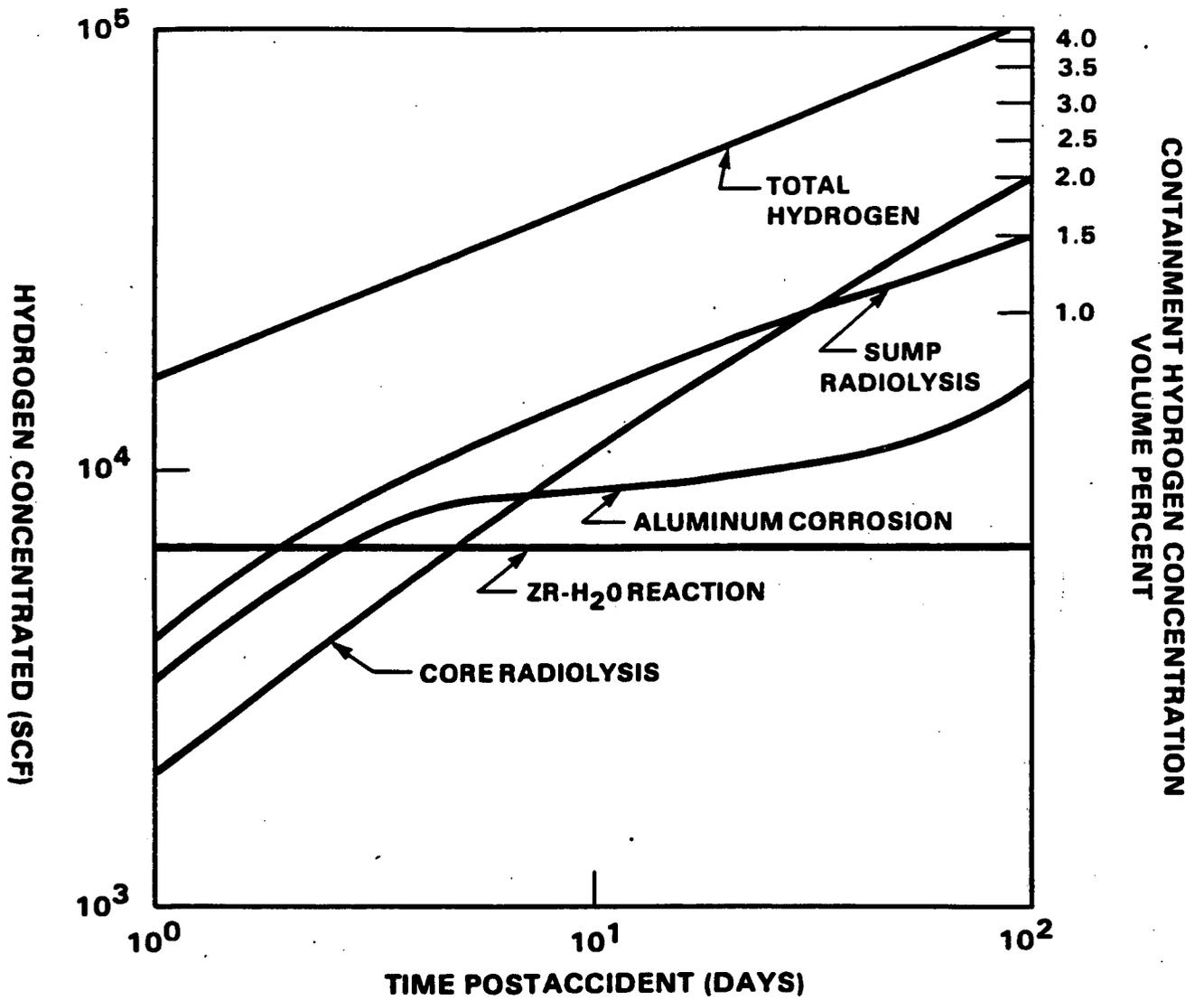


Figure 7-1 Hydrogen Contribution From All Sources
(Indian Point Unit 2 FSAR Figure 6.8-8)

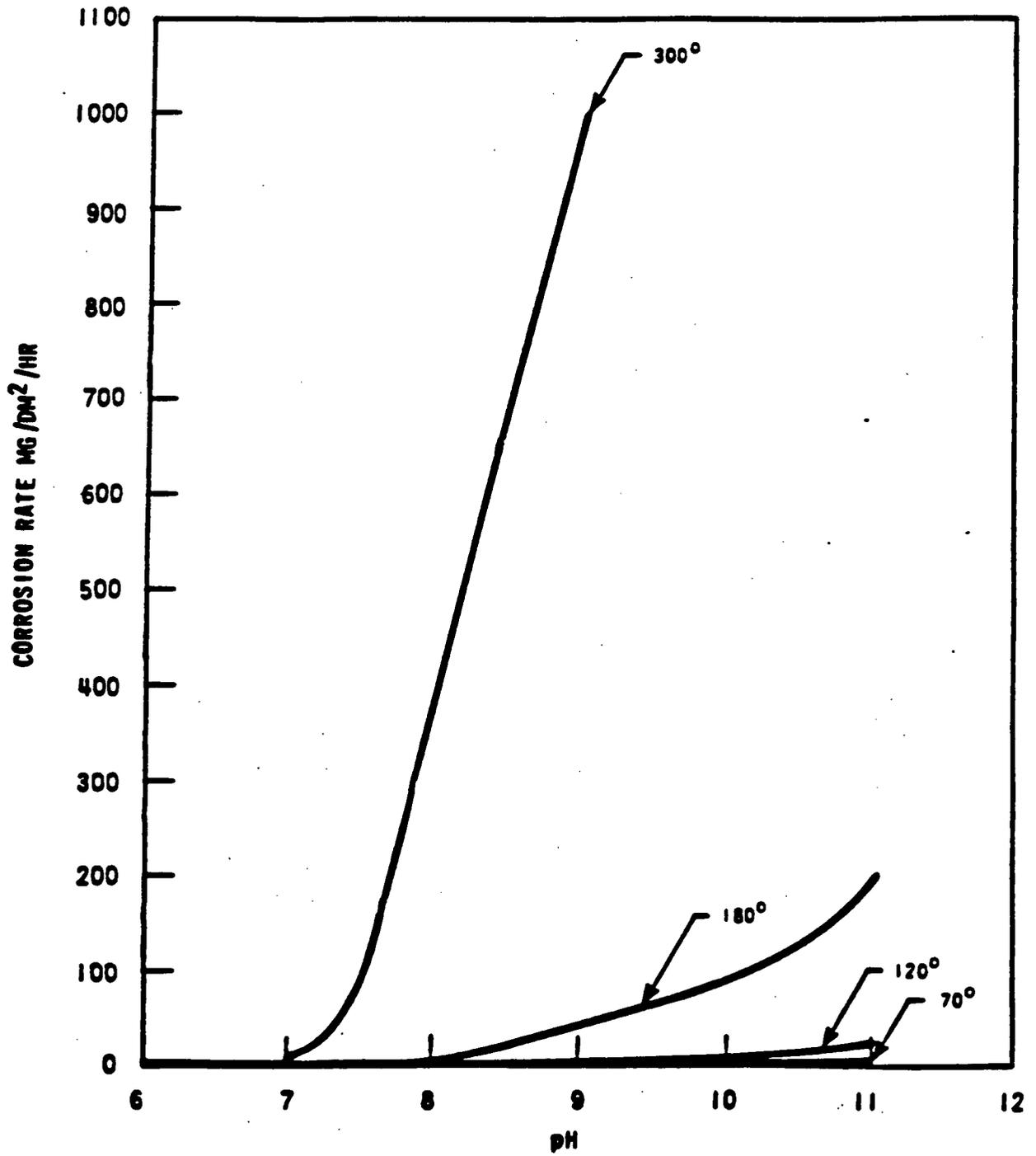


Figure 7-2 Aluminum Corrosion Versus pH (Ref 1)

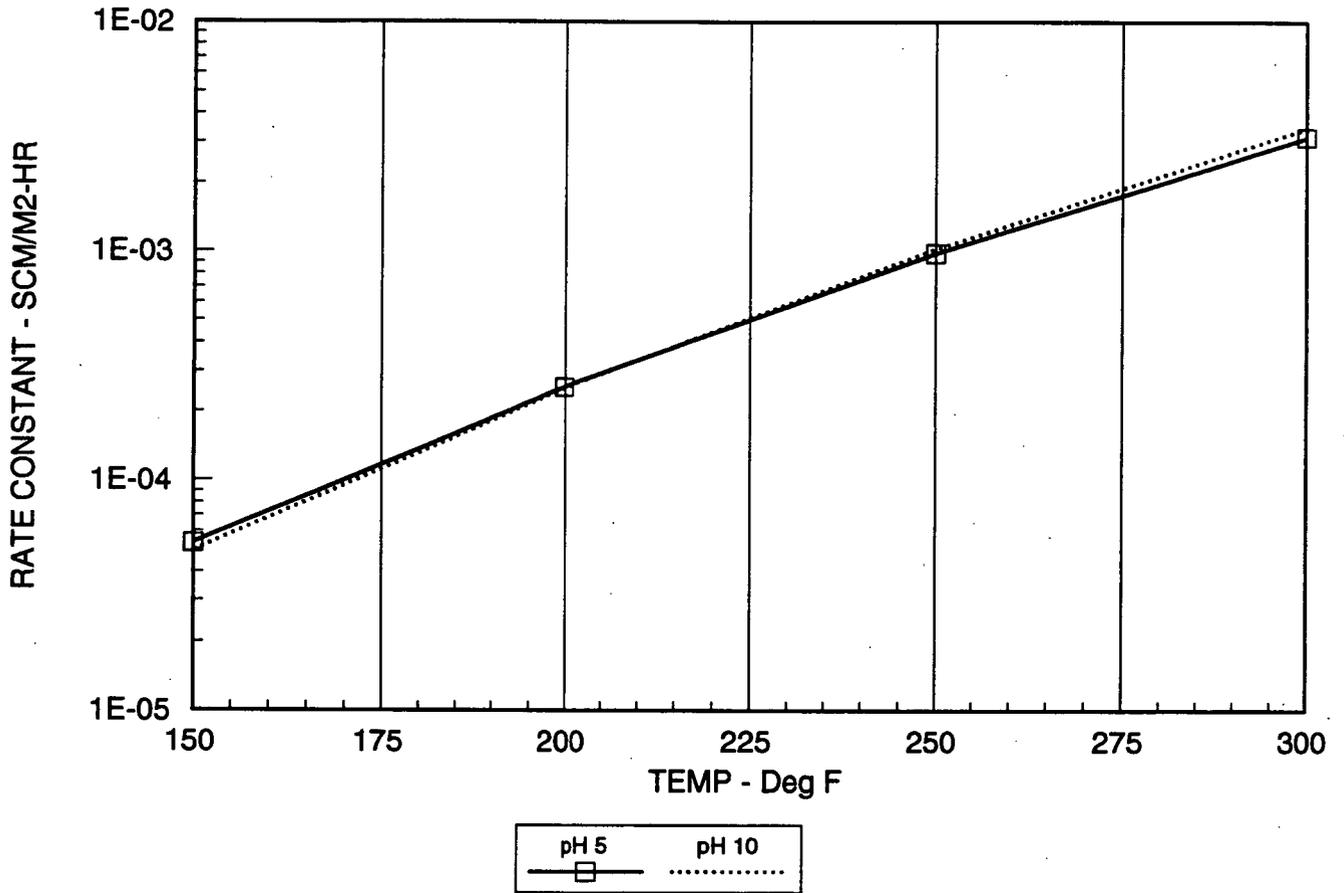


Figure 7-3 Zinc (Galvanized Steel) Corrosion Rate Constants for Spray Injection

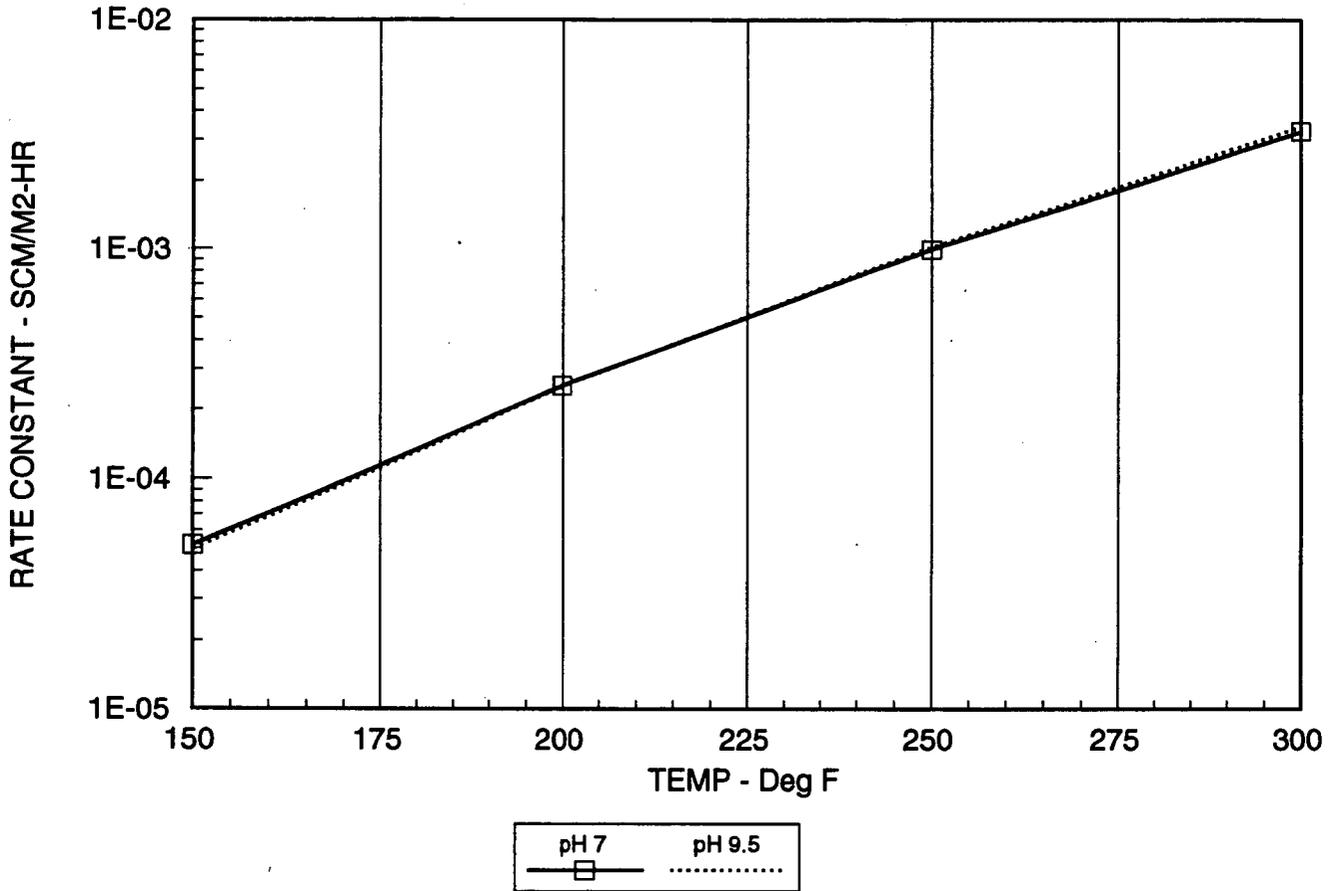


Figure 7-4 Zinc (Galvanized Steel) Corrosion Rate Constants for Spray Recirculation

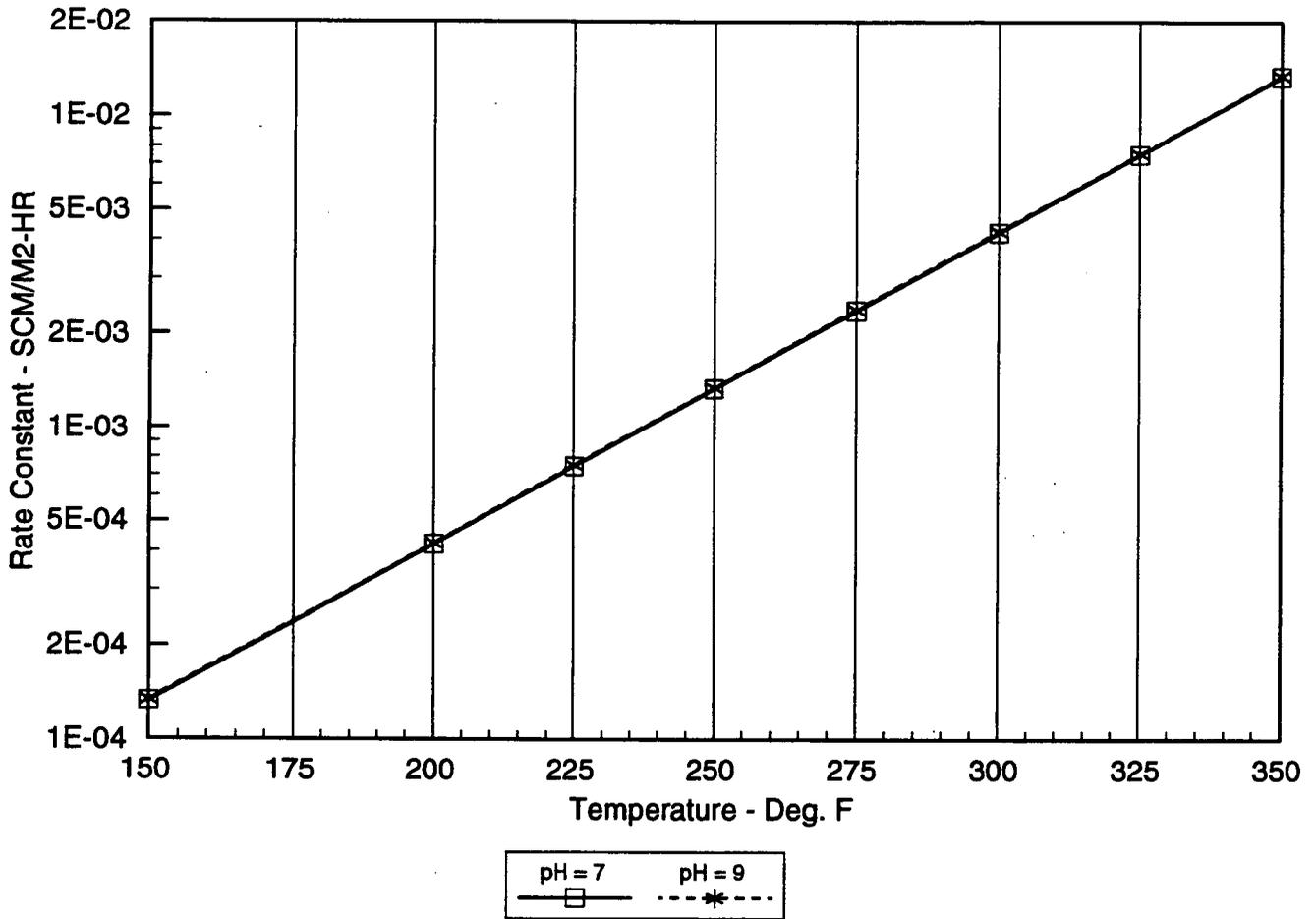


Figure 7-5 Zinc Based Paint Corrosion Rate Constants

8.0 ADJUSTMENT OF SUMP SOLUTION pH

8.1 Definition of Required Long Term pH

As discussed in Section 5.3, a sump solution pH of ≥ 7.0 is required to assure that the iodine removed by the sprays is retained in solution. From Section 7.1 it is seen that the long term corrosion rates for galvanized steel and zinc based paint will be comparable to the FSAR rates at pH 7 to approximately 11. Also in Section 7.1 it is seen that the long term aluminum corrosion rates at pH 7 will be significantly less than the FSAR rates. In Section 7.2 it is stated that the minimum pH recommended to protect stainless steel from chloride cracking is 7.0.

A minimum pH of 7.0 satisfies all of the Section 5 and 7 requirements.

8.2 Caustic Addition Using Trisodium Phosphate

The proposed replacement for the liquid sodium hydroxide spray additive system consists of granular trisodium phosphate stored in baskets strategically located in the post-LOCA flooded region of the containment. Physical data for trisodium phosphate is presented in Table 8-1.

TABLE 8-1

PHYSICAL DATA FOR TRISODIUM PHOSPHATE (Ref. 1)

- Formula: $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$
- Na_3PO_4 , minimum: 42.97%
- Bulk density: $57 \pm 3 \text{ lbs/ft}^3$
- Screening (US Standard Sieve)
 - on 20 mesh: 5%
 - on 65 mesh: 85%
 - Thru 100 mesh: 5%
- Solubility in water

<u>Temp - °F</u>	<u>Wt %</u>
104	43.9
140	73.3
176	94.0
212	112.8

The initial containment spray will be boric acid solution from the refueling water storage tank which has a pH of approximately 4.5. As the initial spray solution and subsequently the recirculation solution comes in contact with the trisodium phosphate, the TSP dissolves raising the pH of the sump solution to an equilibrium value between 7.0 and 9.5.

Titration curves for TSP in boric acid solution are provided in Figure 8-1. For Indian Point Unit No. 2, the mass of TSP (as $\text{Na}_3\text{PO}_4 \cdot 12 \text{H}_2\text{O}$) required to provide an equilibrium sump solution pH of 7.0 is less than 4000 pounds. To address the potential for long term generation of acids in the containment, this amount is doubled (to 8000 lbs).

TSP is a free flowing granular material that is highly soluble in water (112.8 Wt% - Reference 1). However, TSP will clump in a humid environment such as exists inside the reactor containment and, in a worst case, will form a solid block.

The time (T) required to dissolve the TSP can be estimated as follows:

$$T = M / (R * A)$$

Where M = total mass of TSP in container

R = dissolution rate constant - 0.7 lb/ft²-min (derived from data in Reference 2, based on TSP in the form of a solid block, water at 160°F, and no agitation of the solution)

A = surface area in contact with solution - ft²

The TSP will be stored in four baskets, four feet by five feet and having a depth of two feet. A conservative contact surface area is assumed based on neglecting the side surfaces (assumes that the TSP is in contact with the sump solution only at the top and bottom surfaces). With a required mass of TSP of <4000 pounds in the short term (8000 pounds in the long term) and a surface area of 160 ft², the dissolution time would be 36 minutes for 4000 pounds of TSP and 72 minutes for 8000 pounds.

Assuming that the TSP is submerged in approximately 50 minutes, the conservative total dissolution time is approximately 1.5 hours for 4000 pounds of TSP and two hours for 8000 pounds. In an actual post-accident situation, all of the basket surfaces would be exposed to the sump solution and submersion of the TSP would be expected earlier than 50 minutes into

the accident. Further, the initial water temperature would exceed 200°F and there would be significant agitation. All of these factors would reduce the time for dissolution of the TSP.

TSP will be stored in-containment at an elevation that will be flooded post-LOCA. The TSP will be stored in four small baskets rather than in one large basket. Distributing the baskets around the containment will assure a more uniform mixture in the sump solution.

The TSP baskets will be mesh sided to facilitate wetting post-accident and still retain the TSP granules during normal operation. The baskets have a low profile which will enhance submergence and TSP dissolution.

The baskets will be designed to hold the weight of the TSP and, with the bolting, will withstand seismic loads.

8.3 References - Section 8

1. Occidental Chemical Corporation, Data Sheet No. 909A, April 1985.
2. Letter from J. L. Wilkins, Assistant General Manager, Omaha Public Power District, to R. C. De Young, Assistant Director for PWRs, U.S. AEC, November 14, 1973.

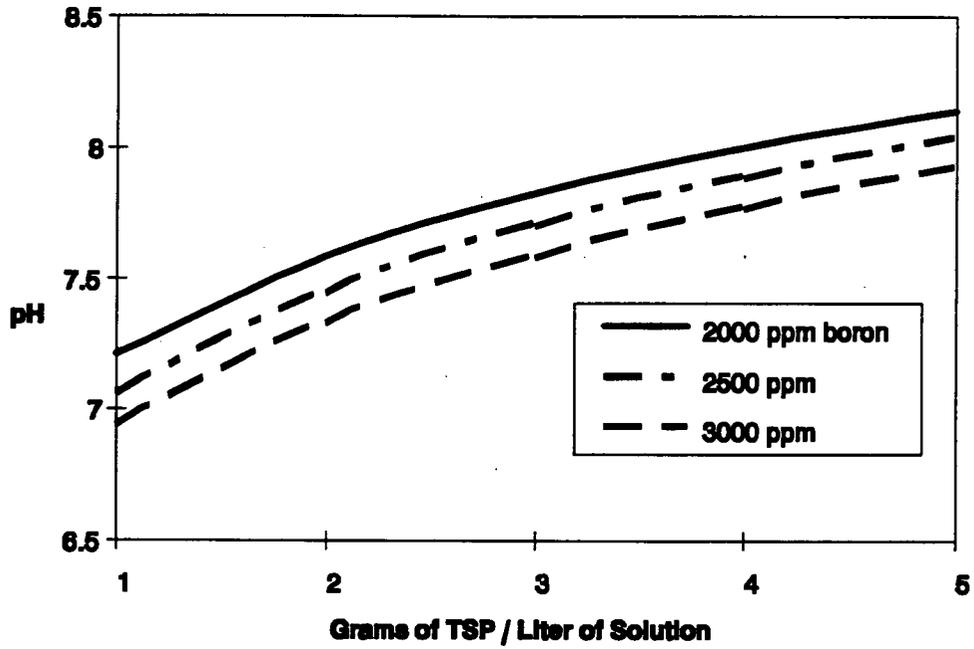


Figure 8-1 Titration Curves for TSP in Boric Acid Solution

ADDENDUM A

LOCA DOSES WITH THE NUREG-1465 SOURCE TERM MODEL
AND WITH CONTAINMENT FAN COOLER FILTERS IN OPERATION

INTRODUCTION

In order to provide a better perspective of the impact of the removal of spray additive and post-accident filtration a separate study was performed which retains the filters and uses the NUREG 1465 (Reference 1) source term methodology. This study provides a benchmark dose determination. Retaining the post-accident filtration provides the ability to remove organic iodine from the containment atmosphere while at the same time enhances the removal of the elemental and particulate iodine which, for the case with no filters, was only provided by the containment sprays. Because of the small fractions of organic and elemental forms of iodine as specified by Reference 1, the impact of the charcoal filters is not significant; however, use of the HEPA filters significantly increases the rate of removal of particulates.

This section of the report documents the evaluations and analyses that were performed to compare two modes of control room operation and incorporates the two duration times of the injection flow previously discussed in Section 4.4.3. Four distinct cases were modeled as follows:

- CASE A: Non-pressurized control room (recirculation mode) with an injection spray duration of 50 minutes.
- CASE B: Pressurized control room with an injection spray duration of 50 minutes.
- CASE C: Non-pressurized control room (recirculation mode) with an injection spray duration of 20 minutes.
- CASE D: Pressurized control room with an injection spray duration of 20 minutes.

In addition to these four cases, additional cases were evaluated which varied the flow through the charcoal filters to determine the effect of reduced flow through the filters. For these cases, the flow through the charcoal filters in the Containment Fan Cooler (CFC) units varies from 8000 cfm to 0 cfm. These cases only affect the halogen group of nuclides.

PLANT SPECIFIC PARAMETERS AND ASSUMPTIONS

The parameters used in these evaluations are the same as the parameters and assumptions listed in Section 4 of this report with the following exceptions:

Fan Coolers

Flow rate - 3 units operating - 65,000 cfm per unit - 195,000 cfm total. This change incorporates the flow reduction resulting from maintaining the charcoal and HEPA filters in the CFC units.

The filter efficiencies per Regulatory Guide 1.52 (Reference 2) for the charcoal filters are 90% for elemental iodine and 30% for organic with flowrates varying from 8000 cfm to zero cfm. The HEPA filters have an efficiency of 99% for the particulate iodine and use the full flow rate of the CFC units.

Control Room Models

As previously discussed, two modes of control room operation were evaluated for this report; a pressurized control room, which is the same as the model described in Section 4.5 of this report, and a non-pressurized control room or recirculation mode, which is the current mode of operation at Indian Point Unit 2. The parameters for the non-pressurized control room are listed below.

Intake air flow rate - 0 cfm

Recirculation air flow rate - 1660 cfm

Filter efficiencies (for recirculation)

Elemental iodine	95%
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Organic iodine	90%
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Particulates	99%
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Unfiltered inleakage - 500 cfm

Consolidated Edison is planning to include control room modifications to a pressurized mode of operation along with the project to remove the charcoal and HEPA filters. Both control room models are included in this report to identify the differences in the radiological consequences between these modes.

RADIOLOGICAL CONSEQUENCES

The potential radiological consequences due to containment leakage during a postulated LOCA were recalculated to include the effects of retaining the CFC unit filters. As discussed in Section 6.0, the potential doses associated with a 20 minute duration of injection spray were slightly higher than the cases incorporating 50 minutes of injection spray and remains so with the CFC filters in operation.

Two sets of results for the potential doses are provided with respect to the range of flows through the charcoal filters. These results show only a small difference between the thyroid, whole body, skin and TEDE dose such that it can be determined that the charcoal filters have an insignificant effect on the potential radiological consequences when incorporating the NUREG 1465 source term methodology.

Since the only difference between CASE A and CASE B is the control room model only the doses to the control room operator are listed for CASE B. The same is true for CASES C and D. The overall results of this dose analysis are shown below for each case.

CASE A - Non-pressurized control room with injection spray duration of 50 minutes

	Calculated Dose (rem)	
	Charcoal Filter 8000 CFM flow	Charcoal Filter 0 CFM flow
Site Boundary		
Thyroid Dose	97.1	100
Whole Body Dose	1.38	1.39
TEDE Dose	6.23	6.34
LPZ Boundary		
Thyroid Dose	47.7	52.7
Whole Body Dose	2.30	2.31
TEDE Dose	4.66	4.83
Control Room		
Thyroid Dose	71.3	85.8
Whole Body Dose	0.307	0.308
Beta skin Dose	13.7	13.7
TEDE Dose	3.84	4.29

CASE B - Pressurized control room with injection spray duration of 50 minutes

	Calculated Dose (rem)	
	Charcoal Filter 8000 CFM flow	Charcoal Filter 0 CFM flow
Control Room		
Thyroid Dose	8.29	12.7
Whole Body Dose	0.375	0.375
Beta skin Dose	14.6	14.6
TEDE Dose	0.756	0.894

CASE C - Non-pressurized control room with injection spray duration of 20 minutes.

	Calculated Dose (rem)	
	Charcoal Filter 8000 CFM flow	Charcoal Filter 0 CFM flow
Site Boundary		
Thyroid Dose	99.1	102
Whole Body Dose	1.39	1.40
TEDE Dose	6.35	6.46
LPZ Boundary		
Thyroid Dose	48.7	53.7
Whole Body Dose	2.31	2.32
TEDE Dose	4.72	4.88
Control Room		
Thyroid Dose	72.7	87.2
Whole Body Dose	0.308	0.308
Beta skin Dose	13.7	13.7
TEDE Dose	3.92	4.37

CASE D - Pressurized control room with injection spray duration of 20 minutes.

Control Room	Calculated Dose (rem)	
	Charcoal Filter	Charcoal Filter
	8000 CFM flow	0 CFM flow
Thyroid Dose	8.42	12.9
Whole Body Dose	0.375	0.375
Beta skin Dose	14.6	14.6
TEDE Dose	0.763	0.901

The offsite thyroid and whole body doses are within the dose guidelines of 10 CFR 100 (300 rem thyroid and 25 rem gamma whole body) for each of the cases listed above. In addition, the offsite TEDE dose is well below the dose limit of 25 rem TEDE that is proposed by Reference 3.

In addition, for each of the cases the control room whole body and beta skin doses are within the dose limits defined in SRP Section 6.4 (Reference 4) of 5 rem whole body and 30 rem beta skin. The control room TEDE dose is well below the 5 rem limit specified in GDC 19 (10 CFR Part 50, Appendix A) for dose to the whole body or its equivalent to any part of the body.

For CASES A and C, which model the non-pressurized control room, the control room thyroid dose exceeds the dose limits defined in SRP Section 6.4 (30 rem) with a worst case of 87.2 rem. For CASES B and D, which model the pressurized control room, the control room thyroid doses are within the acceptable dose limits defined in SRP Section 6.4.

Along with the project to remove the charcoal and HEPA filters, Consolidated Edison is planning to include control room modifications to change from a non-pressurized control room operating in a recirculation mode to a pressurized control room. This change is supported by the acceptable control room doses determined in CASES B and D.

REFERENCES

1. "Accident Source Terms for Light-Water Nuclear Power Plants," USNRC NUREG-1465, Feb. 1995.
2. "Design, Testing, and Maintenance Criteria for Postaccident Engineered Safety Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light Water Cooled Nuclear Power Plants," USNRC Regulatory Guide 1.52, Revision 2, March 1978.
3. SECY-94-194, "Proposed Revisions to 10 CFR Part 100 and 10 CFR Part 50, and New Appendix S to 10 CFR Part 50," 7/27/94
4. "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", NUREG-0800, Section 6.4, Revision 2, July 1981.