APPENDIX K

H_2 SENSOR AGING

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GENERAL ELECTRIC
SPACE DIVISION
PHILADELPHIA

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FROM	TO
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SUBJECT

H_2 SENSOR AGING

INFORMATION REQUESTED/RELEASED

The qualified life of the sensor is presently limited to two years. Aging for this short time prior to LOCA and seismic vibration will have negligible degrading effect and therefore is not an essential step in the qualification testing.

To further insure that no detrimental aging effects would occur during the operational life, a review was made of the materials that could be considered age sensitive. These materials for the sensor are:

Ethylene Propylene - Used in O-Rings, expansion bladder

Polysulfone - Housing Parts

Kapton - Used as Diffusion Membrane

Viton - Ball Seals

Lifetimes or specific end points to useful life and activation energies are not available for all of these materials. An age equivalency can be made between the effect of aging under service condition versus the acceleration aging induced during testing.

From the Arrhenius equation for aging an equivalency per EPRI NP-1558 page 4-15 can be determined from:

$$\ln \frac{t_o}{t_s} = \frac{\emptyset}{K}\left(\frac{1}{T_o} - \frac{1}{T_s}\right)$$

where

t_o = time at temperature T_o in °K

t_s = time at temperature T_s in °K

$\emptyset$ = activation energy assume 1 ev

K = Boltzman's constant $.8617 \times 10^{-4}$ ev/°K

The time and temperature conditions specified in paragraph 4.6.5.1.1.3 of Spec. S023-508-17 are converted to an equivalent time at the normal temperature of 120°F. Assuming a LOCA at the very end of the 2 year qualified life of the sensor, the

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equivalent 120°F life would be 1744 days as tabulated below.

Time		Temp.		120°F Equiv. Time	
Seconds	Days	°F	°K	Days	
$0 - 10^4$	.115	300	422	589	Post LOCA
$10^4 - 10^5$	1.04	220	377	199	Post LOCA
$10^5 - 10^6$	10.4	150	350	186	Post LOCA
(2 years)	730.	120	322	730	
				1744	

Similarly, using the time temperature profile applied during the sensor qualification testing, an equivalency of 4034 days is calculated from:

Time	Temp.		120°F
Days	°F	°K	Equiv. Days
.125	340	444	2498
88	200	377	1536
			4034

The excess aged factor is 4034/1744 = 2.3.

This assumed an activation energy of Ø = 1. For a range of activation energies from .6 to 1.3, the excess aging factor would be 1.5 to 3.1.

Again, this does not attempt to put a limit on the qualified life but rather to establish an additional level of confidence in the present two year sensor life capability. Further testing to extend the qualified life of the sensor is anticipated.

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HYDROGEN MONITOR LOCATION

The post accident hydrogen monitoring system is designed to provide indication of containment hydrogen concentration subsequent to a loss-of-coolant accident. The monitors were located above the operating deck (elevation 63'-6") to obtain representative containment air samples. The factors governing monitor location were accessibility during power operation, equipment environmental qualification and routing of high energy piping. The monitors were also located in areas of high post accident air flow rates. The final monitor installation meets the electrical separation requirements for Class 1E equipment.

Periodic testing and calibration of the hydrogen monitoring system is required by the plant technical specifications. Failure of a monitor channel to pass the surveillance could require containment entry to replace the affected instrument. To minimize plant outages, containment entries to replace instrumentation are done during power operation when possible. FSAR Figures 12.3-1 and 12.3-5 depict radiation zones inside the Unit 2 and Unit 3 containments along the operating deck during power operation. The monitors were located outside the high radiation zones (>100 mr/hour) and adjacent to the personnel lock. This location satisfies the radiation ALARA considerations by minimizing the personnel exposure were the monitors to require replacement. The shielding provided by the secondary shield wall and the concrete elevator structure substantially reduces radiation levels at the monitors below those levels in comparable locations. Additionally, personnel need not traverse high radiation areas to conduct maintenance activities.

The post accident hydrogen monitors are qualified to receive an integrated dose of 3.2×10^7 Rads. This dose limit necessitates special shielding considerations which minimize the dose contribution from normal operation and post accident sources.

Locating the monitors in low radiation areas (<100 mr/hour) minimizes the 40 year integrated equipment dose. This dose must be minimized to ensure that the post accident dose does not exceed the qualification limit. One hundred mr/hour dose rate over 40 years is equivalent to less than 1×10^6 Rads. Therefore, this location will ensure that the normal operating dose is less than 5 percent of the qualification limit and is considered negligible.

The post accident dose rate to equipment inside containment derives from sump, plateout and airborne sources. Location of the monitors above the operating deck ensures that the dose contribution from the sump is negligible. Due to the effectiveness of the sprays and post accident mixing, plateout is uniform throughout containment above the operating deck. Therefore, further reduction in the post accident dose rate is accomplished by shielding from the airborne sources.

The airborne activity includes both beta and gamma sources. The additional shielding provided by the elevator structure effectively eliminates the gamma dose contribution from the airborne cloud behind the monitors. The current monitor location significantly reduces the volume of containment and the size of the airborne source viewed by the monitor. No other location above the operating deck provides post accident shielding as effective as that provided by the elevator structure.

Another factor considered in locating the hydrogen monitors was the routing of high energy piping. The high energy line break analysis (HELBA), discussed in FSAR Section 3.6, considered postulated mechanistic pipe break events throughout the containment in accordance with detailed criteria. Jet impingement boundaries resulting from each postulated break are mapped on zone-of-influence (ZOI) drawings. The hydrogen monitors were located outside of all high energy line break jet impingement boundaries. The electrical conduits supplying power to the monitors are not impacted by jet impingement resulting from a LOCA.

Hydrogen mixing inside the containment under post accident conditions is accomplished by the containment spray system, emergency air coolers, dome air circulators and the containment internal design. One emergency air cooler and one dome air circulator are provided in each quadrant of the containment. Each emergency fan cooler draws 31,000 cfm of air from the operating deck and circulates the air to lower containment elevations. Each dome circulator draws 37,000 cfm of air from the dome and discharges at the 130 ft. elevation along the containment wall. Turbulence created in the containment atmosphere by the spray system, the ventilation system and convective mixing will ensure a relatively uniform distribution of hydrogen. The present monitor location will provide the monitors with a representative sample of the hydrogen dispersed in the containment under post LOCA conditions.

Regulatory Guide 1.75 defines the separation requirements for Class 1E safety-related electrical equipment. The Class 1E post accident hydrogen monitors meet the requirements of Regulatory Guide 1.75 as discussed in FSAR Appendix 3A.

The post accident hydrogen monitors are Seismic Category I, Quality Class II, Class 1E instruments. The monitors are each provided with a representative sample of post LOCA, in-containment hydrogen concentration. The hydrogen monitors meet Regulatory Guide 1.75 separation requirements. Therefore, the monitor locations are independent and the instruments considered adequate to meet their design criteria.

SAN ONOFRE UNITS 2 AND 3
POST LOCA HYDROGEN MIXING

Post LOCA hydrogen monitoring requires that the monitors be exposed to a representative sample of containment air. The monitor location at elevation 76 ft., in front of the elevator shaft, is within the well mixed volume of air subject to mixing by the dome circulator system and the containment sprays.

Hydrogen in the upper containment will be uniformly mixed in the air by several natural and forced mechanisms. These include the initial mixing as hydrogen is released along with steam, molecular and eddy diffusion, convective mixing, forced mixing by the dome circulators and the emergency fan coolers and turbulent mixing by the containment spray system.

The initial mixing by the dispersion and cooling of the steam and hydrogen and the San Onofre containment design will prevent local pocketing of hydrogen in the volume where the hydrogen is released. As discussed in NUREG/CR-2540 (Ref. 1), the heat content and potentially large quantities of the steam and hydrogen will result in the hydrogen flowing out into the larger, cooler volumes of the containment.

The natural mechanisms of eddy and molecular diffusion and convective heat transfer have been discussed in NUREG/CR-0304 (Ref. 2) and NUREG/CR-1575 (Ref. 3). These documents indicate that natural air circulation patterns will be set up in the containment such that the air and hydrogen will rise from the hotter core/steam generator regions toward the top of the containment, and then cool off as it falls down the containment walls towards the floor. The San Onofre containments are designed to allow these air flow patterns. NUREG/CR-1575 indicates that for as little as a 5°F temperature differential between the containment wall and the inside air, hydrogen concentration differential did not exceed .25 percent. Thus, hydrogen mixing is uniform. Measurements of air flows in the San Onofre containment in the vicinity of the hydrogen monitors show significant air velocities even in the absence of large identifiable temperature differentials. Natural convective flows were measured at between 15 to 60 ft/min. With the dome circulators running, the flow rates were 25 to 300 ft/min. With the emergency coolers on, flow rates of 15 to 80 ft/min were measured.

The natural air flow mixing patterns in the San Onofre containments are further enhanced by the dome circulators and emergency coolers. The dome circulators (4 X 37,000 cfm) take suction near the center of the dome roof and discharge at the outer walls just above the polar crane. The emergency coolers (4 X 31,000 cfm) take suction at the operating deck (Elevation 63'-6") and discharge into the lower levels of the containment.

Finally, the turbulence of the spray system assures local mixing. The heat removal function of the sprays results in cooler volumes in the upper containment and the subsequent mixing caused by heat and hydrogen rising from the hotter reactor vessel areas. In addition, several references support the uniform dispersal of fission products (and similarly hydrogen). These include Regulatory Guide 1.4, NUREG/CR-0009 (Ref. 4) and NBWL-1457 (Ref. 5). The latter indicates that measurements of iodine dispersion throughout the Containment Systems Experiments' Test containment were uniform within the errors of the detection instruments.

Evaluations using the methodologies in Reference 4 have shown that for mixing rates on the order of 80 to 100,000 cfm between sprayed and unsprayed containment volumes, the resulting iodine concentrations are reasonably uniform even as the iodine is removed from the air by the sprays. The mixing is exponential in nature in that while 80,000 cfm may result in 90 to 95% mixing, 100,000 cfm will give over 99% mixing. It is expected that smaller air flows would assure uniform hydrogen mixing because hydrogen is not being removed from the air as is the iodine.

In the San Onofre containment, natural convective air flows in excess of 50,000 cfm may be expected during a LOCA. The additional forced air flows by the dome circulators, emergency coolers and the spray system further enhance the uniform mixing of hydrogen in containment under post accident conditions. Therefore, the monitor location above the operating deck should see a representative hydrogen concentration.

REFERENCES

1. NUREG/CR-2540, "A Method for the Analysis of Hydrogen and Steam Releases to Containment During Degraded Core Cooling Accidents", P. Cybulskis, USNRC, February 1982.

Abstract:

The Nuclear Regulatory Commission is considering requirements that reactor containments be able to accommodate without loss of containment integrity or degradation of vital equipment the large amounts of hydrogen that may be generated during severe degraded core cooling accidents. Conformance with the proposed requirements may entail the installation of hydrogen control systems in certain containments. In order to assist with the implementation of these requirements, analyses have been performed to define steam and hydrogen release rates into PWR and BWR containments during representative severe degraded core cooling accidents. These envelopes of hydrogen and steam source terms to the containment can be used for performing containment response analyses. This approach is intended to obviate the need for extensive case-by-case analyses of the progression of a variety of accident sequences and allow the attention to be focused on the containment response evaluations. The use of the hydrogen and steam release rates into containment developed in this study is one of several alternatives under consideration by the Nuclear Regulatory Commission.

2. NUREG/CR-0304, "Mixing of Radiolytic Hydrogen Generated Within a Containment Compartment Following a LOCA", G. J. E. Willcutt, USNRC, August 1978.

Abstract:

The objective of this work was to determine hydrogen concentration variations with position and time in a closed containment compartment with radiolytic hydrogen generation in the water on the compartment floor following a Loss-of-Coolant-Accident (LOCA). One application is to determine the potential difference between the compartment maximum hydrogen concentration and a hydrogen detector reading, due to the detector location.

Three possible mechanisms for hydrogen transport in the compartment were investigated: (1) molecular diffusion, (2) possible bubble formation and motion, and (3) natural convection flows. A base case cubic compartment with 6.55-m (21.5-ft.) height was analyzed. Parameter studies were used to determine the sensitivity of results to compartment size, hydrogen generation rates, diffusion coefficients, and the temperature difference between the floor and the ceiling and walls of the compartment.

Abstract: (Cont.)

Diffusion modeling indicates that if no other mixing mechanism is present for the base case, th maximum hydrogen volume percent (vol%) concentration difference between the compartment floor and ceiling will be 4.8%. It will be 24.5 days before the maximum concentration difference is less than 0.5%. Bubbles do not appear to be a potential source of hydrogen pocketing in a containment compartment. Compartment natural convection circulation rates for a 2.8°K (5°F) temperature difference between the floor and the ceiling and walls are estimated to be at least the equivalent of 1 compartment volume per hour and probably in the range of 4 to 9 compartment volumes per hour. Related natural convection studies indicate there will be turbulent mixing in the compartment for a 2.8°K (5°F) temperature difference between the floor and the ceiling and walls.

3. NUREG/CR-1575, "Hydrogen Mixing in a Closed Containment Compartment Based on a One-Dimensional Model with Convective Effects", G. J. E. Willcutt et al., USNRC, September 1980.

Abstract:

A transient, one-dimensional, finite-difference model was developed for determining the hydrogen concentration variation with position in a closed containment compartment caused by radiolysis following a LOCA. The model includes mixing due to molecular and eddy diffusion and natural convection. For representative compartments, the maximum hydrogen concentration difference between the bottom and top of the compartment never exceeds 0.25 volume percent when all three mixing mechanisms are considered for a range of parameters.

4. NUREG/CR-0009, "Technological Bases for Models of Spray Washout of Airborne Contaminants in Containment Vessels", A. K. Postma et al., USNRC, October 1978.

Abstract:

The Staff of the Nuclear Regulatory Commission has developed mathematical models for assessing the washout rate of airborne contaminants under postulated loss-of-coolant-accident (LOCA) conditions. Heretofore there was not one document that summarized the technological bases of the models.

In this report the models currently used by the staff are described in detail. The theoretical and experimental bases which underlie the models are reviewed, and model predictions are compared with experiments to demonstrate the conservatism inherent in the models.

Spray systems are included in containment vessels of water reactors as an engineered safety feature to suppress pressure and to scrub airborne contaminants in the unlikely event of a LOCA. The efficacy of spray scrubbing is important in the siting of power reactors because the spray removal rate directly affects the calculated radiation dose which could be received by people in the plant environs.

Abstract: (Cont.)

A large body of information is available to aid in the assessment of spray performance. In this report the most relevant work is reviewed to show the technical bases for the spray models which are currently used by the NRC Staff.

5. BNWL-1457, "Natural Transport Effects on Fission Product Behavior in the Containment Systems Experiment", R. K. Hilliard, L. F. Coleman, Battelle Pacific Northwest Laboratories, Richland, Washington, June 1973.

Abstract:

The results of six experiments in the 26,000 ft^3 Containment Systems Experiment (CSE) containment vessel are reported. In these tests, no active safety feature operated and all transport was by natural passive processes. The time dependence of iodine, methyl iodide, cesium, ruthenium and uranium concentrations was measured at various locations in the vapor space and in the steam condensate. Parameters which were varied from test to test included the ratio of surface area to volume, temperature and pressure of the atmosphere, heat transfer rate to walls, paint age, and initial iodine concentration. Most of the tests were at steady temperature with steam feed to replace heat losses, but in one experiment the steam feed was zero and the temperature and pressure decreased with time.

The results are compared with theoretical predictions with good agreement for iodine behavior and reasonable agreement for particulate materials when suitable particle sizes are used in predictive calculations. The initial rate controlling mechanism for elemental iodine is shown to be gas phase diffusion across boundary layers. For particles, gravitational settling dominate, with turbulent deposition and diffusiophoresis being of secondary importance. Whether the temperature and pressure were held constant or allowed to decrease with time had essentially no effect on the iodine behavior; but particle deposition was significantly slower in the temperature decay case.

The best estimates of the 2-hr dose reduction factor (DRF) due to fission product removal by natural processes for large PWR containment systems are about 2.6 for inorganic iodine, 1.15 for particulate matter and 1.0 for methyl iodide. At longer times the estimates for DRF are considerably larger.

POST LOCA HYDROGEN GENERATION

The following information addresses hydrogen generation rates for degraded core scenarios.

Typical hydrogen generation scenarios developed by Battelle Columbus Labs for NRC and the 10CFR50.44 proposed rulemaking in NUREG/CR-2540, "A Method for the Analysis of Hydrogen and Steam Releases to Containment During Degraded Core Cooling Accidents" were investigated. Most of the accidents result in a 60 to 80% metal-water reaction within approximately one hour. The most probable and most often analyzed accident is the S2D', a small break LOCA with ECC initiation before core melt. This is similar to the TMI accident and is the scenario used by NRC to evaluate the Sequoyah igniter system. This is also a reasonable choice for evaluating the response characteristics of the hydrogen monitors as it includes the high hydrogen release rates which occur during the ECC initiation/reflood conditions.

Hydrogen concentrations vs. time are given in the table below. The concentrations can be assumed to increase linearly between the data points given. The values were derived from NUREG/CR-2540 Figure C-10 with the conversion factor of 2400 lb. of hydrogen (100% metal-water reaction) resulting in 10.3 v% hydrogen at 200°F in the San Onofre containment. This conversion approximates the values used in the Pilgrim Hydrogen Study and the San Onofre ACRS presentation. Similar estimates of the steam and hydrogen release rates from the reactor vessel are also shown in Figures C-6 through C-9 of NUREG/CR-2540.

San Onofre Containment Hydrogen Concentration vs. Time

Time (Minutes)		Released	Containment
Of Accident	Of H_2 Release	H_2 (lbs.)	H_2 Vol. %
235	0	0	0
250	15	150	.65
280	45	975	4.2
295	60	1600	6.9
325	90	1800	7.75