Technical Report

MONITORING HYDROGEN GAS IN CONTAINMENT DURING THE EARLY PHASES OF A SEVERE ACCIDENT

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MONITORING HYDROGEN GAS IN CONTAINMENT DURING THE EARLY PHASES OF A SEVERE ACCIDENT

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1.0 Purpose

The fundamental purpose of this paper is to investigate the usefulness of monitoring Hydrogen gas concentration in containment during the early phases of a severe accident. The time frame considered in this study is from time zero until approximately 1.5 hours into the accident.

2.0 Background

A severe accident may be defined as an event where prolonged core uncovery has resulted in elevated temperatures and corresponding damage to the core. The subsequent creation of large amounts of Hydrogen due to the Zirconium-water reaction that occurs at such temperatures is a direct consequence of such scenarios unless the core is for some reason "starved".

NUREG-0737, Item II.F.1, Attachment 6 requires continuous indication and recording of Hydrogen concentration in the containment atmosphere to be functional within thirty minutes of initiation of safety injection. Although the basis for this time requirement is not explicitly provided, it may be inferred that the objective is to quickly provide plant personnel (operators, management, TSC personnel, etc.) with early indication of whether a severe accident may be in progress.

In addition to the measurement of Hydrogen in containment, there may be other plant parameters that could be more easily or more rapidly assessed on a quantitative basis by the operators. Use of these other parameters may be effective in reducing the time for operator action during an accident scenario that demands prompt operator response.

The purpose of this paper is to investigate this issue and to formulate conclusions that may be used to defend a request to the NRC to permit initiation of Hydrogen monitoring at a more reasonable time of, say, sixty to ninety minutes. The NRC has previously been approached to relax the thirty minute requirement based on historical DBA arguments where significant Hydrogen accumulation in containment occurs only over a period of days. These requests have been disapproved, with the most recent correspondence citing that only DBA arguments had been presented.

The rationale to be developed herein takes into consideration events that are well beyond the design basis. For such postulated events, measurable quantities of Hydrogen will be produced early in the accident sequence. However, arguments are developed to show that, in the time frame of interest, the measurement of these quantities of Hydrogen is of essentially no use in such a rapid event.

3.0 Design Basis Accident (DBA) Considerations

ABB C-E has reviewed t issue of Hydrogen generation and the resulting Hydrogen concentrations in containment that may result from varying degrees of Zirconium oxidation in a DBA. This review, entitled, "A Study of Core Wide Cladding Oxidation and Hydrogen Release During Design Basis LOCAs", was conducted based on the Arkansas plant. The large and small break LOCA events studied are the only FSAR events for which Hydrogen is explicitly calculated as part of the associated core uncovery. Hence, they are excellent starting points for breaking out important phenomena concerning beyond DBA events that will be discussed later in this paper. The above mentioned study is provided as Appendix A to this paper and a synopsis is provided in the following paragraphs.

Within the design basis of a Pressurized Water Reactor there are strict licensing limits that constrain the amount of Zirconium-water oxidation that is allowed (e.g., 10CFR Appendix K, where the maximum fraction of Zirconium oxidation allowed is 1%). For a typical C-E core, oxidation of **all** the Zirconium (and assuming that all of the Hydrogen is transported to the containment) will yield a containment Hydrogen concentration of about 20% by volume. The 1% limit for the oxidation of Zirconium referenced above thus corresponds to a 0.2% Hydrogen concentration in containment. For a 0% - 10% Hydrogen monitor scale, 0.2% is just at or possibly slightly above the approximate threshold of visual observation. Theoretically, for a Hydrogen burn to occur in containment, localized concentrations of approximately four volume percent would have to be reached.

In general, the Hydrogen will originate from four sources:

1. Zirconium clad and other Zirconium in the active core region that reacts with water and steam

2. Radiolysis of water from the decay of fission products

3. Corrosion of other metals and materials in containment

4. The limited amount of Hydrogen routinely present in the RCS during steady state operation.

For a DBA, the primary source of Hydrogen early in the event will be from Zirconium clad oxidation (Source #1 above). Data provided by Arkansas pertaining to Hydrogen buildup in containment following a DBA large break LOCA confirms that after approximately the first two hours of such an event, 85% of the Hydrogen that will have been produced originates from the oxidation of Zirconium clad in the active fuel region. The Hydrogen in containment data provided in the ANO FSAR is based on a very conservatively chosen initial amount of cladding oxidation (five times the 1% limit referenced earlier), and includes the results of reaction rate calculations for hydrolysis and corrosion of the metal surfaces in containment. As shown, days into the event, the Hydrogen concentration approaches deflagration (burnable) levels but the use of a single recombiner is easily able to prevent the minimum theoretical burn limit (≈4%) from being reached.

A single recombiner at 100 CFM and 95% efficiency can remove about 200 SCF per hour of Hydrogen from the containment at a containment concentration of 3.5%. By contrast, the sum of all reaction rates together produces less that this (about 125 SCF per hour at the time 3.5% Hydrogen concentration in containment is reached). Hence, a single recombiner is adequately sized to handle the DBA event. As will be shown, this is not the case for the early phase of a severe accident since the Hydrogen generation rates for these situations is much larger than the recombiner capacity.

Figure 1 shows the concentration of Hydrogen present in containment, and Figure 2 shows the Hydrogen concentration as indicated in the control room for a number of modeled accident scenarios at Arkansas (both DBA and beyond DBA events). Figure 2 includes a delay time of thirty minutes to reflect the delay expected from the time a Hydrogen sample is drawn from containment to the time that sample reaches the instrument for analysis and indication becomes available to the operators in the control room. Table 1 provides a description of each of the cases being considered in the analysis, and includes both DBA and beyond DBA events.

The two design basis cases considered were large break LOCAs with full or partial injection capability and the design basis (three out of four) Safety Injection Tank (SIT) availability. The calculations were performed using the MAAP code for a generic C-E plant design with the data properly scaled to reflect an Arkansas containment free volume of approximately 1.86E+6 cubic feet. The figures clearly show that, with a thirty minute time delay between the drawing of a sample from containment and the indication of sample results in the control room, the design basis LOCA events (Cases 2 and 3) do not yield Hydrogen concentrations in containment prior to 1.2 hours, and will not yield measurable data in the control room **at all** during the first 1.5 hours of the event.

Therefore, it seems clear that the NUREG-0737 time requirements for Hydrogen monitoring are based on accident scenarios that progress well beyond the DBA envelope. Under these conditions, ABB C-E feels that Hydrogen monitoring capability is only one of many information elements present, and will be the element with the most lag time to the operators. Therefore, it is evident that although it is important during an overall accident sequence, the ability to measure Hydrogen will not be uniquely critical during the early phases of a DBA. For DBA events over longer time scales, Hydrogen monitoring is clearly useful to show the slower buildup of Hydrogen (over a period of days) that can determine when recombiners should be activated so as to prevent combustible mixtures from forming in the containment atmosphere. The same may be said for beyond DBA events occurring over longer time scales.

4.0 Beyond DBA Considerations

4.1 General Criteria

With the obvious exception of events characterized by Reactor Vessel failure, core uncovery will only occur when there is a loss of RCS integrity coupled with inadequate Safety Injection flow. These events include:

1. Loss of all secondary side heat removal, without once through cooling (feed and bleed). This event will cause the RCS mass to be depleted through lifting of the pressurizer primary safety valves. (This event is very similar to a complete Station Blackout except that RCS leakage (e.g. RCP seal leakage) was not addressed. Over the times of interest, RCS leakage (≈100 GPM for four RCP seals, per NUMARC guidelines) is only about 14% of RCS inventory, so that it is not significant here. Hence, the event analyzed is essentially a Station Blackout).

2. Loss of coolant with inadequate injection capability. Large breaks were analyzed to obtain the fastest response. Small LOCAs would provide similar results, but over longer time frames. LOCAs beyond DBA were also analyzed to provide continuity with the previously referenced DBA LOCA results and because such severe LOCAs will easily demonstrate measurable amounts of Hydrogen in containment within 1.5 hours.

Th ext section of this report contains a survey of the various parameters that will play a part during the aforementioned beyond design basis accident scenarios and will include the measurement of Hydrogen in containment. The purpose of this section will be to show that, even though Hydrogen may be theoretically measurable during the time frame of interest for some very low probability severe accidents, many other measurable parameters exist that are much more relevant and timely, and are more easily obtained from more familiar control room instrumentation.

4.2 Survey of Measurable Parameters

The spectrum of measurable parameters includes Core Exit Temperature, Containment Radiation Levels, Ex-Core Detector Readings, Hydrogen Concentrations, and finally, other parameters that are directly available in the control room that can play an integral, real time part in determining the course of the accident. Each is discussed in turn in the following paragraphs.

4.2.1 Core Exit Temperature

In general, the single most useful parameter in the early recognition of a severe accident is the core exit temperature. Excessive core exit temperature (above, say, 700°F) is considered to be the earliest indication of the onset of core damage. By contrast, Hydrogen monitoring requires some amount of core damage to have occurred before detection is possible. In addition, the measurement of core exit temperature is a parameter that is very familiar to plant operators. Therefore, by choice alone, it is likely that the operator may look to this parameter before examining other possibilities.

Figure 3 shows a survey of core exit temperature profiles versus time (up to ninety minutes) for the same accident sequences described in Table 1, and includes both DBA and beyond DBA events. It is noteworthy that an indication of elevated (and increasing) core exit steam temperature will occur very early in the accident for all sequences, and before any significant fuel damage occurs. The data shown was arbitrarily truncated at 2200°F.

The useful range of the Core Exit Thermocouples at ANO extends up to about 2300°F. Hence, the technical range of the CETs is quite adequate for this purpose. Note that in the ANO Control Room, CET indication is provided on the Safety Parameter Display System and covers the range from 0° to 2300°F.

4.2.2 Containment Radiation Levels

Another very effective means for confirming (or flagging the strong potential for) the onset of core damage in a severe accident is containment radiation data. Once the core has been damaged and fission products are released to the containment atmosphere, control room monitors reading high levels of radiation are a very real-time means of determining that some degree of fuel damage has occurred. Figure 4 shows the generic results for radiation levels versus time and the degree of core damage. The figure, plus the supporting information for the figure, provide the following data at about 1.5 hours into a severe accident:

DEGREE OF CORE DAMAGE	APPROXIMATE CORE TEMP RE:DAMAGE STATE (F°)	CONTAINMENT RADIATION RAD/Hour
• NO FUEL DAMAGE	Up to 750	10^0
• INITIAL CLAD FAILURE	(1300 - 2000)	Up to 2×10^4
• INTERMEDIATE CLAD FAILURE		2×10^4 to 2×10^5
• MAJOR CLAD FAILURE		2×10^5 to 5×10^5
• INITIAL FUEL OVERHEAT	(2000 - 2450)	2×10^5 to 5×10^5
• INTERMEDIATE FUEL OVERHEAT		5×10^5 to 3×10^6
• MAJOR FUEL OVERHEAT	2450 - 3450	Over 3×10^6
• MELTING	Over 3650	Not Correlated

While this information is broad based in nature and obviously relies on a number of specific assumptions regarding fission product dispersion and plate out, etc., it is clear that there is at least a crude correlation between core outlet temperatures, fuel damage, and containment radiation levels.

Moreover, for the core exit temperatures shown in Figure 3 at one hour (at or above 2200°F for all five events) the corresponding radiation levels in containment will be at least 10^4 RADs/Hour. The Arkansas monitors read from 10^0 to 10^6 RADs/Hour, with a normal reading of 10^0 RADs/Hour. As can be seen, the increasing radiation readings versus core heatup are an excellent qualitative and unambiguous indication of core damage.

Unlike Hydrogen monitors, the radiation readings are continuously available, do not require operator actions to activate, and have no delay time. Hence, on a purely qualitative basis, significant radiation readings are equivalent to Hydrogen data. Indeed, the times at which the core exit temperatures reach the lower threshold of core damage (≈ 1300°F) which in turn corresponds to ≈ 10^2 RADs/Hour, and the times at which the hydrogen concentration in containment reaches 0.1% are quite similar.

Stated differently, clad rupture (at 1300 - 2000 °F) produces ≈ 10^3 - 10^4 RADs/Hour in containment just as rapidly as detectable levels of Hydrogen in containment are produced. Hence the lack of a specific Hydrogen monitor reading early in a severe accident is not essential to a clear understanding that core damage has occurred.

This is not surprising since the root cause of both the Hydrogen and the release of the fission products is excessive fuel temperature. Since there is only one source of fission products versus more than a single source of Hydrogen, it is clear that the use of containment radiation readings easily compensates for the short term lack of Hydrogen data. The redundancy of plant instrumentation relative to the diagnosis of a severe accident is thus more than flexible enough to accommodate the short term absence of a single component from the mix of instrumentation and indications available.

4.2.3 Ex-Core Detector Readings

Ex-Core detector readings will show levels as high as ten to one hundred times normal as the core uncovers. At TMI, about thirty times the normal readings for post-shutdown were measured. This ratio is easily explained in terms of the lack of neutron attenuation by the RV water as the level drops. The TMI operators initially interpreted the large readings as a reactor startup. It is now well known that these data can serve very well as a coarse, but instantaneous RV level indicator.

4.2.4 Additional Measurable Parameters

During the early stages of a DBA, or a severe accident that progresses beyond DBA "space", there are many other measurable parameters available in the control room that can help to diagnose the plant condition in a timely fashion. At Arkansas, much of this information is collected in the control room at the Safety Parameter Display System (SPDS), which is readily available to the operators. Included in the SPDS is the Reactor Vessel Level Monitoring System (RVLMS) which measures fluid level in the active fuel region during a LOCA event; this information is supplemented by Ex-Core detector readings that increase as the core uncovers as outlined above.

In addition, the operators monitor pressurizer fluid level, RCS pressure and temperature, containment pressure and temperature, and secondary water levels in the steam generators. For a large LOCA class of accident, the operators can easily read low pressurizer level, elevated containment pressure (approximately 50 psig), loss of RCS subcooling, and high containment temperature. In addition, the operators will read no unusual conditions in the steam generators. For a total loss of feedwater scenario, the operators will see an indication of high steam generator pressure and, eventually, low water level. This indicates a loss of secondary heat sink. In addition, once secondary side heat removal is lost, the operators will read RCS repressurization as well as Primary Safety Valve actuation. During the early phases of LOCA events and total loss of feedwater events, these measurements can be taken quickly and efficiently, and the operators can assess the plant condition and take whatever appropriate actions are deemed necessary.

4.2.5 Hydrogen Monitoring

There is no disagreement that the ability to measure Hydrogen in containment can be a useful means of assessing degrees of core damage during certain severe accident scenarios. This would be a TSC function. From an operator's perspective, Hydrogen concentration information can be used to actuate recombiners. This information can also be used to strategically select actions to enhance containment integrity when appropriate.

There are however, certain noteworthy difficulties associated with the use of Hydrogen indication, and with its potential usefulness to the operator during fast moving accidents where core uncovery occurs very rapidly.

1. Hydrogen production due to Zirconium oxidation processes will only occur after high core temperatures have resulted in fluid boiloff and subsequent core uncovery. By the time Hydrogen concentration data were available, it would have been possible to use the other means discussed above to determine that core uncovery has occurred (e.g., core exit temperature trends, Ex-Core detector readings and containment radiation levels).

2. Core damage assessment based on Hydrogen concentrations in containment is normally an activity conducted later in an event by the Technical Support Center (TSC). Since the TSC may not be manned until sixty to ninety minutes into the a severe accident, this function may not be particularly useful in fast moving accidents such as those discussed in this paper.

3. During an accident sequence Hydrogen may be produced due to processes other than Zirconium oxidation. This can complicate its use for purposes of quantitative core damage assessment. Radiolysis effects with water, as well as oxidation of other metals in containment, can both add to the Hydrogen term. For very rapid events the early Hydrogen production is dominated by the Zirconium-water reaction. Nevertheless, "backing-out" the contributions from radiolysis and corrosion is time consuming and subject to approximations and assumptions.

4. The method used for collecting a Hydrogen sample involves an inherent lag time. Even if a sample is taken at time zero in an accident sequence, it will take some time to obtain and assess the sample for use as a viable, useful data point. During a fast moving accident sequence, other means may be more readily available, more rapid, and therefore more useful to the operator.

5. There is no specific operator action associated with a Hydrogen reading over the time frames of interest, except for starting the recombiners. However, since the recombiners are sized only for DBA events, their absence for a short amount of time will not affect the event significantly. For example, if 2% Hydrogen concentration is produced over 0.3 hours (See Figure 1), then this corresponds to about 130,000 SCF per hour. By contrast, at 2% concentration, a single recombiner will only remove about 120 SCF per hour under these conditions. Hence

the ratio of production to removal is about 1,000 to 1, so that recombiners have essentially zero effect for these events and time scales.

As previously mentioned, Figures 1 and 2 include Hydrogen concentrations in containment and as measured in the control room (respectively) for three selected accidents that are well beyond the design basis. Specifically, these cases include two large LOCAs with no injection (Cases 4 and 5) and a total loss of all feedwater event with no injection (Case 1). The figures clearly show that only the worst of the two LOCA cases will progress fast enough to produce measurable amounts of Hydrogen on control room instrumentation by thirty minutes into the event (Figure 2).

Table 2 provides a summary of the scenarios and the estimates of the concentration and timing of Hydrogen in containment and as indicated in the control room. For the higher probability (but still highly unlikely) LOCA with three SITs and no Safety Injection, indication in the Control Room is not initially received until one hour into the event.

5.0 Procedural Considerations

5.1 Current EPGs/EOPs

The ANO Emergency Operating Procedures (EOPs) are based on the Combustion Engineering Emergency Procedure Guidelines (EPGs), CEN-152, Revision 03. These EPGs have been approved on an interim basis by the NRC and a Safety Evaluation Report is pending.

Previous editions of CEN-152 (prior to Rev 03) directed operators to monitor for Hydrogen in a number of instances. This action had been included in the Standard Post Trip Actions (SPTAs) that are used immediately after each reactor trip (See Note 2). Revision 03 of the EPGs however, does <u>not</u> direct this action so long as there is no evidence from other plant parameters to indicate a need to do so.

The reason for this change is that operators are heavily tasked following a reactor trip to obtain a comprehensive and accurate picture of plant safety and to support efforts to help diagnose the cause of the trip. Many operators had reported that the efforts of the Control Room staff were better focused on using

Note 2: The CEN-152 structure is entered into and is based on events that either have an automatic reactor trip or that are manually tripped as needed to insure plant safety. By contrast, NUREG-0737 references the actuation of Hydrogen monitoring to the initiation of a Safety Injection Actuation Signal (SIAS). It is felt that this SIAS reference is based either on a strictly LOCA orientation or possibly, on the Westinghouse orientation to entry into the EPGs. In a C-E plant, it is not realistically possible to have a SIAS signal prior to reactor trip. In this context, it is suggested that procedural steps to monitor Hydrogen not be based on SIAS. An obvious but specific example of this would be a Steam Generator Tube Rupture (SGTR) event that has SIAS, but does not require Hydrogen monitoring.

normally available instruments to perform the SPTAs, and that Hydrogen monitoring was best performed for those cases where other plant indications dictated the need for that information.

Simply stated, the current EPGs do not use Hydrogen monitoring as part of the initial event diagnostic process, as outlined above. An additional reason to support this fact is that even very severe accidents do not produce measurable quantities of Hydrogen during the time after trip when using SPTAs and when initial diagnostics are being performed (typically zero to five, or possibly ten minutes, depending).

Hence, in the EPGs, Hydrogen monitoring is done only for LOCAs, ESDEs, and for functional recovery unless there are indications present to show a need for monitoring. This philosophy is quite consistent with the other reasoning presented regarding Hydrogen monitoring, which is to use the capability when it is needed as opposed to using it by a certain time.

The SER for Rev 03 has been pending for over three years; to date, there have been no comments from the NRC regarding this issue. Also note that CEN-152 does not address the need to have the capability (at any particular time) except implicitly in that it cannot be used if it is not available. The ANO attempts to relax the thirty minute requirement have been quite correct within a DBA context since Hydrogen accumulates significantly only over days of time and since the only procedural guidance currently in existence is the DBA based EPGs/EOPs. The implications of Hydrogen monitoring requirements for events beyond DBAs are briefly discussed in the next section.

5.2 Severe Accident Management

Procedures (or guidance) for events beyond DBAs do not exist at this time for PWRs in the United States. While much research has been conducted since TMI in separate phenomena, the U.S. industry is just starting to address severe accident management issues via a NUMARC initiative. Currently, there are no NRC requirements for utilities to have such guidance, and the purpose of the NUMARC initiative is to proactively work with the NRC to develop guidance that will be mutually acceptable to the NRC and implementable by the utilities. An NRC generic letter on this topic is anticipated during 1992.

The NUMARC initiative has currently proceeded to the point where the individual owners groups are starting their work to produce draft generic guidelines by early 1993. The CE Owners Group schedule is commensurate with this and will start in early January, 1992. ANO is a participant in this task (CEOG Task No. 726). None of the NUMARC work to date has been at the level of detail required to address when a Hydrogen monitoring capability is functionally needed.

ABB C-E feels that this paper represents the leading edge of this issue based on extensive severe accident initiatives with NUMARC, EPRI, all other owners groups and many individual utilities. It is also felt that the arguments presented herein adequately support the fact that there is no overwhelming functional need to monitor Hydrogen in the early phase of any event, given the other indications that are available, the time scales involved for Hydrogen generation, the non-availability of TSC guidance over these times, and the complexity of interpreting Hydrogen concentration in terms of core damage assessment.

It has been shown that significant containment threatening quantities of Hydrogen are not present this early in any known events, that very rapid events produce Hydrogen many times faster than it can be removed by recombiners, and that there are many easier-to-use indications of a severe accident than Hydrogen early in an event. In short, the knowledge of Hydrogen concentration early in a severe accident is not expected to play a major role in the guidance to be developed since this information is at best only corroborative and at worst may be superfluous or not pragmatically useful.

6.0 Summary

It is clear that Hydrogen concentration in containment can be an important parameter in assessing post accident conditions. The unavailability of this parameter, with its inherent time delay, is not crucial to the activities that must be performed and the decisions that must be made in the first sixty to ninety minutes into a severe accident. Other parameters that read out in real time, or in near real time, are of much greater utility to the operator in the time frame of interest.

Key among these activities is the operator's overriding concern to restore adequate injection to the RCS. The existence of measurable quantities of Hydrogen in containment, even if measured, will not change this priority. The one step currently dependent on Hydrogen concentration is the starting of the recombiners. For the beyond DBA events under consideration, recombiner operation will not significantly affect the Hydrogen concentration in containment since they are sized for DBA events, not severe accidents.

The conclusion from these arguments is that Hydrogen monitoring early in an event does not play a crucial role in mitigating the event. Later in the event, when this information can be used effectively, the data is important to the decisions concerning mitigating actions chosen, particularly in regard to possibly inerting the containment with steam to prevent explosive Hydrogen concentrations from forming. During the first sixty to ninety minutes after an event however, other parameters provide the real time information upon which the operators can assess the event and make the appropriate decisions for its mitigation.

TABLE 1

DESCRIPTION OF ACCIDENT SEQUENCES ANALYZED

CASE 1:	Total loss of all feedwater with no injection available
CASE 2:	Five square foot cold leg break with both trains of injection available and SITs available (3 out of 4). Recirculation mode not available.
CASE 3:	Five square foot cold leg break with one train of injection available and SITs available (3 out of 4). Recirculation mode not available.
CASE 4:	Five square foot cold leg break with no injection capability, but with SITs available (3 out of 4).
CASE 5:	Five square foot cold leg break with no injection capability and no SITs available.

GENERAL NOTE: These are not necessarily limiting cases as analyzed. They are intended however, to show approximate magnitudes, time scales and trends. The use of more limiting cases would not affect the arguments and conclusions of this paper. In particular, note that while none of the cases analyzed showed flammable concentrations in containment within 1.5 hours into the event, other, more limiting cases, could possibly show this. Hence, no arguments were made herein based on flammability conditions not being reached. The cases analyzed do show that only very extreme and limiting cases would show flammability this early into an event.

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TABLE 2

SURVEY OF SCENARIOS TO ESTIMATE HYDROGEN CONCENTRATION IN CONTAINMENT

	CASE 1 TLOF NO SI	CASE 2 3 SITS/ 2 SI	CASE 3 3 SITS/ 1 SI	CASE 4 3 SITS/ NO SI	CASE 5 NO SITS/ NO SI
H_2 Mass by 1 hr (lb mass) *	0	0	0	295	250
H_2 Mass by 1.5 hr (lb mass) *	26	195	140	310	300
H_2 Volume in Containment by 1.5 hr (v/o) *	0.23	1.71	1.23	2.72	2.63
Earliest Indication of H_2 in Control Room (hrs) +	2.0	1.9	1.9	1.0	0.5

* Includes Zirconium oxidation, radiolytic effects, and other metal oxidation

\+ Assumes 0.1 v/o instrument threshold and 30 minute instrument delay time

Figure 1

H2 % IN CONTAINMENT VS TIME

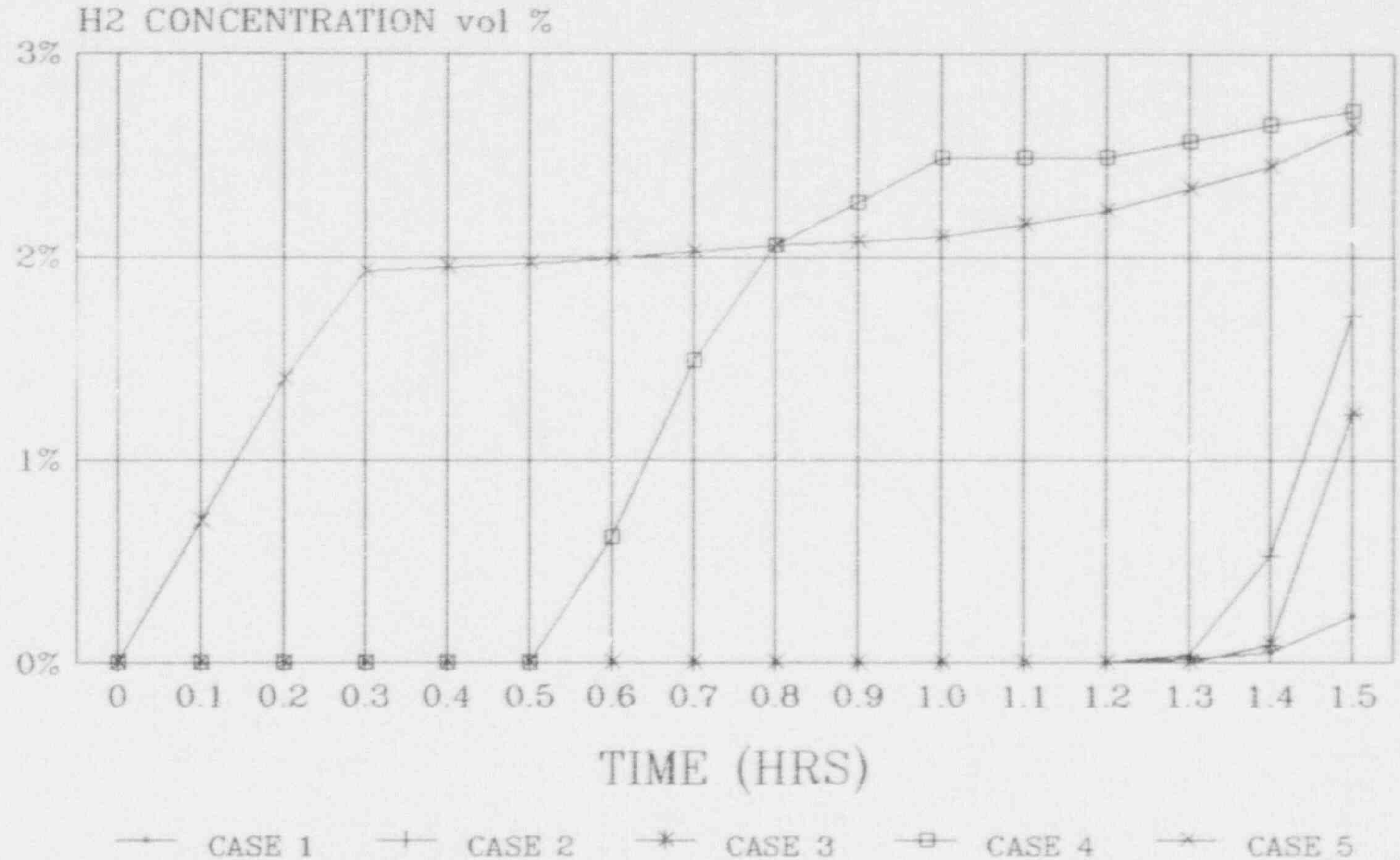

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Figure 2

H2 % AS INDICATED IN CONTROL ROOM

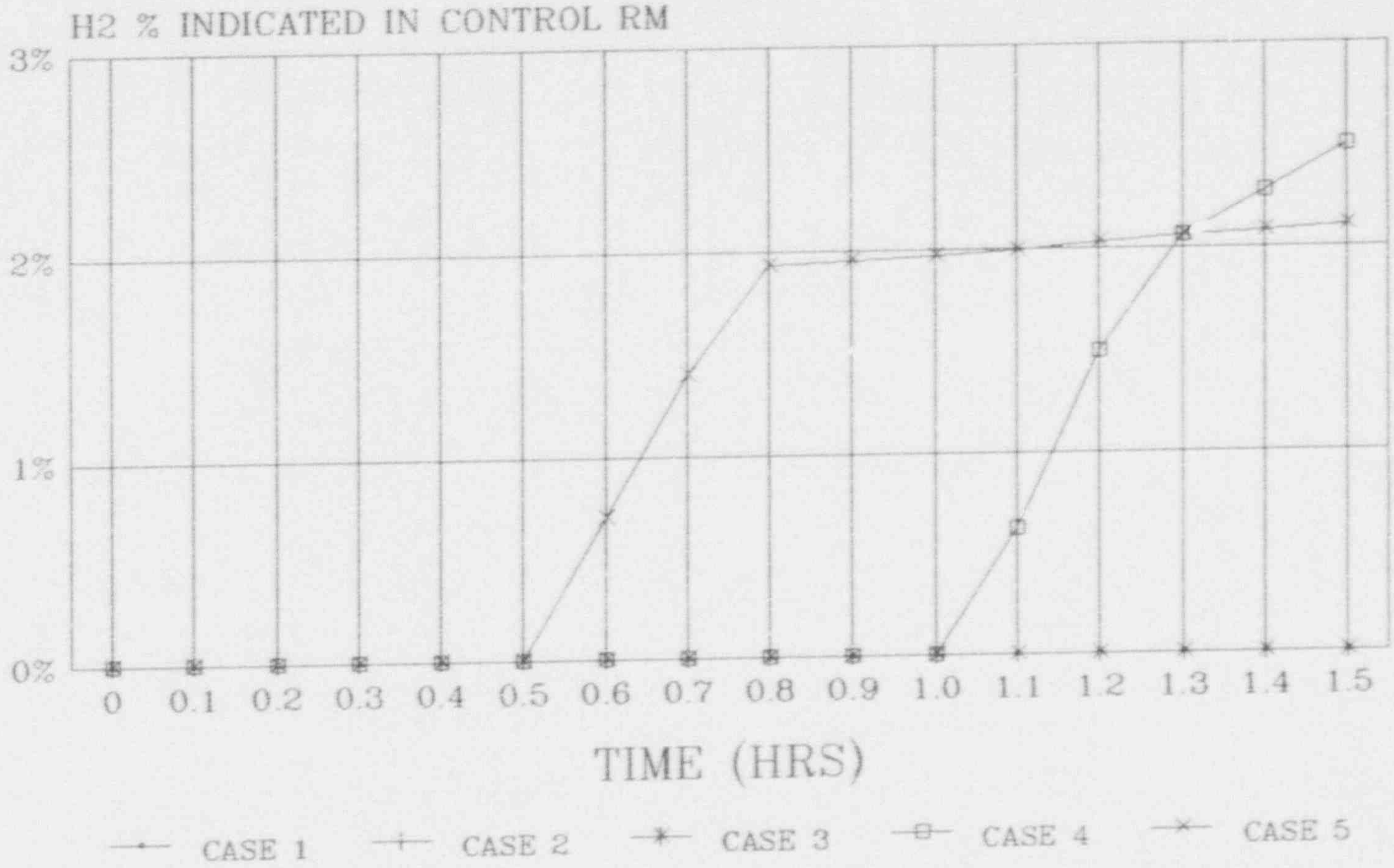

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Figure 3

CORE EXIT TEMPERATURE VS TIME

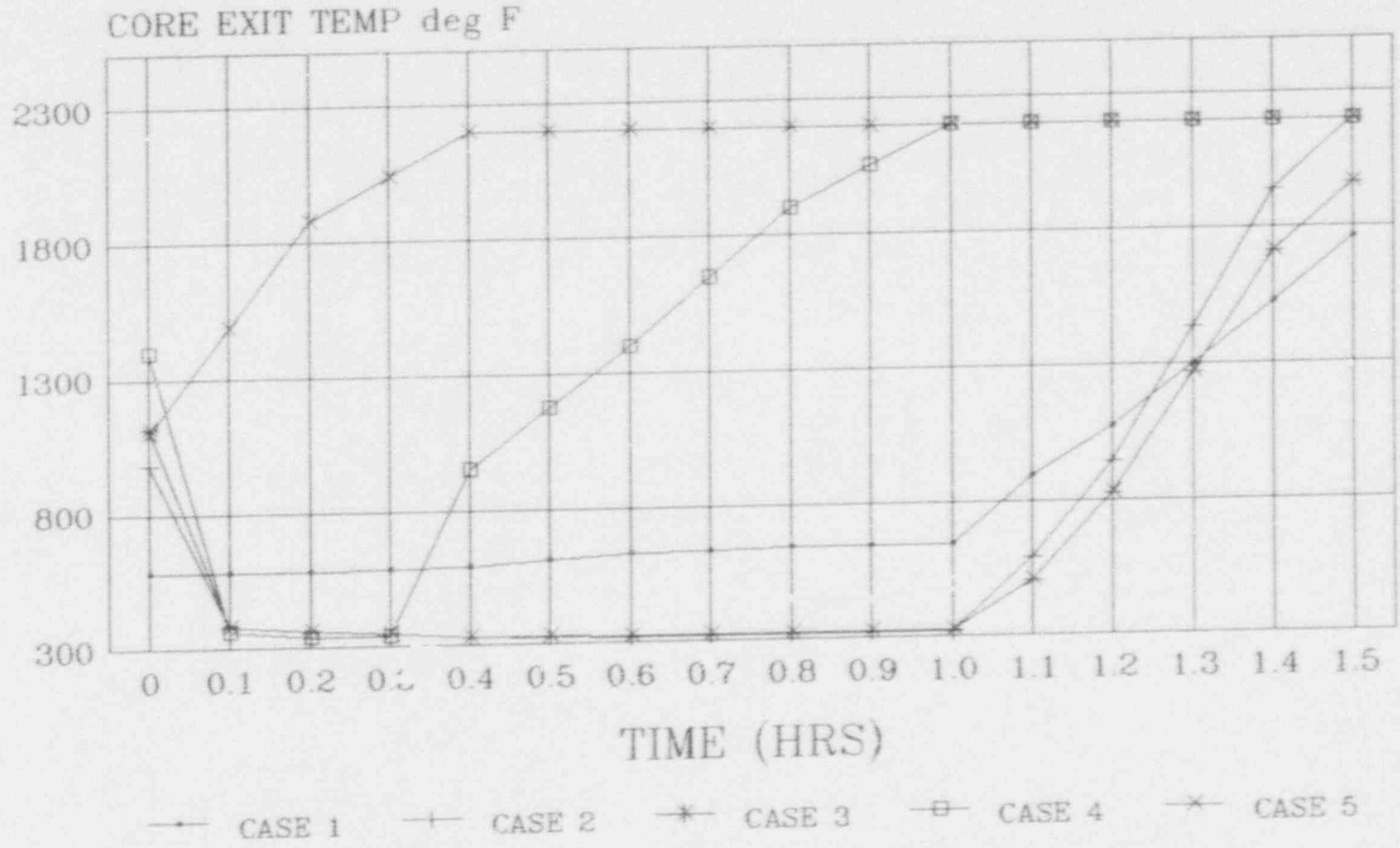

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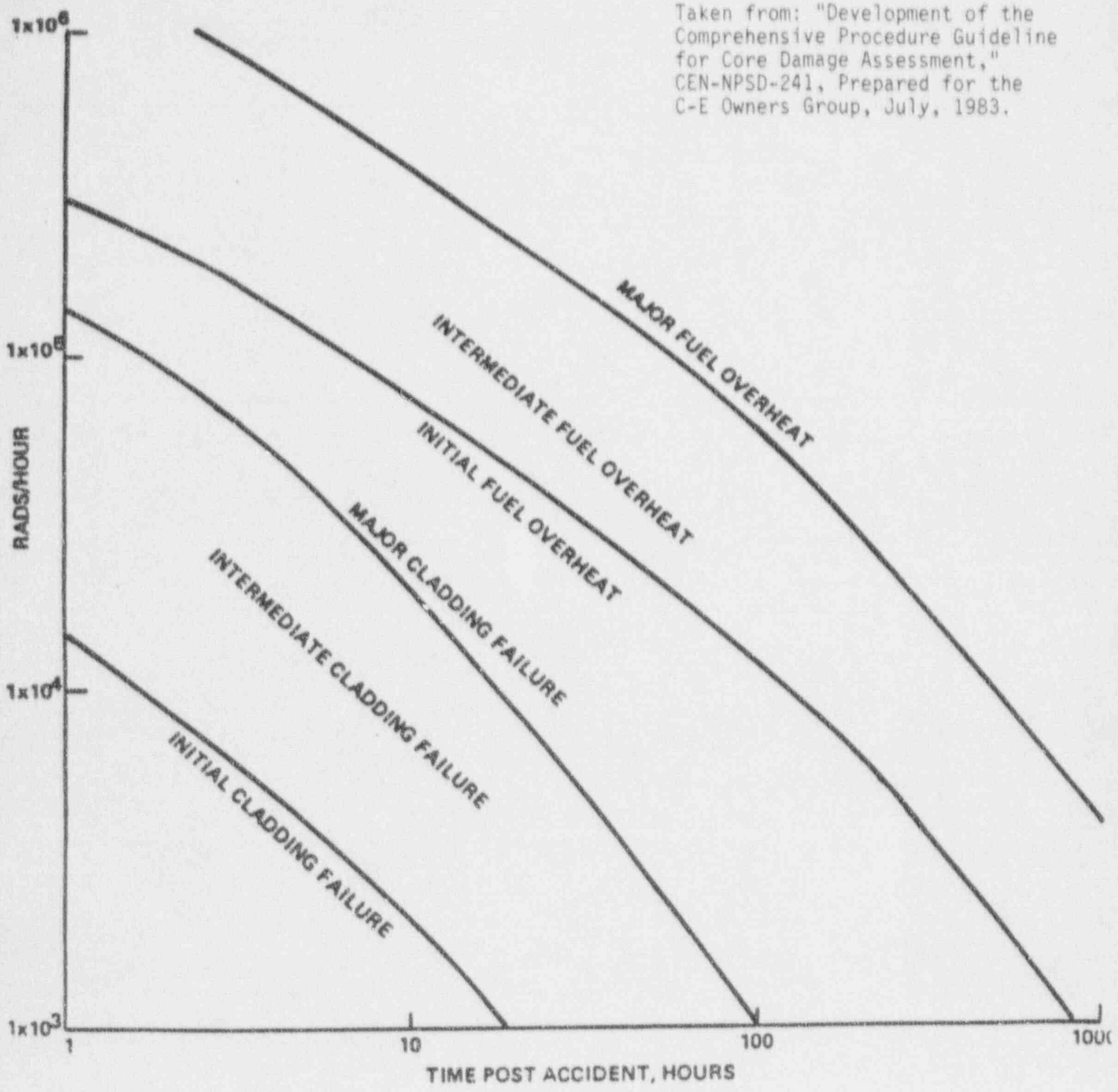
FIGURE 4

TYPICAL ANALYSIS FOR POST ACCIDENT DOSE RATE INSIDE A CYLINDRICAL CONTAINMENT



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APPENDIX A

A Study of Core Wide Cladding Oxidation and Hydrogen Release During Design Basis LOCAs

A cursory review of ABB recorded calculations for licensing the Arkansas NSSS was made to survey the calculations of core wide cladding oxidation during postulated design basis LOCAs. The purpose of this review is to form a qualitative picture of the timing and extent of Hydrogen release to the containment resulting from design basis core uncovery calculations. As required by 10CFR50.46, the calculated core wide cladding oxidation must be less than 1% for a broad spectrum of postulated breaks in the primary piping. The survey which covered both large break and small break LOCAs showed that the Cycle 1 results have remained bounding for all future cycles, namely, Cycles 2 through 9.

The core wide cladding oxidation result is translated to Hydrogen released to the containment using the following conversion:

> For the SONGS 3410 Mwt NSSS, oxidation of 100% of the core's Zircaloy produces 5.07E+5 std ft^3 of Hydrogen (Reference: CENPSD-241). Using total core power as a basis for similitude, for the Arkansas 2825 Mwt NSSS, oxidation of 100% of the core produces roughly 4.2E+5 std ft^3 of Hydrogen.

Using this conversion, the 1% licensing criterion for core wide cladding oxidation translates into 4.2E+3 std ft^3 of Hydrogen for Arkansas.

The containment Hydrogen monitors have scales which read from 0% to 10% of the containment volume. Using rough numbers, for a containment of 2.0E+6 ft^3 and assuming the Hydrogen monitor reads 0.1%, the monitors will first detect Hydrogen in excess of 2,000 std ft^3. Therefore, at the limit of design basis licensing space for 1% core wide oxidation the Hydrogen monitors should just show a reading low on the scale of roughly 0.2% of containment volume.

Large Break LOCA

For the most limiting large break LOCA, the core wide cladding oxidation for Cycle 1 was calculated to be 0.617%. This translates to 2.6E+3 std ft^3 of Hydrogen. At this level of Hydrogen production in design basis licensing space, the containment monitors may just show a reading very low on the scale of 0.1% of containment volume. (Core wide cladding oxidation is based on the results of the COMZIRC code's analysis of the 1.0 double ended guillotine break in the pump discharge leg for the limiting time-in-life for the core of 1000 MWD/MTU.)

The limiting large break LOCA hot rod peak cladding temperature was calculated to be 2060°F (See Note 1) at 243 seconds into the transient. The peak local cladding oxidation for the hot rod is 9.79% of the cladding thickness. Further analysis of the hot rod thermal response shows that the highest rate of local oxidation occurs between 150 and 250 seconds and that after core reflood the local oxidation process reduces to a very low level before 500 seconds into the transient. Cladding rupture of the hottest fuel rod is predicted; therefore, the oxidation calculations include both sides of the ruptured cladding. This local oxidation in the ruptured region of the fuel rod is used in the core wide calculation with the added conservatism that all rods in the core are assumed to rupture.

Based on the hot rod thermal response described above for the postulated large break LOCA, if a reduction in ECCS performance were assumed beyond design basis space, either the maximum PCT limit of 2200°F or the local cladding oxidation limit of 17% would be exceeded well before the core wide cladding limit of 1%. This means that cladding embrittlement and "shattering" of the affected fuel rods upon reflood of the core with cold ECCS inventory would occur well before Hydrogen release from excessive core wide oxidation became a problem.

Note 1: A temperature of 2060°F is the current value (from the Cycle 9 Analysis); a more limiting value of 2078°F (from the Cycle 1 Analysis) is referenced in the FSAR.

Small Break LOCA

A similar survey for the small break spectrum of breaks shows that the long term core uncovery process in not as limiting as the large break blowdown and reflood process. Even though the time of core uncovery for the limiting small break LOCA was over ten minutes, the peak local cladding oxidation of the hot rod was only 0.2046% of the cladding thickness compared to 9.79% for the large break LOCA. The limiting small break PCT is only 1460°F, which is more than 500°F less than the large break limiting LOCA. This PCT occurred for the 0.1 ft^2 cold leg break at 760 seconds into the transient.

The core wide cladding oxidation calculation was not performed for the small break spectrum or for the limiting small break size since these results are clearly bounded by the large break calculations. However, using the peak local oxidation for the hot rod as if the entire core consisted of hot rods, the core wide oxidation is estimated to be less than 0.04% for this limiting small break LOCA. Using the conversion method described above, this translates into less than 200 std ft^3 of Hydrogen. This level of Hydrogen release is probably not detectable by the containment monitors.

Based on the hot rod thermal response describe above for the postulated small break LOCA, if a reduction in ECCS performance were assumed beyond design basis licensing space, the local cladding oxidation process would reach a "run-away" condition during the core uncovery period before the ten minute point in the transient. Excessive embrittlement of the cladding in the core would therefore occur before Hydrogen release from core wide oxidation becomes detectable.