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SUBJECT: Provides summary of analyses rept for analytical effort. Analyses demonstrate that containment structural integrity will not be threateded by hydrogen generation & combunstion.

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Donald C. Cook Nuclear Plant Units 1 and 2
Docket Nos. 50-315 and 50-316
License Nos. DPR-58 and DPR-74
HYDROGEN CONTROL PROGRAM (10CFR50.44(c))
SUBMITTAL OF ANALYSES

U. S. Nuclear Regulatory Commission
Document Control Desk
Washington, D. C. 20555

Attn: T. E. Murley

February 26, 1993

Dear Dr. Murley:

In an NRC letter dated April 10, 1989, it was indicated that the 10CFR50.44 hydrogen control review effort for the Donald C. Cook Nuclear Plant, which had been terminated by the NRC in 1986, would be subsumed into the Individual Plant Examination (IPE) effort. As a result of this direction, the IPE and 10CFR50.44 analysis efforts for Cook Nuclear Plant were performed as parallel but separate interfacing programs. Indiana Michigan Power Company (I&M) submitted the Individual Plant Examination results in letter AEP:NRC:1082E dated May 1, 1992. In letter AEP:NRC:500X dated August 5, 1992, I&M committed to complete by February 28, 1993, the analyses pursuant to 10CFR50.44 to demonstrate the ability of the hydrogen control system to mitigate the consequences of the release of hydrogen into Cook Nuclear Plant containment during postulated degraded core accidents. The purpose of this letter is to provide the report of this analytical effort.

The attachment to this letter provides a summary of the analyses required by 10CFR50.44 paragraph (c)(3)(vi)(A). The sequences selected for analysis were based on significant sequences found in the IPE. These analyses demonstrate that the containment structural

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integrity will not be threatened by hydrogen generation and combustion, and that necessary equipment will survive the conditions created by the burning of hydrogen.

Sincerely,

E. E. Fitzpatrick
Vice President

rbb

Attachment

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ATTACHMENT TO AEP:NRC:0500Y

HYDROGEN CONTROL PROGRAM (10CFR50.44(c))

FOR THE

DONALD C. COOK NUCLEAR PLANT

SUBMITTAL OF ANALYSES

1.0 INTRODUCTION

The Nuclear Regulatory Commission requires in 10 CFR 50.44 that reactor containments be able to accommodate, without loss of containment integrity or degradation of vital equipment, the hydrogen that may be generated during degraded core accidents. As a result, the ice condenser containment design at the Cook Nuclear Plant was required to include hydrogen control systems capable of accommodating an amount of hydrogen equivalent to that generated from the reaction of 75% of the cladding in the active fuel region with steam. The hydrogen generated by such a reaction has been judged to bound the amounts of hydrogen likely to be generated in degraded core accidents in which core degradation is arrested prior to core meltdown.

In response to the above requirement, the Distributed Ignition System (DIS) was installed at the Cook Nuclear Plant. This system is currently operable and it has been reviewed and approved by the NRC staff in a Safety Evaluation dated December 17, 1981 [1]. Considerable analyses and experiments have been performed to demonstrate conformance with the above requirements, as required by 10 CFR 50.44 paragraph (c)(3)(vi)(A). In an NRC letter dated April 10, 1989, it was indicated that the final confirmatory analysis effort, which was terminated in 1986, would be subsumed into the Individual Plant Examination (IPE) effort. The base IPE analysis was submitted to the NRC on May 1, 1992 in letter AEP:NRC:1082E [2]. This current report describes the use of the IPE analysis to address compliance with the requirements of 10 CFR 50.44. As described in this report, the IPE analysis was used to establish the more likely degraded core sequences. The containment response analysis performed for the IPE was modified to include the requirements of 10 CFR 50.44, and analysis of appropriate sequences was then performed.

The computer analysis of the containment response to hydrogen generating sequences provides an understanding of the timing and related hydrogen combustion rates in the various regions of the containment. This information is useful in determining heat loads on equipment required to survive the hydrogen combustion environment. Due to the approximations necessary to perform an integrated analysis of both the reactor coolant system and containment, the detailed combustion characteristics predicted by the computer code only approximate the conditions expected in a containment region, particularly for the pressure response to hydrogen combustion. In containment regions where pressure response is of particular interest, hydrogen flow conditions predicted by the sequence analysis are used to re-evaluate the code predictions based on the response expected from a review of

applicable experiments. Conclusions on the adequacy of the DIS for hydrogen control are then drawn on the combination of experiment and analysis, as required by 10 CFR 50.44 paragraph (c)(3)(iv)(A).

Two other hydrogen control systems are installed in the Cook Nuclear Plant, the hydrogen skimmer system and the hydrogen recombiners. The hydrogen generation criteria of 10 CFR 50.44 (c)(3)(vi) are well beyond the capability of either of these systems. The hydrogen skimmer system was installed to draw air from confined areas in the containment to prevent a combustible mixture of hydrogen from building up in these areas in the event of a design basis accident. In a design basis accident, less than 1% of the zirconium is expected to react with water. The DIS has igniters in these same confined areas, which can take over for the hydrogen skimmer system in controlling hydrogen in those areas in the event for the more severe accident conditions. Likewise, the hydrogen recombiners were not intended to control hydrogen in the concentrations and at the generation rates required under this section of the regulation. The use of hydrogen recombiners will be reserved for long term hydrogen control after the accident conditions have stabilized. This report only addresses the effectiveness of the DIS in controlling hydrogen. The existing UFSAR addresses both the hydrogen skimmer system and the hydrogen recombiners.

Section 2 provides a summary description of the methodology used to choose accident sequences for analysis, the computer code and models used to analyze those sequences, and the results of the sequence analysis. A complete report on the sequence analysis is provided in the Appendix. The containment structural adequacy is reviewed in Section 3 of this summary, and equipment survivability analysis is reviewed in Section 4. Section 5 discusses the use of the head vents on the hydrogen control analysis. The conclusions of the hydrogen control analysis are summarized in Section 6.

2.0 ACCIDENT SEQUENCE ANALYSIS

In an accident sequence that leads to a degraded core, water inventory is lost from the reactor coolant system until the core is uncovered. With the core uncovered, there may be insufficient steam to carry the decay heat away, resulting in a heatup of the fuel rods. When the fuel rod zirconium cladding reaches approximately 1800°F, the zirconium begins reacting with steam to form zirconium dioxide and hydrogen in an exothermic reaction. Within minutes, the core will reach the uranium dioxide and zirconium melting point, and the core will begin to slump. During the time of core uncovery, hydrogen generation is usually limited by a lack of steam to a relatively low rate. To stop the progression of the accident, the core must be recovered with water. This recovery will produce a large amount of steam as the core is quenched. This steam, with the already overheated cladding, will allow for a large but brief peak in the hydrogen generation rate. The thermal shock may also shatter the intact fuel rods at that time.

The hydrogen generated by the zirconium water reaction is released to the reactor coolant system and then out the coolant system breach into the containment. This breach could be a break in the reactor coolant system or a release path through the reactor coolant pump seals or through the safety or power operated relief valves if the accident was initiated by a transient. The hydrogen may reach a burnable concentration in containment, threatening equipment by the high heat flux. If the hydrogen builds up to a sufficiently high concentration before the burn begins, the resulting pressure pulse may even threaten the containment integrity.

This section overviews the methodology and results of the sequence analysis. The complete report on the hydrogen control sequence analysis is provided in the Appendix to this report. The acceptance criteria for this hydrogen control analysis are containment structural integrity and survivability of vital equipment. The various sequences and analytic assumptions used in the analysis provide a basis for showing compliance with the acceptance criteria, which appears in subsequent sections of this report.

Accident Sequence Selection

Sequences were selected for analysis based on several criteria. First, the most probable sequences were chosen based on the Individual Plant Examination. These were then binned into similar

sets of sequences based on the hydrogen generation rates, and a representative case for each set was chosen for analysis. Note that these are not necessarily the most probable sequences. The core pressure is important to the rate of core reflood, since it limits the ECCS flow rate available to reflood the core. Thus, for hydrogen generation, the core pressure at the time of core recovery is the primary variable in dictating the hydrogen generation rate. Therefore, a large LOCA sequence, a small LOCA sequence, and a sequence initiated by loss of component cooling water was analyzed to cover the spectrum of low, intermediate, and high system pressures at core recovery. These sequences cover the range of near atmospheric pressure, steam generator pressure (about 1100 psi) and full reactor coolant system pressure (above 2250 psi). In addition, several sensitivity analyses were performed. Detailed justification for the selection of these sequences is provided in the Appendix.

Accident Sequence Modelling

To analyze the sequences, the MAAP3.0B [3] code was used. This code combines a nuclear steam supply model with an ice condenser containment model, and was used in the IPE analysis. The original MAAP hydrogen burn models were modified to reflect the hydrogen burn completeness correlation provided in an earlier submittal [4]. This correlation is the same as is used in the HECTR code [5,6], and was supported most recently by the Nevada Test Site (NTS) [7] large scale hydrogen burn experiments for premixed conditions.

For any scenario in which the core geometry is sufficiently intact to be recoverable, less than 75% of the cladding would have reacted. To have a reasonable expectation of a recoverable core, recovery is initiated so that approximately 50% of the core nodes have reached the melting point. The core geometry is kept artificially intact to maximize the surface area for steam water reaction on recovery. To achieve the 75% zirconium cladding reaction required by 10 CFR 50.44 (c)(3)(vi), an artificial hydrogen tail was added to the analysis. This was similar to the strategy used by the Boiling Water Reactors with Mark III containments [8].

A maximum ignition criteria of 6% hydrogen concentration for typical containment regions was used in this analysis, consistent with the most recent hydrogen analysis effort for the Cook Nuclear Plant [4]. This ignition criteria bounds the 5.3% hydrogen concentration for a pre-mixed volume which is supported by the NTS experiments [7]. The MAAP hydrogen burn models were developed based on the assumption of discrete burns in pre-mixed volumes. For continuous injection of hydrogen into a well mixed volume, as would

be the case for most containment regions of the Cook Nuclear Plant in a degraded core accident, ignition would be at a sufficiently low average hydrogen concentration that no significant pressure pulse would typically be expected [7,8]. Since the assumption of ignition at a maximum of 6% hydrogen concentration does produce a substantial pressure peak, this assumption was used to provide a conservative bound on the pressure response to a hydrogen burn in containment.

The hydrogen ignition criterion of 6% was used in both the upper and lower regions of containment as an initial ignition criterion. The first ignition would promote very good local mixing. After the first ignition, the ignition criterion is reset to the lower flammability limit of hydrogen. The lower flammability limit is the lowest concentration of hydrogen that will propagate a flame, and in the MAAP code is calculated by including the affects of temperature and steam concentrations. For containment conditions typically calculated in the MAAP code, the lower flammability limit is about 4.9% hydrogen. The code results will then more closely approximate a continuous burn as seen in continuous injection experiments. This lowering of the ignition criterion in the lower containment is assumed to affect both the lower compartment and annular regions of the lower containment, since they are adjacent with a large interconnection area.

In the presence of a water fog at the outlet of the ice condenser, the energy required to vaporize some or all of the water in the fog would suppress the flame propagation. Therefore, an ignition and flame propagation penalty would be expected in this region. Earlier analysis [4] expected a 2% penalty on the ignition of hydrogen in this region, for an ignition criterion of 8% hydrogen. More recent experiments have measured the production of fog at the outlet of the ice condenser [9] and a new analysis has addressed the impact of fog on the propagation of hydrogen flames [10]. Based on the newer work, ignition and relatively continuous burning would be expected at the outlet of the ice condenser for most sequences. This work found a best estimate ignition criterion of slightly over 7% when using the worst fog concentration measured in the experiments. The ice condenser inlet steam conditions for typical accident sequences are less severe than the inlet steam conditions of the experiments. Therefore, even lower ice condenser outlet fog concentrations would be expected for typical accident sequences, resulting in an ice condenser outlet hydrogen ignition criterion significantly lower than 7%. However, adequate proof of this would require extensive work. Therefore, a fogging ignition criterion of 8% at the outlet of the ice condenser was used in this analysis. The upper plenum ignition criterion was not set lower after a burn since the fog actually inerts the incoming flow stream.

Hydrogen Production Results

The three base case sequences provide a spectrum of hydrogen generation rates and mechanistic zirconium oxidation fractions. For each case, a non-mechanistic hydrogen production "tail" of 0.1 lb/sec. was added to obtain an effective hydrogen production equivalent to 75% zirconium oxidation. The low pressure sequence produced the least mechanistically produced hydrogen and the highest peak hydrogen generation rate at reflood. The high pressure sequence showed the opposite pattern, with the lowest peak rate on reflood. The intermediate pressure sequence produced intermediate results on both of these parameters. These are summarized below.

Mechanistic Hydrogen Generation

	Large LOCA	Small LOCA	CCW
Generation Rate (lb/sec)			
- prior to reflood	0.13	.012	.018
- during reflood (peak)	8.1	5.0	3.0
Mechanistic oxidation	19.3%	35.6%	51.0%

Hydrogen Combustion Characteristics

In the three base cases, the first burn does not occur until the high production rate associated with core reflood has begun. This first burn is in the lower containment for all cases. For the CCW case, the first lower compartment burn is nearly simultaneous with the first burn in the upper plenum of the ice condenser. In all cases, significant burning is predicted in the lower compartment. The lower containment sprays keep the steam concentration in lower containment sufficiently low that the burning is nearly continuous. Only brief periods of inertion by steam were observed.

Burning is predicted at the outlet of the upper plenum of the ice condenser in only the loss of CCW sequence, although the ignition point is nearly reached during reflood in the large break LOCA sequence. Although the peak hydrogen production rate is higher in the large LOCA case, the total amount of hydrogen generated during the large LOCA reflood is not very large, resulting in a somewhat smaller hydrogen concentration passing through the ice condenser.

The loss of CCW sequence is also the only case that shows hydrogen concentrations reaching the ignition point in upper containment.

The relatively high hydrogen production rate for the long reflood period allows sufficient concentration to build up in this region to reach the ignition point.

The hydrogen laden air is drawn from the upper containment to the annulus, which is a region of lower containment. With the hydrogen burning in the adjacent lower compartment region, the ignition criterion has been reset to the lower flammability limit. For the small and large break LOCA cases, the initial ignition criterion for the upper containment was not met, but the mixture exceeded the concentration of the lower flammability limit for a long period of time. It should be noted that the lower flammability limit was exceeded for these two cases only during the non-mechanistic period of the hydrogen release. This leads to significant burning in the annulus. In the loss of CCW sequence, the initial burn in the upper containment resets the ignition criteria to the lower flammability limit, shifting the majority of the burning from the annulus to the upper containment for this case. If the upper containment initial ignition criterion had been set closer to the lower flammability limit in the small or large break LOCA cases, a similar pattern would have been seen. In any event, it can be concluded that the air returning to the lower compartment will have no larger hydrogen concentration than allowed by the lower flammability limit.

The following table summarizes the amount of hydrogen burned in each region for the base sequences.

Hydrogen Burnt by Region (lbs)

	Large LOCA	Small LOCA	CCW
Lower Containment	160	340	231
Upper Plenum	0	0	198
Upper Containment	0	0	583
Annulus	900	605	46

3.0 CONTAINMENT STRUCTURAL ADEQUACY

The containment compartment pressure and temperature results of the sequence analyses were used to determine if the acceptance criteria were met. The maximum pressure peak is used to determine if the containment maintains structural integrity. The acceptance criteria of 36 psig was used for the ultimate containment structural capacity, as approved in a Safety Evaluation from the NRC dated February 21, 1985 [11].

Only relatively low pressure pulses are shown in the sequence analyses which were summarized in Section 2 and the Appendix. The maximum pressure pulse of 28 psia, or 13.3 psig, was seen in the loss of CCW sequence. This pressure pulse was caused by the initial burn in the upper containment. This pressure is well below the acceptance criteria of 36 psig.

In addition, the conclusion of the series of experiments ending in the NTS experiments [7] was that large deflagrations are not expected in well mixed containment atmospheres with continuous hydrogen injection in the presence of active igniters. This supports the conclusion of the sequence analyses.

4.0 EQUIPMENT SURVIVABILITY

The equipment needed to achieve and maintain shutdown conditions for a degraded core accident were provided in the Safety Evaluation Report for the DIS [1] and are reproduced below. The original analysis of the survivability of instrumentation and equipment utilized heat transfer calculations of the critical equipment supplemented by evaluations of equipment subject to hydrogen burn environment [12]. This methodology took credit for the submergence of equipment when possible. Subsequent to that date, more extensive experiments have been performed at the Nevada Test Site facility, which support both the methodology and conclusions of the earlier analysis [13]. For this study, survival of the critical equipment has been verified for the conditions calculated in the MAAP analyses.

Essential Equipment
a) Narrow-range steam generator level monitors
b) Pressurizer level monitors
c) Pressurizer pressure monitors
d) RCS wide range pressure monitors
e) Core exit thermocouples
f) RCS loops RTDs
g) Air recirculation/ hydrogen skimmer fans
h) Distributed ignition system components
i) Containment water level monitoring system

also to be considered

a) Containment isolation valves
b) Gaskets and seals for flanges, electrical boxes, air locks, and the equipment hatch
c) Electrical penetrations

Consistent with the Safety Evaluation [1], the pressure transmitters located in the lower containment are taken as representative of the critical equipment, and specifically analyzed for thermal response. The adequacy of this approach is supported by the extensive NTS equipment experiments. In these experiments, a broad range of equipment was exposed to hydrogen burn conditions, including cables, pressure transmitters, solenoid valves, a motor operated valve, limit switches, a fan motor, resistance temperature detectors, hydrogen igniters, and containment penetrations. All but a few equipment specimens operated normally during and after all tests, and all cables passed post-test electrical checks.

Hydrogen Burn Thermal Effect on Equipment

In the sequence analyses, the high initial ignition criteria in the various regions allows the maximum amount of hydrogen to return to the lower containment volumes. This will maximize the hydrogen burning in the lower volumes, which will maximize the thermal load on equipment in those volumes. It was shown above that the hydrogen to be returned to the lower compartment is limited to the lower flammability limit in the upper containment. However, in all but the loss of CCW case, the high upper containment ignition criterion forces the burning to be in the annular region surrounding the lower compartment, which maximizes the heat flow into the lower compartment. In the loss of CCW case, the bulk of this burning occurs in the upper containment.

A simple, thin steel (1/4") heat structure was added to the MAAP model to represent a piece of equipment. The peak temperature of this heat structure was used as an indicator of the most severe conditions in the lower compartment for further analysis. The large break LOCA base case was found to be limiting for thermal response, since the hydrogen burns in that region occurred shortly after blowdown when the equipment is still quite hot. This is true even though the small break LOCA case predicted over twice the amount of hydrogen to burn in the lower compartment.

To ensure the limiting loads on the equipment were obtained, two variations of the large break LOCA case were analyzed. First, two instead of one containment air recirculation fans were assumed to be operating. This is shown to not significantly affect the hydrogen burn characteristics and locations; the base case large LOCA was found to remain limiting.

The second variation of the large break LOCA case was to use core parameters representative of Unit 2 instead of Unit 1. Unit 1 was originally chosen since it contains more zirconium than Unit 2. Unit 2, however,. operates at a 5% higher power. In addition, the fuel rod array in Unit 2 is 17x17 instead of 15x15, with a greater surface area for zirconium oxidation. The Unit 2 sensitivity case results in a slightly greater peak hydrogen generation rate at reflood, and a slightly greater peak equipment temperature in the lower compartment.

A third sensitivity with a potential interest to equipment thermal response is the CEQ fan failure case. Although fan failure is not expected as discussed below, it was the intent of this sensitivity to determine whether survival of the containment air recirculation (CEQ) fan was necessary to obtain acceptable equipment

survivability results. The loss of CCW sequence provides the greatest challenge to the fans, so that base case was modified to assume CEQ fan failure at the time of the first burn in the upper containment. The lower circulation flow has the effect of increasing the hydrogen concentration exiting the ice condenser, where most of the hydrogen burning now occurs. The impact of the CEQ fan failure was found to have no effect of the peak equipment temperature in the lower compartment.

A thermal model of a Foxboro pressure transmitter was developed to obtain the temperature response of the transmitter internals. The external conditions for this heat transfer calculation were calculated by the MAAP code for the limiting sequence for thermal response, the Unit 2 large break LOCA. The analysis determined the temperature of the pressure transmitter cover, the air inside the cover, and the surface of the electronics inside the cover. The results indicate that the electronics temperature is not expected to exceed 200°F. The NTS experimental measurements of the electronics of a Foxboro pressure transmitter reached 246°F, and continued to function. Therefore, essential equipment is concluded to survive the thermal environment caused by hydrogen burning under the rules of 10 CFR 50.44 (c) (3)(iv)(A).

Containment Air Recirculation Fan

The assumption of the high ignition criterion of 8% hydrogen concentration at the ice condenser outlet due to fogging has a significant impact on the evaluation of the survivability of Containment Air Recirculation fans. Given a more moderate fogging ignition penalty at the ice condenser outlet, significant burning would be expected there. As described above, the ignition criterion of 8% includes significant conservatism in the estimation of the fog concentrations at the ice condenser outlet. As a result of hydrogen burning in the upper plenum, insufficient hydrogen would be expected to build up in the upper containment to support a global burn on a best estimate basis. A global burn is a burn that propagates through a large fraction of a volume, consuming a significant fraction of the hydrogen. A global burn initiated at a relatively high hydrogen concentration in this region has been shown before to cause the collapse of the Containment Air Recirculation fan housing [14]. However, based on the evaluation of continuous injection experiments provided below, a hydrogen burn induced pressure excursion sufficient to destroy the fans is not expected.

In the MAAP analyses presented in the Appendix, the initial pressure rise of 10 psid which accompanied hydrogen burning in the upper compartment is due to the conservatism employed in the

analysis, i.e., ignition criterion of 6 vol.% H_2 and the use of the HECTR code burn completeness correlation. The HECTR code burn completeness correlation represents an upper bound of scattered burn completeness test data of premixed combustion in a closed chamber without continuous injection. In the NTS tests with continuous injection, the observed pressure rise was modest compared to that without injection. The upper compartment is an open through-flow volume with continuous injection of hydrogen from the upper plenum. The pressure rise associated with burning is expected to be small. Therefore, the hydrogen modelling combination is overly conservative in the prediction of pressure pulses for the Cook Nuclear Plant upper containment region. Insights gathered from the NTS tests support this observation [7, 15]. Although pressure pulses due to hydrogen burning of up to 6 psid were observed in NTS continuous injection tests at the time of first ignition, these pressure pulses were only seen for special conditions. In cases where a significant pressure pulse was observed, a wide boundary layer of a combustible mixture of hydrogen grew until it came in contact with an igniter. The pressure pulse was due to the rapid propagation of the hydrogen burn through this boundary layer. The boundary layer was fed by the injection source of hydrogen and steam.

The configuration and hydrogen injection source in the Cook Nuclear Plant upper containment differs from this scenario. The hydrogen injection source in the upper containment is diffuse with a maximum hydrogen concentration of 8%, inerted by fog. The rate of increase in hydrogen concentration in the upper compartment is very slow (40,000 cfm fan flow at a maximum 8% concentration into the 746,000 cu. ft. volume upper containment). Containment spray induced upper compartment flows are expected to be high (in the range of several meters/second [16]), promoting good mixing. No boundary layer between ignitable and non- ignitable regions should exist, and combustion should initiate at the lower flammability limit. Therefore, a significant pressure producing deflagration is not expected in the Cook Nuclear Plant upper containment. For this region, the rate of hydrogen burning will rise to equal the hydrogen flow rate into upper containment. Therefore, the CEQ fans are concluded to survive the conditions caused by hydrogen burning under the rules of 10 CFR 50.44 (c) (3)(iv)(A).

Even though the fans are not expected to fail due to a burn in the upper containment, as a sensitivity analysis these fans were assumed to fail at the first burn in upper containment. Since this sensitivity analysis does not produce more severe results than the base case analyses, it can be concluded that the design function of the CEQ fans would have been met, and that failure of the CEQ fans would have been acceptable.

There are two design objectives for these fans. First, the fans are intended to provide good circulation of the steam released in the lower containment through the ice condenser to reach upper containment. This ensures that the ice condenser and upper containment sprays remove steam effectively, keeping the containment pressure to within its design basis value of 12 psig. However, due to the fact that the subject degraded core accident conditions are well beyond the design basis, the acceptance criterion for containment pressure for this analysis is the containment ultimate strength of 36 psig. The sequence analyzed shows that, even with a postulated fan failure, the peak containment pressure is 13.3 psig, (28 psia) which is well below the containment ultimate strength of 36 psig.

The second design basis for the Containment Air Recirculation system is support for the Hydrogen Skimmer System (HYS) flows. The HYS draws gases from the steam generator and pressurizer doghouses and the containment dome region to prevent combustible concentrations of hydrogen from accumulating in a design basis accident, in which a small percentage of the cladding is assumed to react with steam. For the degraded core accident sequences, the HYS would be greatly overloaded and this criteria cannot be met. For degraded core accidents, the DIS takes over, eliminating the need for HYS operation.

5.0 REACTOR HEAD VENTS

The reactor head vents were installed in the Cook Nuclear Plant in response to 10CFR50.44 (c)(3)(iii) to vent a hydrogen bubble in the reactor head in the event of a degraded core accident with significant hydrogen generation. This head vent is also used in the Emergency Operating Procedures to aid in vessel depressurization after all other mechanisms have failed, including both the primary and secondary power operated relief valves. The reactor head vent vents to the lower level of upper containment, and as such is a potential hydrogen source that can bypass the igniters in the lower containment and ice condenser upper plenum.

The primary purpose for the head vent is to relieve a "hard bubble" after hydrogen generation has occurred. At this time, it is assumed that the core is covered, and that hydrogen has accumulated in the reactor head. Since the core is covered, no time criteria exists for the speed of venting this bubble. The Emergency Operation Procedures direct the operator to read the hydrogen concentration in the upper containment before venting the hydrogen, and limit the time of venting so that a combustible mixture of hydrogen could not accumulate in the upper containment. The hydrogen could then be removed by the hydrogen recombiners. Since the venting procedure explicitly prevents a combustible mixture from accumulating, this use of the reactor head vent is supported.

The second use of the head vent is to relieve primary system pressure when all other depressurization system fail. Given the number of system failures needed to reach this point, this use is considered extremely unlikely. The head vent geometry and flow characteristics are very similar to the continuous injection experiments performed at NTS [7,15]. If the head vent is used to aid in depressurizing the core, a mixture of steam and hydrogen will be released at a high flow rate and momentum to the upper containment. For this configuration in the NTS experiments, a slow approach to ignition was found, with no significant pressure pulse when ignition occurred. In fact, the only cases where significant pressure pulses were seen in the NTS continuous injection experiments were those cases with only bottom igniters. The Cook Nuclear Plant upper containment has igniters both in the upper dome of the upper containment and on the steam generator and pressurizer doghouse walls. As seen in the NTS tests with continuous injection of a jet of hydrogen and steam, ignition would either be at a point where the jet passed a relatively low igniter, or as the hydrogen reached the top of the containment. In either event, ignition would occur while the hydrogen occupies a relatively small portion of the containment volume, and a pressure pulse sufficient to

damage or destroy the CEQ fans would not occur. Therefore, the use of head vents to depressurize the primary system in the event of a degraded core accident is acceptable.

6.0 SUMMARY AND CONCLUSIONS

To meet the hydrogen control requirements of 10 CFR 50.44, the Distributed Ignition System was installed at the Cook Nuclear Plant. As required by Section (c)(3)(vi) of that regulation, analyses have been completed to support the design of the hydrogen control system.

The analyses were based on the accident sequences identified in the Cook Nuclear Plant Individual Plant Examination. These analyses assumed that the core was recovered before the core became severely degraded, and that 75% of the zirconium in the core reacted with steam to generate hydrogen. The containment conditions that resulted from this hydrogen burning in the presence of the Distributed Ignition System was then calculated.

The regulation requires that the containment maintains its structural integrity, and that the equipment necessary to maintain safe shutdown and containment integrity be capable of performing their function during and after exposure to the environment created by the hydrogen burning. The analyses show that the maximum pressure predicted for hydrogen burn conditions is far less than the ultimate structural capability. In addition, the maximum temperature calculated in important equipment is shown to be less than the temperature required to threaten the capability of that equipment. Therefore, the analyses show that the design of the Distributed Ignition System is sufficient to control hydrogen under the requirements of 10 CFR 50.44.

APPENDIX TO

ATTACHMENT TO AEP:NRC:0500Y

HYDROGEN CONTROL PROGRAM (10CFR50.44(c))

FOR THE

DONALD C. COOK NUCLEAR PLANT

SUBMITTAL OF ANALYSES