UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
DUKE POWER COMPANY	)	Docket Nos. 50-369 O.L.
	)	50-370 O.L.
(William B. McGuire Nuclear Station, Units 1 and 2)	)	

NRC STAFF PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW IN THE REOPENED LICENSING BOARD PROCEEDING REGARDING HYDROGEN GENERATION IN THE FORM OF A SUPPLEMENTAL INITIAL DECISION

Joseph F. Scinto
Counsel for NRC Staff

Edward G. Ketchen
Counsel for NRC Staff

Stephen H. Lewis
Counsel for NRC Staff

April 13, 1981

TABLE OF CONTENTS

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
DUKE POWER COMPANY	)	Docket Nos. 50-369 O.L.
	)	50-370 O.L.
(William B. McGuire Nuclear Station, Units 1 and 2)	)	

NRC STAFF PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW IN THE REOPENED LICENSING BOARD PROCEEDING REGARDING HYDROGEN GENERATION IN THE FORM OF A SUPPLEMENTAL INITIAL DECISION

I. INTRODUCTION

1. On November 25, 1980, the presiding Atomic Safety and Licensing Board ("Licensing Board") entered an unpublished order[1/] which granted the August 15, 1980 revised motion of Carolina Environmental Study Group (CESG)[2/] to reopen this operating license proceeding and admitted CESG's revised Contentions 1-4, which are set out in the following pages.

2. Based on the evidence addressed at the reopened hearings held by the Licensing Board, we find that there is little likelihood of a loss-of-coolant accident sequence entailing generation of substantial quantities of hydrogen, hydrogen combustion, and containment breach that could result in offsite radiation doses in excess of 10 C.F.R. Part 100 guideline values. Our finding

---

1/ Duke Power Co. (William B. McGuire Nuclear Station, Units 1 and 2), Memorandum and Order Regarding CESG's Motion to Reopen Record, Slip Op. (November 25, 1980).

2/ "CESG Revised Motion to Reopen the Operating License Proceeding; Motion to Deny Applicant's Request for Fuel Loading, etc.; and Revised Contentions," dated August 15, 1980.

in this regard is based on measures which were adopted by Duke Power Company ("Duke") to reduce the possibility of operator interference with automatic ECCS operation and the measures adopted by Duke, including an Emergency Hydrogen Mitigation System, to deal with hydrogen generation if a low probability loss-of-coolant accident resulting in degraded core conditions should occur. These measures provide adequate assurance that such a sequence of events will not occur.

II. STATEMENT OF THE CASE AND REFERENCE TO RULINGS

3. As a result of previous hearings in this proceeding, the Licensing Board issued an Initial Decision on April 19, 1979,[3/] deciding all matters raised in issue in this proceeding prior thereto, in favor of the issuance of a full power operating license for both Units 1 and 2 of the McGuire station. However, the Licensing Board stayed the effectiveness of the initial decision "until further order by the Board following the issuance of a Supplement to the NRC Staff's Safety Evaluation Report addressing the significance of any unresolved generic safety issues." 9 NRC 489, at 547-48. NRC Staff Safety Evaluation Report, Supplement 3, which addressed the significance of the unresolved safety issues as they relate to the McGuire facilities, was published in May 1980.[4/] All that remains of the issues raised prior to April 1979 is for the Board to terminate the stay of its Initial Decision with respect to such issues, and to supplement such decision to reflect our decision on the matters in this reopened proceeding.

4. On June 9, 1980, CESG moved to reopen the record in this proceeding to consider issues relating to hydrogen release and rapid combustion in a pressure suppression station like McGuire.[5/] The Commission has previously ruled in

---

3/ Duke Power Co. (William B. McGuire Nuclear Station, Units 1 an 2), LBP-79-13, 9 NRC 489 (1979).

4/ SER Supplement 3 was entered into the evidentiary record without objection. Staff Exhibit H, Tr. 4006.

5/ "CESG's Motion to Admit New Contentions and To Reopen the McGuire Operating License Hearing," June 9, 1980.

the TMI case that certain issues relating to hydrogen generation and control are litigable under 10 C.F.R. Part 100 (CLI-80-16, 11 NRC 674 at 675, (1980)). By memorandum and Order dated November 25, 1980, we granted CESG's revised motion to reopen the record and admitted CESG Contentions 1 through 4 relating to hydrogen generation and control. Our November 25, 1980 Memorandum and Order indicates the Licensing Board's judgment that CESG's proposed contentions related to the matter of hydrogen generation control arising out of the TMI-2 accident may well shed significant light upon key safety findings which are required to be made before operation of McGuire Units 1 and 2 can be authorized. On November 25, 1980, we also granted Duke's motion for a low power license to the extent of authorizing fuel loading, initial criticality, and zero power testing.[6/]

5. On November 7, 1980, CESG moved to admit two additional contentions relating to "Class 9 accidents" and to emergency planning for such addidents.[7/] On February 13, 1981, the Licensing Board denied CESG's motion to add these two additional contentions.[8/]

6/ "Memorandum and Order Regarding Applicant's Motion for Summary Disposition" (unpublished). This Memorandum and Order denied Duke's request with respect to low power testing at up to 5% of full power. License NPF-9 for fuel loading, initial criticality and zero power testing was issued January 23, 1981. Two amendments have been issued to that license.

7/ "CESG's Reply to Applicant's Motion for Summary Disposition Regarding Application for License Authorizing Fuel Loading, etc.; Motion to Consolidate Near Term Operating License and Operating License Proceedings, and Further Contentions," November 7, 1980.

8/ "Memorandum and Order (Denying CESG's Motion to Add 'Further Contentions')," February 13, 1981.

6. Hearings on the hydrogen generation matters were held in Charlotte, North Carolina, on February 24-27, and March 3-6, 10-13, 17-19, 1981.[9/]

7. The decisional record in this proceeding consists of the following:

1. The material pleadings filed herein, including the petitions and other pleadings filed by the parties, and orders issued by the Board during the course of this proceeding.
2. The transcripts of the testimony of the evidentiary hearings held on February 24-27, and March 3-6, 10-13, 17-19, 1981 in fifteen volumes with pagination from 2674 to 5257.
3. All of the exhibits received into evidence.

8. In making the findings of fact and conclusions of law which follow, the Licensing Board considered the entire record of the proceeding and all of the proposed findings of fact and conclusions of law submitted by the parties. Each of the proposed findings of fact and conclusions of law which

---

9/ The record remained open for the limited purpose of providing the Staff with an opportunity to supplement the record, if needed, on questions relating to the potential for pyrolysis and combustion of polyurenthane insulating material. A Staff affidavit was submitted on March 27, 1981 and has been admitted as Staff Exhibit Q. We permitted the parties an opportunity to respond thereto and Duke filed an affidavit in response which has been admitted as Duke Exhibit 9. On the same day as Staff filed its affidavit, Mr. Jesse L. Riley, on behalf of CESG, also filed an affidavit in which he commented on a number of matters in the record. Mr. Riley's affidavit is discussed in Section VI.F. *infra*.

is not incorporated directly or inferentially in this supplemental Initial Decision is rejected as being unsupported in law or fact or as being unnecessary to the rendering of this Decision.

9. The Board is guided in this operating license proceeding by Appendix A, Section VIII of 10 C.F.R. Part 2, which in subsection (b) provides that the Board will make findings on matters in controversy among the parties.

III. STATEMENT OF THE ISSUES

10. Our Order of November 25, 1980 admitted the following four CESG contentions:

Contention 1 - The licensee has not demonstrated that, in the event of a loss-of-coolant accident at McGuire:

1. substantial quantities of hydrogen (in excess of the design basis of 10 CFR section 50.44) will not be generated; and

2. that, in the event of such generation, the hydrogen will not combust; and

3. that, in the event of such generation and combustion, the containment has the ability to withstand pressure below or above the containment design pressure, thereby preventing releases of off-site radiation in excess of Part 100 guideline values.

Contention 2 - Neither licensee nor NRC staff has demonstrated that a McGuire ice containment will not breach as the result of the rapid combustion of quantities of hydrogen which a dry containment would withstand.

Contention 3 - Neither licensee nor NRC staff has demonstrated that the emergency planning radius of 10 miles is sufficient for protecting the public from the radioactive releases of a low pressure, ice condenser containment ruptured by a hydrogen explosion.

Contention 4 - Licensee and NRC planning do not provide for crisis relocation which would be reuqired as a result of containment breach and radioactive particle release.[9/]

IV. SCOPE OF THE REOPENED PROCEEDING REGARDING HYDROGEN-GENERATION CONTROL MATTERS

11. Although 10 C.F.R. § 50.44 limits the amount of hydrogen, generated during the course of a loss-of-coolant accident, which must be taken into account in the design of nuclear reactor containment systems, the Commission, in its Memorandum and Order in the Three Mile Island case,[10/] indicated:"

> The Three Mile Island accident has in fact raised a safety issue regarding hydrogen control measures following a loss-of-coolant accident that should be addressed. The Commission believes that, quite apart from 10 CFR 50.44, hydrogen gas control could properly be litigated in [the Three Mile Island Nuclear Station, Unit No. 1] proceeding under 10 CFR Part 100. Under Part 100, hydrogen control measures beyond those required by 10 CFR 50.44 would be required if it is determined that there is a credible loss-of-coolant accident scenario entailing hydrogen generation, hydrogen combustion, containment breach or leaking, and offsite radiation doses in excess of Part 100 guideline values. The design basis assumptions of 10 CFR 50.44, in particular the assumption that hydrogen generation following a loss-of-coolant accident is dependent on ECCS design as opposed to actual ECCS operation, do not constrain the choice of credible accident sequences used under 10 CFR 100.11(a). Union of Concerned Scientists v. AEC, 499 F.2d 1069, 1090 (D.C. Cir. 1974). Thus we answer the second certified question in the affirmative. (emphasis added)
>
> *   *   *   *
>
> ". . . the hydrogen control issue can be litigated under 10 CFR Part 100. Under Part 100 the likelihood of an accident entailing generation of substantial (in excess of 10 CFR 50.44 design bases) quantities of hydrogen, the likelihood and extent of hydrogen combustion, and the ability of the reactor containment to withstand any hydrogen combustion at pressures below or above containment design pressure would all be at issue. A critical issue here would be the likelihood of an operator interfering with ECCS operation.

10/ Metropolitan Edison Co. (Three Mile Island Nuclear Station, Unit No. 1), Memorandum and Order, CLI-80-16, 11 NRC 674 (1980).

* * * *

> However, after the Three Mile Island accident the Staff has given licensees explicit instructions not to turn off prematurely the ECCS system. As noted above, it was operator interference with ECCS operation that was the root cause of the hydrogen generation problem at Three Mile Island Unit 2. In our view this instruction, which had not been issued when 50.44 and General Design Criterion 50 were promulgated, compensates for the less conservative analytical framework of Part 100, and serves as a basis to sustain the present hydrogen generation assumptions of 50.44 at least for the interim until the degraded core rulemaking can be completed.

11 NRC 674, 675-676.

12. Thus, the question of whether there is a credible loss-of-coolant accident scenario entailing hydrogen generation, hydrogen combustion and containment breach or leakage, with consequent offsite doses in excess of the Part 100 guideline values, is litigable under 10 C.F.R. Part 100, notwithstanding the provisions of 10 C.F.R. § 50.44. On the basis of this Commission precedent, the Licensing Board admitted CESG's Contentions 1 through 4, which taken together, assert that adequate protection against containment damage resulting from combustion of substantial quantities of hydrogen in the event of a loss-of-coolant accident, and against the potential offsite effects therefrom, had not been demonstrated for the McGuire facility.

13. It is clear from the Commission's decision in CLI-80-16 and the nature of the contentions admitted in this reopened proceeding that the basic question posed for this proceeding is whether or not there is a credible overall sequence of events involving the generation of hydrogen which can result in breach or failure of containment with releases exceeding Part 100 values. For this case, such an overall sequence would have to entail all of the following elements:

- the initial loss-of-coolant accident;
- interruption in the function of the automatic ECCS by operator action, etc., for a sufficiently long time to cause core uncovery;
- generation of substantial quantities of hydrogen;
- combustion of such hydrogen in a fashion which damages containment; and
- release of radioactivity in excess of Part 100 values from such damaged containment.

14. It is the overall sequence of events - on the basis of the plant design before this Board, a design which includes McGuire's Emergency Hydrogen Mitigation System (hereafter, "EHM or igniter system") - as to which we must reach our judgment concerning whether the facility comports with 10 C.F.R. Part 100, insofar as the issues in controversy are concerned. While each of the steps may have differing degrees of certitude, it is the ultimate conclusion as to the sequence as a whole which is in issue.

15. The case developed with two distinct major phases. One major phase dealt principally with the likelihood at McGuire that a loss-of-coolant accident of the TMI type would result in severe core damage entailing hydrogen generation.[11/] This phase of the case involved evidence related to the adequacy of Duke's training and procedures to assure that operators would not improperly terminate ECCS, and evidence concerning stress under accident conditions. The second major phase of

---

11/ This phase is treated in the section of this Decision entitled, "Hydrogen Generation."

the case dealt with the efficacy of the McGuire's installed EHM system to assure that hydrogen that might be generated by a loss-of-coolant accident of the TMI type would be ignited without damage to containment.[12/] This phase involved evidence related to the range of conditions under which the system would be effective, the potential for hydrogen detonation under various conditions, the capability of the structure to withstand the loads resulting from the buring hydrogen , and the effect of the burning hydrogen on other safety systems, (which included a related matter concerning the potential damage that might result from pyrolysis and combustion of certain polyurethane foam insulation material in containment).

16. With respect to Contention 2 which simply poses an issue of comparative containment capability between the McGuire containment and a large dry containment, little evidence was directed specifically to this point. Rather, the evidence in response to the overall issue was directed toward demonstrating that with the McGuire igniter system, the assumed generation of hydrogen from substantial metal-water reaction involving as much as 75 percent of the cladding, and the intentional combustion of such hydrogen by the igniter system, would not result in loads which threatened the structural integrity of the McGuire containment.

17. The Board did not receive evidence on Contentions 3 and 4. These contentions - asserting inadequate emergency response capability in the event of a rupture of containment caused by a hydrogen explosion - are contingent upon a

---

12/ This phase is treated in the section of our Decision entitled "Hydrogen Control."

threshold determination that such a rupture of containment from a hydrogen explosion is a credible event.13/ In the absence of a finding in favor or CESG on Contention 1, the events upon which Contentions 3 and 4 are premised would have no basis.

Range of Accident Sequences Considered

18. We pointed out in our Memorandum and Order dated November 25, 1980 admitting CESG's additional Contentions 1 through 4 that these contentions "related to the matter of hydrogen control arising out of the Three Mile Island-2 (TMI-2) accident."14/ We indicated that these matters "may well shed light upon key safety findings . . . ." Similarly, the Commission, in the context of the Three Mile Island-1 Restart proceeding indicated "the Three Mile Island accident has in fact raised a safety issue regarding hydrogen control measures following a loss-of-coolant accident that should be addressed." 11 NRC 674, 675.

19. Thus, for consideration in the context of the reopened proceeding, the accident sequences with respect to which the Licensing Board must render its judgment are those involving hydrogen control questions "arising out of the TMI accident" - that is, sequences having some reasonable relationship to the accident at TMI-2.

20. There was some argument among the parties concerning whether there is an obligation on intervenors, under the Commission's decision, to propose specific scenarios for assessment. However, Duke in this proceeding took the lead and offered evidence concerning the lack of credibility of TMI-

---

13/ Contention 3 is explicitly premised upon a rupture caused by hydrogen explosion. The only statement of "bases therefor" for Contention 4 is the same premise - see "CESG's Revised Motion . . ." dated August 15, 1980.

14/ See also "CESG's Revised Motion . . ." dated August 15, 1980, footnote 2, supra.

type accident sequence events and the ability of the installed EHM system to safely handle hydrogen that might be generated from TMI-type accident events. This evidence was not limited to consideration of an exact replay of the sequence which took place at TMI. Indeed, the evidence concerning the EHM related principally to a sequence characterized as S2D, which is a small break LOCA sequence with the break occurring anywhere in containment, not just a small break sequence caused by an open relief valve initially actuated because of a loss-of-feedwater event. Tr. 3086-3089, 3374, 4065. Moreover, examination inquiry was not only permitted into exact replay of TMI and into the S2D sequence, but into other sequences in which the evidence suggested a relevance or similarity to the TMI-type events or to the S2D sequence.

21. A broader range of potential accident sequences and appropriate measures for hydrogen control may well be considered by the Commission in connection with its proposed rulemaking activities in connection with degraded or melted cores.15/ But those issues are not before this Board. The issues in this proceeding are limited to hydrogen generation and control matters associated with accident sequences bearing some reasonable relevance to the TMI-2 accident. That is an important distinction, because some of the evidence that was offered in this proceeding also discussed hydrogen generation associated with a broader range of scenarios, which included larger breaks and sequences in which ECCS interruption continued until full core melt (also referred to as "core

---

15/ Domestic Licensing of Production and Utilization Facilities: Consideration of Degraded or Melted Cores in Safety Regulation, 45 Fed. Reg. 65474, October 2, 1980.

slump"). We permitted inquiry into many of these matters to ascertain to what extent, if any, such sequences had a reasonable relationship to the issues before this Board.

V.

FINDINGS OF FACT - HYDROGEN GENERATION

A. McGuire Facility - Procedures to Prevent Improper ECCS Termination

22. Introduction - Duke presented two panels of witnesses regarding the premature termination of ECCS to show that in an accident situation there is a very low probability that there would be premature termination of ECCS leading to core uncovery and then generation of substantial amounts of hydrogen. (Tr. 2838-2995, 2999-3034).

Duke's first panel[16/] asserted that the primary cause of the production of excessive hydrogen at the Three Mile Island Station, Unit 2 ("TMI") (Tr. 2839-3034) was the premature termination/reduction in operation of the ECCS. (Duke Panel 1, p. 1; Tr. 2870). The evidence shows that measures taken at the McGuire Nuclear Station ("McGuire") after the TMI accident reduce the possibility of improper operator termination of the ECCS to very low levels. (Duke Panel 1, p. 1; Tr. 2843-2891; 2920-3104). These measures include changes in operating personnel, equipment modifications, changes in the McGuire administrative and operating procedures, changes in the McGuire emergency procedures, and changes in the McGuire operator training program to reflect the lessons learned from the accident at TMI. Taken together, they will reduce to low levels the possibility of operator termination of ECCS (Duke Panel 1, pp. 1-8; Tr. 3028-32; SE Supp. No. 4, Staff Exhibit I; Tr. 4006).

16/ Testimony of K. S. Canady, L. A. Reed and H. B. Barron Regarding McGuire Operation Relating to Hydrogen Generation" ("Duke Panel 1"), following Tr. 2864. The professional qualifications of Messrs. K. S. Canady, Larry A. Reed, Henry R. Barron are attached to Duke Panel 1 testimony following Tr. 2864.

With ECCS functioning properly, core cooling is assured and only small amounts of hydrogen can be generated. (NRC Staff Analysis of Hydrogen Control Measures for McGuire Nuclear Station, Units 1 and 2, bound into transcript following Tr. 4353, "Staff Analysis," at p. 4).

23. Operating Personnel - Duke has increased the technical and diagnostic capability in the control room by adding a technical advisor to advise the shift supervisor. The shift technical advisors have been selected from among the group of licensed senior reactor operators at McGuire, all of whom have received additional simulator training and have received additional academic training, including instruction in heat transfer, fluid flow, thermodynamics, and plant transients (Duke's Panel 1, pp. 6-7, Staff Exhibit I. pp. 22-32). The technical advisor will be present on all shifts and available to the control room within 10 minutes. (Duke Panel 1, p. 2). He provides additional evaluation and assessment of both normal and unanticipated transients. (Id.) The McGuire technical specifications now require the presence of a Senior Reactor Operator (SRO) in the control room at all times the plant is above the cold shutdown mode of operation. (Duke Panel 1, p. 2; Tr. 2881-84; 3007-3009; 3009-3013). In addition, the assistant shift supervisor has been assigned administrative duties, relieving the shift supervisor of duties which could detract from his management responsibility for safe operation of the plant (Duke Panel 1, p. 4).

24. Control room shift manning is not a problem at McGuire since it has an acceptable number of both reactor operators and senior operators to run the McGuire facility. (Tr. 3007; Staff Exhibit I, pp. 22-6 to 22-10). Duke is engaged in a long-term hiring and training program to obtain additional reactor operators and senior operators, including additional personnel to account for attrition. (Staff Exhibit I, pp. 22-9 to 22-10).

25. Equipment and Instrument Modifications - Modifications and additions will increase the assurance that operation of the plant will be done in a safe manner. Pressurized water reactors are operated at temperatures below the saturated temperature. (Duke Panel 1, p. 3). The saturated temperature is that temperature at which water will boil at a corresponding pressure. (Id.) Duke's recent equipment modifications were designed to warn the operator of operation beyond the normal operation approaching the saturated temperature that could lead to inadequate core cooling. (Duke Panel 1, pp. 2-3). New instrumentation such as a subcooling monitor and associated equipment would monitor the approach to inadequate core cooling conditions. Duke has installed a subcooling monitor that will monitor inadequate core cooling conditions. (Tr. 2924-27; 2983-86; 2991-93; 3013-17). This monitor, which is part of the McGuire in-plant computer system, will display to the operator in graphical form on the computer video screens the actual system conditions, on a temperature and pressure type graph. Thus, it will indicate to the operator what the core conditions are relative to a saturation curve. (Tr. 2925-2943; 3009-3011, Duke Panel 1, p. 3). Alarms are provided to install a reactor vessel water level monitor system at McGuire which will provide additional information regarding the approach to inadequate core cooling. (Duke Panel 1, p. 3; Tr. 2928).

26. In response to cross-examination it was also brought out that there is a visual display in the control room associated with the subcooling monitor, which was installed and operational in 1976 (Tr. 2982-86). It shows a two-axis graph of pressure versus temperature for water for subcooled operating conditions to a minimum of 55°F. Although the subcooling monitor is not incorporated in the simulator, Duke's operators are thoroughly trained through the use of steam

tables to calculate margins to saturation. Thus, they can compute margins even if the monitor were to fail (Tr. 2983-2986). There is no problem similar to that which occurred at TMI due to computer backlog with respect to input to the control room via the subcooling monitor. The subcooling monitor is basically software, which utilizes hard-wired inputs that are scanned at a minimum of once per minute and gives the operator a video display of the information. Tr. 3032-34. Thus, the problem with computer backlog due to the delay in the printers that occurred at TMI, which did not have a video display, will not occur at McGuire. (Tr. 2884-87, 3009-11, 3032-34). On redirect it was brought out that a hydrogen bubble would not occur and would not interfer with natural circulation, Duke has installed a redundant reactor coolant system venting system located directly off the top of the reactor vessel head. Duke's sytem allows for detection of any hydrogen bubble formed in the reactor vessel and for venting any hydrogen off into the pressurizer relief tank rather than into the containment atmosphere. (Tr. 3061-63; Tr. 3092-93).

27. Procedures - Duke's changes to its administrative and operating procedures are designed to enhance the ability of the reactor operators to operate the plant in a safe and efficient manner. (Duke Panel 1, p. 4; Tr. 2986-2993). Operating lines of authority and management responsibility have been clarified and formalized. (Duke Panel 1, p. 4.) Procedures have been provided to require verification of safety system availability when systems are removed from or returned to service and notificat on of operators when

safety systems are removed from or returned to operation. Detailed shift turnover procedures have been provided, including the use of detailed check-lists to assure that current information is provided to the oncoming shift. (Duke Panel 1, p. 4).

28. Significant changes have been made in the McGuire emergency procedures which will reduce the likelihood of premature termination of ECCS and the possibility of inadequate core cooling. (Duke Panel 1, pp. 5-6; Tr. 2953-74, 3000-17). The revised emergency procedures provide specific criteria for terminating ECCS operation. (Duke Panel 1, p. 6). The procedure provides specific steps for evaluating the event, directs the operators to the appropriate emergency procedures, or provides specific criteria for ECCS termination. (Duke Panel 1, p. 5). Each emergency procedure has been modified to specify the criteria for ECCS termination (Id.) Thus, prior to termination of ECCS the operator must assure that the following four criteria are met:

(1) Reactor coolant system pressure is greater than a specified minimum value and increasing; and

(2) Pressurizer level is greater than a specified minimum value; and

(3) The reactor coolant system is subcooled by greater than 50°F; and

(4) Adequate auxiliary feedwater flow for core heat removal is injected into at least one non-faulted steam generator. (Id., p. 5; Tr. 2953, 2973-78).

29. Licensed operators have been thoroughly instructed in the use of these procedures. (Duke Panel 1, p. 5).

30. Training - Duke's post-TMI operator training has been substantially enhanced. The training program, which is approximately 2-1/2 years long, is a coordinated training effort that insures qualified operating personnel, and is designed to prepare initial and replacement personnel for new stations and improve and maintain performance of existing personnel. (Duke Panel 1, pp. 6-8; Tr. 2868-69, 2875-79, 2884-88, 2921-24, 2953-74, 2978-83, 2993-94, 3000-07, 3022-26). Duke's training program for its operators includes a mix of formal classroom presentation, research reactor training, on-the-job training (using task lists), simulator operation, which now includes a TMI-2 type sequence, and normal and abnormal events, and rigorous evaluations that consist of both written and oral examinations. (Duke Panel 1, pp. 6-8, Tr. 2976, 2983-86, 3028, 3029). Duke will require its licensed operating personnel to participate in a requalification program that includes both classroom presentations and simulator operations. (Duke Panel 1, pp. 6-8). Duke's training has also been modified to reflect the lessons from the TMI-2 accident. Additional instruction is provided in thermodynamics and heat transfer; additional information in hydrogen generation, hydrogen flammability and explosive limits; use of nuclear instrumentation and the effects of voiding in the core on excore indication. More emphasis is given in training to small break LOCAs (including the TMI scenario) and abnormal and emergency plant evaluations. A demonstration of a TMI accident, and also natural circulation and ECCS operation has been added to the simulator program. (Duke Panel 1, pp. 6-7). In response to cross-examination it was also brought out that, with the exception of one reactor operator, all Duke's operator training instructors hold senior reactor operator licenses. (Tr. 2852).

31. Resumption of ECCS operation - If ECCS operation has been interrupted, through improper operator action or otherwise, the evidence indicates that there is an extended period before significant hydrogen production occurs - over 2 hours in the event of a loss of feedwater event with cooling by circulation through all four steam generators (Duke Panel 2[17/], p. 2; Tr. 3046-48) and approximately 1 hour after the more general S2D small break LOCA event. (Staff Analysis, p. 2). Emergency procedures require logging every 15 minutes for 2 hours following ECCS termination of the parameters used in the ECCS termination criteria (Duke Panel 2, p. 3). If the log entries are above the specified criteria, emergency procedures require reinitiation of ECCS operation. (Duke Panel 2, pp. 2-3).

32. In its cross-examination of Duke's testimony concerning operator performance, CESG asked a wide range of questions concerning: the cause of the TMI event; operator training, selection and manning; operating procedures, and equipment and instrumentation. Although CESG's questioning explored the above subject areas in some detail, the evidence elicited by CESG in cross-examination failed to establish in any of these areas any material basis for concluding McGuire would be operated in such a manner that ECCS would be improperly terminated in a TMI accident.

17/ "Testimony of K. S. Canady, L. A. Reed, R. A. Muench and H. B. Barron Regarding McGuire Nuclear Station Operation Relating to ECCS Termination," "(Duke Panel 2)" following Tr. 3045. The professional qualifications are attached to the direct testimony of Duke Panel 2 bound into the record following Tr. 3045.

B. CESG Psychologists

33. In this proceeding CESG's direct case regarding CESG's Contentions 1 and 2 consists of the testimony of five psychologists.18/ CESG subpoenaed five psychologists to show that reactor operators would perform poorly under accident conditions in spite of operator training and work. CESG subpoenaed Dr. John Philip Brockway,19/ Dr. Gary Thomas Long,20/ Dr. James Richard Cook,21/ Dr. Edward Leo Palmer,22/ and Dr. John Edward Kello.23/ The testimony of the five psychologists offered by CESG was directed toward general psychological phenomena under certain work conditions: boring tasks, information overload, fatigue, stress, cognitive dissonance, group think, risky-shift,

18/ The direct, prefiled written "Testimony of Jesse L. Riley Regarding Hydrogen Generation, Combustion, and Containment Response" with attached "Professional Qualifications of Jesse Riley", bound into the record following Tr. 3780, was rejected by the Licensing Board as evidence as in this proceeding. Tr. 3967-69. The Licensing Board also rejected Mr. Riley's oral direct testimony given on the record at Tr. 3767-3811, 3816-3824, 3864-3875. (Tr. 3967-69). The proferred testimony concerned the generation and combustion of hydrogen, effects of such combustion on the containment structure, the McGuire containment design loading, chemical reactions, reactor systems, and reactor operator performance. The Board concluded, that Mr. Riley was not qualified to testify as an expert on matters relating to strength of containment structure, particularly structural engineering aspects, and was also not qualified on hydrogen burning or detonation. (Tr. 3967, 3969, See also Tr. 3875-3967). Nor was there a showing of substantial personal working knowledge concerning the systems proposed and installed in the McGuire plant. Cf. Tr. 4326-4348. Moreover, as the Board noted, other aspects of the proferred testimony were redundant of information in the record (Tr. 3967).

19/ Tr. 3624-3643. The Professional Qualifications of Dr. John Phillip Brockway are bound into the record following Tr. 3624.

20/ Tr. 3835-44. The Professional Qualifications of Dr. Long are bound into the record following Tr. 3835.

21/ Tr. 3844-3851. The Professional Qualifications of Dr. Cook are bound into the record following Tr. 3845.

22/ Tr. 3852-59. The professional qualifications of Dr. Palmer are bound into the record following Tr. 3853.

23/ Tr. 3977-3997. The Professional Qualifications of Dr. Kello are bound into the record following Tr. 3978.

obedience to authority, massed and distributive learning, all or none learning, overlearning, and amnesia. (Tr. 3624-39, 3635-58, 3977-82). However these witnesses had no background with respect to operation of nuclear power reactor facilities and did not relate the general phenomena discussed to nuclear power plant operations or to control room activities. 24/

34. Duke presented a panel of psychologists in rebuttal of the testimony of the five psychologists called by CESG; namely, Dr. Lewis F. Hanes, 25/ Dr. Julien M. Christensen, Dr. Eric F. Gardner, Mr. Robert M. Koehler, and Mr. Richard J. Marzec. (Tr. 4715-4841). These witnesses, unlike CESG witnesses, were able to provide a link between theory and practice. The testimony of Duke's panel of psychologists demonstrated that the psychological phenomena mentioned by CESG's psychologists had been taken into account in the structure of its operator training program, the structure of the control room, the organization of the operating personnel, and in the function and duties of the control room operator, or that those concepts do not apply to nuclear power plant operators or operation. (Tr. 4715-4841; 4740-4772). For example, the testimony of Duke's panel demonstrates that there is little risk of operator error in a nuclear power plant that would affect safe operation of the plant from the effects of such psychological phenomena as, "cognitive dissonance", risky shift", "group think", "forgetfulness",

---

24/ Stipulations (Regarding CESG's Psychologists) March 17, 1981; Duke Exhibit 8, Tr. 4674.

25/ The professional qualifications of Dr. Hanes, Dr. Christensen, Dr. Gardner, Mr. Koehler, and Mr. Marzec are bound into the record separately following Tr. 4719.

"information overload", "boredom", or mental or physical fatigue. (Tr. 4740-4772). "Obedience to authority" is considered a positive attribute for an operator who is required as a matter of safety to follow set safety procedures. (Tr. 4766; 4765, 4766). It was pointed out that application of psychological concepts and theories, developed on an experimental basis, to real world operation of nuclear power plant operations must be done with extreme caution. (Tr. 4740-42, 4773, 4774).

35. It was indicated that procedures for operating Westinghouse designed reactors are symptom-based rather than event-based. (Tr. 4793, 4814-4822, 4839-4841; see Tr. 4736, 4737). In addition, Dr. Hanes testified that due to "chunking"[26/] an individual with training can handle increasingly greater amounts of information that may seem complex to the outsider. (Tr. 4750, 4784-4788).

36. Stress on operators will not affect the safe operation of the McGuire facility (Tr. 4759-4764). Furthermore, because stress levels in operators of nuclear plants are generally low, the effects of stress on safe operation are reduced to even lower levels by operator training and experience, by set procedures that an operator is required to follow, by the structure of the job, by open communications, and by the elimination of individuals who do not perform well under stressful conditions during the testing and training phases of the operator training and qualification program. (Tr. 4759-4764, 4782-4784).

26/ "Chunking" involves an ability to grasp increasingly large "chucks" of complex sets of information as training and experience is increased. Tr. 4749, 4750.

Also, it was pointed out that supervisors of Duke's operating personnel are trained to recognize any aberrant behavior due to such things as fatigue that might occur in its operators. (Tr. 4799-4781).

37. On the other hand, Duke's training program which mixes training, work experience, and simulator training is a good example of the learning concept of "articulation" (Tr. 4770) and of how Duke includes such phenomena as "distributive learning" in its training process. (Tr. 4765, 4766, 4740-4772).

C. Staff Testimony

38. The staff testimony on the issue of the likelihood at McGuire of a loss-of-coolant accident of the TMI type was limited to its review of conformance with Commission requirements in Staff Exhibit I and to its observation that NRC actions to enhance operator training, technical competence and review of operating procedures, have substantially reduced the likelihood of recurrence of an event such as TMI-2 (Staff Analysis, p. 3; Tr. 4054). However, such conclusion was not based on quantitative measurement in terms of risk, but rather on a qualitative assessment (Tr. 4055).

39. The staff indicated that its position on hydrogen mitigation systems in ice condenser plants was based in the main on the desirability from a safety standpoint of incorporating hydrogen control techniques in order to compensate for their smaller volume and lower design pressure (Staff Analysis, p. 7).

40. The staff indicated its belief that McGuire should be treated in the same manner adopted by the Commission in its review of the staff's recommendations in connection with Tennessee Valley Authority's Sequoyah 1 plant. In that licensing action, the Commission imposed a 2-step approach: first, a requirement for prompt verification that the hydrogen control system installed by TVA would provide adequate protection against containment failure in the event that large quantities of hydrogen are generated; second, a longer range requirement that by January 31, 1982, the licensee was to demonstrate not only that such systems provide protection against failure, but that they do so with margins adequate for long term operation (Staff Analysis, p. 8).

41. Although Sequoyah did not involve a contested proceeding decided on an adjudicatory record, the Commission's action in that case warrants due deference by the Board in its assessment of the record before it.

D. Overall Findings on Hydrogen Generation

42. We find on the record before us: that premature termination/reduction in operation of the ECCS was a primary cause of the production of excessive hydrogen at TMI-2; that since the accident at TMI-2 there have been significant improvements in the areas of operating personnel, equipment and instrumentation, operating and emergency procedures and training of operating personnel; that these improvements provide substantial assurance that improper operator termination of ECCS is highly unlikely, even though unquantified on the record before us.

VI. FINDINGS OF FACT - HYDROGEN CONTROL

A. Introduction

43. The accident at TMI-2 resulted in a metal-water reaction involving between 30 and 60% of the fuel cladding which in turn resulted in substantial hydrogen generation, well in excess of amounts previously considered (Staff Analysis, pp. 3, 20). At TMI a pressure spike of 28 psig recorded some 10 hours after the start of the accident has been assumed to have been caused by ignition of substantial quantities of hydrogen (Tr. 3368-73), by random ignition sources (Rasin HMS testimony, p. 1[27/]; Tr. 3219).

44. Hydrogen combustion can under certain conditions involve deflagation, a slow burning flame, and under other conditions, it can involve detonation, a shock wave with peak transient pressures exceeding the pressures of deflagations (Duke Combustion Testimony,[28/] p. 5).

45. The ice condenser containments, like McGuire, are smaller in volume than the TMI containment and could fail in the event of combustion of hydrogen associated with more than about 25-30% of the fuel cladding, under unfavorable conditions - homogeneous mixing of such amounts of hydrogen with containment atmosphere and subsequent ignition (Staff Analysis, p. 7).[29/] This amount of hydrogen is less than the amount generated at TMI (Staff Analysis, p. 3).

27/ "Testimony of William Rasin Regarding the Hydrogen Mitigation System," following Tr. 3488 (Rasin HMS testimony).

28/ "Testimony of William Rasin, David Goeser, Bela Karlovitz, Bernard Lewis and Edward McHale Regarding Hydrogen Generation and Ignition," following Tr. 3144 (Duke Combustion testimony). The professional qualifications of the witnesses are attached to the Duke Combustion testimony.

29/ Cf Tr. 4056-4037.

46. While the NRC staff was developing generic policy relating to hydrogen control in ice condenser plants, the Tennessee Valley Authority (TVA) proposed, in connection with the licensing of the Sequoyah plant, a system of igniters. Duke also proposed a similar system for the McGuire facility (Tr. 4057).

47. That system has been installed at McGuire and forms the central focus of these issues in this proceeding relating to hydrogen control.

B. System Description

48. During the TMI event, hydrogen released to containment was ignited by existing ignition sources in containment. Duke indicated that it is reasonable to assume that in a similar situation inside the McGuire containment, without the igniter system, hydrogen would be ignited by existing sources (Rasin HMS testimony, p. 1). The purpose of the distributed ignition system is to provide additional ignition sources to assure that any hydrogen released to containment will ignite at concentrations of about 8% (Rasin HMS testimony, p. 1). Combustion of hydrogen at such concentrations does not involve detonation (Duke Combustion Testimony, p. 5).

49. The hydrogen mitigation system installed at McGuire consists of 62 igniter assemblies (46 in the lower containment, 8 in the ice condenser upper plenum, and 8 in upper containment) located in 31 distinct areas of the containment building. Each igniter assembly consists of a glow plug and a control power transformer. (Rasin HMS Testimony, p. 1; Staff Analysis, p. 9).

50. The particular igniter selected by Duke is a glow plug commonly used in diesel engines that is manufactured as Model 7G by General Motors AC Division. The igniter assembly consists of a sealed box housing with 1/8-inch thick

steel plate walls, which contains the transformer and all electrical connections and partially encloses the igniter. The sealed box uses heat shields to minimize the temperature rise inside the igniter assembly and a spray shield to reduce direct water impingement on the glow plug. (Staff Analysis, p. 9). The igniters are powered from the Emergency Lighting System panelboard which has normal and alternate AC power supply from off-site sources. The igniter system is designed to be actuated following the start of an accident and to remain actuated until a safe shutdown condition is achieved. The system is to be manually initiated at the time of the 3 psig containment isolation signal by switching on three circuits at the Emergency Lighting System panelboard located in the auxiliary building. (Id., pp. 9-10).

51. The igniters work in combination with other containment systems, including the ice condenser system, the containment air return system, the hydrogen skimmer system and the containment spray system. (Duke Combustion Testimony, pp. 9-10; Canup testimony[30/]).

52. In the event of a LOCA, pressure differential across the ice condenser lower inlet doors will reach 1 lb/ft^2, thus forcing the doors open and allowing flow of steam and hot gases into the ice bed. Steam will be condensed by the ice and the chilled structures. Air and other gases will pass through the ice bed and open the intermediate and top deck doors venting to the upper containment. When the lower containment pressure reaches 3 psig, the containment spray system is actuated. Spray flow will enter the ring spray

30/ "Testimony of David L. Canup, II Regarding McGuire Containment Systems" (Canup testimony) following Tr. 3488. The professional qualifications of David L. Canup are attached to the Canup testimony bound into the record following Tr. 3488.

headers in the top of the upper containment and be discharged through spray nozzles which break the flow up into droplets less than 700 microns in diameter. These droplets absorb heat from the upper containment atmosphere, thus cooling the containment atmosphere and suppressing the pressure rise. Approximately 10 minutes after the lower containment reaches 3 psig the air return fans are started automatically and begin circulating air from the upper containment into the lower containment, then into the ice condenser and back to upper containment again. Approximately 10 minutes after the lower containment reaches 3 psig the hydrogen skimmer system also is started and begins ventilating dead-ended volumes in the lower containment to prevent hydrogen accumulation in these areas. (Canup testimony, pp. 3-4).

53. In the event of a LOCA involving hydrogen generation, the pressure in the primary coolant system would cause the resulting hydrogen and steam mixture exiting through the break to enter the lower containment in the form of a high velocity turbulent jet, which would rapidly mix completely with air in the lower compartment. In addition, turbulence in the lower containment created by the air-return fans accelerates rapid mixing of hydrogen with the atmosphere in the lower containment. From the lower containment, the hydrogen steam-air mixture will pass through the ice condenser where steam is removed; the resulting hydrogen-air mixture passes into the upper containment where it mixes turbulently with the air in the upper containment. This mixing is aided by the water spray from the containment spray system. The two containment air return fans will circulate such hydrogen-air mixtures from the upper containment back into the lower containment. (Duke Combustion Testimony, pp. 9-10).

54. Some of the hydrogen-steam-air mixture exiting the break will flow into the so-called "dead-ended" chambers. Due to flow and turbulence in these chambers, mixing will be rapid and complete (Duke Combustion Testimony, pp. 9-10). The mixture is ventilated from these areas by the skimmer fans forcing recirculation of the mixture to assure that the concentrations in the "dead ended" chambers do not vary significantly from the remainder of the lower compartment. (Canup testimony, pp. 3-4; Duke Combustion Testimony, p. 9).

C. Testing

55. Duke Power Company, along with other utilities, has sponsored an experimental program (Fenwal, Inc.) to determine the effectiveness of the hydrogen igniters ("glowplugs") such as those installed at the McGuire Unit 1 nuclear power plant, as well as at the TVA Sequoyah facility. (Rasin DHMS testimony, p. 2; Staff Analysis, pp. 10-16). This experimental program demonstrated that the hydrogen igniters which have been installed at McGuire Unit 1 can effectively initiate a hydrogen burn. (Rasin HMS testimony, p. 2; Staff Analysis, pp. 10-16; Duke Exhibits 5A-5D).

56. The results of the Fenwal test program were generally consistent with the applicable published information on hydrogen combustion. (Staff Analysis, p. 13). The tests confirmed that limited combustion occurs over hydrogen concentrations of 6-8% although the completeness of combustion is influenced by the ability to promote mixing and exposure of the igniter to sources of fresh atmosphere. (Id.) Test results indicate hydrogen concentrations of 8-9% represent a transition zone where combustion may proceed to a nearly complete reaction. (Id.) This is consistent with published data and findings

regarding the general limits of upward and downward flame propagation. At the higher hydrogen concentrations of 10-12% the likely sequence is that all the hydrogen present in the atmosphere will be consumed in the combustion process (Staff Analysis, p. 13).

57. The test vessel atmosphere pressure measurements in the Fenwal test reflected the completeness of combustion at the various hydrogen levels. (Staff Analysis, p. 13). Pressure measurements from the testing showed an increase of as little as approximately one psi for single hydrogen burns at 6% concentration and an increase of approximately 70 psi for the burning of a mixture of 12% concentration. (Id.) The portion of the test program dealing with transient hydrogen injection with the glowplug pre-energized resulted in a series of eight burns for the test with continuous injection of both steam and hydrogen. (Id.) The injection flow rates were scaled to simulate the flow rates calculated to enter the lower compartment of an ice condenser containment for a small break loss of coolant accident (LOCA). The results indicate relatively small pressure increases of approximately 2-7 psi for each of the eight discrete burns. (Id.) These lower pressure excursions result from the burning of hydrogen at lower concentrations and allow for heat removal via heat transfer to heat sinks during the transient. (Id., pp. 13-14). This type of sequence simulates the transient that would occur if hydrogen were to be introduced inside McGuire in a like manner. (Id., p. 14).

58. These tests showed that the effects of spray operation on igniter performance appears to be minimal in terms of affecting the ability of the

igniter to initiate combustion. (Staff Analysis, p. 14). Spray operation, by promoting mixing and turbulence, may actually improve the efficiency of the igniters in burning lean hydrogen mixtures. (Id.) Similarly, fan flow across the glow plug, within the considered flow rates, indicates minimal alteration of the ignition time and some improvement in the ability to burn a larger fraction of the hydrogen in lean hydrogen mixtures. (Id.)

59. Independent combustion tests of the thermal igniter conducted by the Lawrence Livermore National Laboratory for the NRC Staff confirmed the ability of the proposed Duke igniter to ignite gas mixtures over a range of conditions. (Staff Analysis, p. 15.) In the dry air tests hydrogen partially burned at lower concentrations (7-8%) and completely burned at higher concentrations, similar to what was seen in the Fenwal test program. (Id.) The measured pressure increase for tests with hydrogen concentrations over the range of 8-12% varied from approximately one psi to 65 psi, showing close agreement to the measured pressure increases during the Fenwal tests. (Id.)

60. In 43 tests of hydrogen-air-steam mixtures ranging from 6-16% hydrogen and with 30% and 40% steam fraction, the igniters never failed to initiate combustion for any of the 30% and 40% steam fraction tests. (Staff Analysis, p. 15). Several tests were also run by Livermore with a nominal steam fraction of 50%. Combustion was not initiated with a 50% steam fraction. (Staff Analysis, p. 16). This steam concentration, which was observed to effectively inert the vessel atmosphere, also approximates the values quoted in the published literature. (Id.) Two tests which began

at nominal steam concentrations of 50%, with no initial combustion, were allowed to continue with the steam fraction being gradually reduced by condensation on the vessel wall. (Id.) Even though the steam fraction was eventually reduced to levels where combustion should have occurred, no substantial pressure increase, as a result of hydrogen burning, was recorded. (Id.) These test results lead to some questions about the potential effects of lower compartment inerting. See subsequent discussion section VI.E.

61. Further tests at Livermore over the next several months are planned to continue to investigate the effects of containment spray operation on igniter performance and to further study hydrogen combustion in steam environments. (Staff Analysis, p. 16).

D. ANALYTICAL ASSESSMENT OF EHM SYSTEM

62. The performance capability of the EHM igniter system and resulting pressure loads imposed on containment, as a result of controlled hydrogen burning, were analyzed using the CLASIX computer code. (Staff Analysis, p. 20-27, Tr 3177 Duke Exhibit 5A-5D). The CLASIX code is a multi-volume containment code which calculates the containment pressure and temperature response in the separate compartments. CLASIX has the capability to model features unique to an ice condenser plant, including the ice bed, recirculation fans and ice condenser doors, while tracking the distribution of the atmosphere constitutents: oxygen, nitrogen, hyrdogen and steam. The code has the capability of modeling containment sprays but does not presently include a model for structural heat sinks. Mass and energy released to the containment atmosphere in the form of steam, hydrogen and nitrogen is input to the code. The code permits variation in the conditions under which hydrogen is assumed to burn and conditions at which the burn will propagate to other compartments. (Staff Analysis 19-20, Duke Exhibit 5A).

63. The rate of hydrogen released to containment, which is an input to the CLASIX code was taken from MARCH code interpretations of a small break LOCA. These MARCH calculated release rates are a time varying function whose average is of the order of 20 lb/min., but which at times reach 70 lb/min. (Staff Analysis, p. 20; Duke Exhibit 5B). These rates are representative of a significant group of releases that might be encountered in typical degraded core accidents short of total core melt or vessel failure. (Staff Analysis, p. 20). The MARCH code is a computer code developed by Battelle National Laboratory for NRC for analysis of the thermal-hydraulic response of the reactor core, primary coolant system and containment to core melt scenarios (Staff Analysis, p. 18). MARCH models hydrogen releases from

various kinds of openings in the primary system (i.e., failures of the power operated relief valve to close, small breaks and large breaks). (Staff Analysis, p. 19).

64. Although the CLASIX code is still under review by the Staff, its results have been compared favorably with the COCO and TMD codes, which have undergone much further verification and refinement. Id., pp. 25-26; Tr. 3276-77. Other independent assessments by the staff also corroborated the results obtained by Duke using CLASIX (Staff Analysis, p. 26). Further refinement of CLASIX is to be carried out by Duke, as part of an owners' group, by January 1982. While further refinements are to be made in CLASIX, the staff concludes that the code adequately predicts the containment transient and Duke concludes that it is conservative (Staff Analysis, p. 26, Tr. 3275-3278).

65. To analyze the performance of the Duke igniter system, the CLASIX and MARCH codes modeled a small break sequence identified as S2D for a range of burns assumed to initiate at 8%, 10% and 12% hydrogen, with two trains of fans and sprays operating and with one train of fans and sprays operating (Duke Exhibit 5B, Section 2.2). The S2D sequence involves a small break LOCA event accompanied by failure of ECCS injection pumping. The break size ranges up to 2 inches and break location may occur anywhere in containment (Tr. 3374, 4065, 4357). The S2D sequence was characterized as including the more likely small break LOCAs which are reasonably related to the TMI sequence (Tr. 3281, 3282, 3374, 4060, 4061, 4065, 4516). The MARCH analysis was carried out until 1550 pounds of hydrogen were released, corresponding to about 80% of the active zirconium cladding mass in the core. This is greater than the amount of metal-water reaction in the actual TMI-2 sequence, which involved between 30% and 60% metal-water reaction.

Duke Combustion Testimony, p. 2; Staff Analysis, pp. 2, 20, 21; Tr 3202. For a range of burn conditions certain burns including burning at 10% hydrogen, burning at 8% hydrogen, and under conditions where only one train of fans and sprays is operative, the results of the calculations showed peak pressures well below the 48 psig value determined by the Staff's structural analysis, discussed infra. to constitute the lower bound of the containment functional capability. (Staff Analysis, p. 23).

66. The Staff also provided its analysis of two additional cases which, although not done for McGuire, were felt to be representative of ice condenser plants. One case shows that even if ice exists only for the first two of seven burning cycles, peak pressures are still well within the 48 psig containment function capability value. On the other hand, the other case shows that, if no air return fans at all are operative, upper compartment pressures could rise to levels which could threaten containment (Staff Analysis, p. 23, 24).[31/]

67. On cross-examination, it was brought out that there were cases in which the pressure calculated by CLASIX under conditions where only one train of fans and sprays were operational would exceed 48 psig. (Tr. 4604, see Duke Exhibit 5B, see 2.2). In any event, the testimony showed no basis for assuming fan failure over and above the assumed initial failures in the S2D

31/ Duke's witnesses Lewis and Karolowitz calculated a pressure rise of approximately 25 to 35 psig for the condition of no sprays and no air return fans assuming 80% metal water reaction (Tr. 3192-3194, 3357-3359). But it is not clear whether this relates to the situation involving burning in the ice condenser upper plenum, rather than the CLASIX analysis case. Duke witness McHale also calculated 30 psig for the condition of burning without air return fans or sprays. (Tr. 3359-3361). It is also not clear whether his calculation related to upper plenum burning.

scenario (Tr. 3341, 4445-4447, 4602).

68. Sequences other than S2D - The staff evidence discussed the work done by its consultants covering a broader range of scenarios than S2D, including medium breaks and large breaks (Staff Analysis, pp. 19, 35; Tr. 4354, 4399). MARCH code runs were made for five-inch and two-inch breaks accompanied by failure of the ECCS system either in the injection or the recirculation mode. None of these scenarios led to pressure pulses more serious than those generated by S2D. (Staff Analysis, p. 19). Although some of these scenarios were beyond the S2D sequence, the Board permitted some inquiry into these matters to ascertain whether such sequences might have a reasonable relation to the issues before the Board.

69. We permitted inquiry into a sequence identified as S2H, a small break LOCA, in which ECCS functioned in injection but failed in the recirculation mode (Tr. 4401-4423, 4461; CESG Exhibit 61). The testimony, however, indicated that the calculated high pressures were due to conditions continuing until core slump occurred, a condition in which the majority of the core material falls into the lower portion of the vessel where there is sufficient water to generate a large spike of hydrogen (Tr. 4423, 4424). Similarly, a number of scenarios worked on by the staff's consultant Brookhaven National Laboratory resulted in upper compartment pressures in excess of 67.5 psig. But these pressures occur after core slump (Tr. 4146, 4148, 4399, 4462). The record is quite clear, however, that the TMI-2 accident did not involve

core melting until core slump. It involved the generation of substantial amounts of hydrogen, but core cooling was maintained (Tr. 4047, 4126). The record contains no reasonable relationship between core slumping events and the TMI-2 accident.

70. We permitted inquiry into whether the staff had considered station blackout in its McGuire assessment and into the regulatory requirements applicable to this event (Tr. 4356, 4449, 4450, 4479, 4491, 4492), despite the absence of any indication that station blackout had any relationship to the TMI-2 accident.

71. We permitted some limited discussion of large and medium break events (Tr. 4147, 4148, 4356, 4461, 4462), but did not permit extensive inquiry of a 5-inch break sequence identified as S1D, since this sequence goes beyond the general range of 1/2 to 2 inches typical of small break LOCA's (Tr. 4425, 4357).

72. For one event discussed on the record, an S2D event in which core cooling is resumed after 89 minutes, pressures of 60-65 psia were reported by Brookhaven (Such pressures would correspond to or slightly exceed the staff's estimate of 48 psig as the lower bound of containment functional integrity) (Tr. 4426-4428). However, the staff witness familiar with the work indicated that Brookhaven's pressure estimate was somewhat high (Tr. 4429-4430).

E. Hydrogen Combusion in McGuire and Its Effects

73. In this proceeding a principal area of focus was on the characteristics of hydrogen combustion and its possible effects on the McGuire containment. Combustion can take the form of either deflagration, the propagation of a slow flame through a flammable mixture, or detonation, a shock wave moving with supersonic speed in which the burning process is completed. Testimony of William Rasin, David Goeser, Bela Karlovitz, Bernard Lewis, and Edward McHale Regarding Hydrogen Generation and Ignition, following Tr. 3144 (hereafter "Duke Combustion Testimony") p. 5 At ordinary temperature and pressure the lower deflagration limit (more commonly referred to as the lower flammable limit) of hydrogen in air is 4% hydrogen by volume for an upward propagating flame, about 6.5% hydrogen for horizontal propagation, and about 8.5 to 9% hydrogen for downward propagation. Id. The lower detonability limit is about 18% hydrogen. Id.

74. Hydrogen has the characteristic of mixing rapidly with other gases. This mixing can occur as the result of jet stream entrainment, convection, and turbulence. Id., p. 4. Once hydrogen has mixed with other gases it will not become unmixed itself and it will distribute itself uniformly in any given compartment. Id., p. 5.

The rate at which a flame propagates into a quiescent mixture at right angles to the flame surface is called its burning velocity (also called laminar burning velocity). Id., p. 6. In the absence of turbulence, the laminar burning velocities of selected hydrogen concentrations of interest in this proceeding are:

7%	hydrogen	about 1 ft/sec.
10%	hydrogen	about 1 2/3 ft/sec.
20%	hydrogen	about 2 ft/sec.

75. A transition from deflagration to detonation may occur as a result of 1) superposition of pressure waves traveling with increasing velocity resulting in the formation of a shock wave, ignition in which may lead to the initiation of a detonation wave or 2) development of a "flame brush", wherein as a flame accelerates its front becomes wider and ragged thus packing more combustible surface into the "brush". In the flame brush phenomenon, a relatively large amount of gas may become available for sudden burning forming a shock from which a detonation wave may emerge. Id., at 7.[32/] A combustion wave has to travel some distance from its ignition source, called the "run-up" distance, before a transition to detonation can occur. Id. Turbulence can have the effect of increasing burning velocity[33/] and, thereby, accelerating transition to detonation. Id., p. 8.

76. Steam in air can have the effect of inerting a hydrogen-steam-air mixture. Id. The precise lower limit of steam concentration at which inerting (or partial suppression of burning) occurs was the subject of examination in this proceeding, but it was uncontroverted that steam concentrations in excess of about 65% will render any hydrogen-steam-air mixture non-flammable. Id.

32/ The possibility of a "shockless" initiation of detonation by "large scale eddy folding of hot combustion products into an already turbulent jet of reactants" was raised in a report by Dr. Roger A. Strehlow, a consultant to the NRC's Office of Policy Evaluation. Staff Exhibit F, for identification only. Although that report is not in evidence in this proceeding, it was addressed in testimony and the shockless initiation of detonation phenomenon was shown not to be possible in the McGuire containment. Tr. 3254-55.

33/ Excessive turbulence can also have the effect of extinguishing flames. Duke Combustion Testimony, p. 8; Tr. 3297.

77. Duke's analysis of the course which hydrogen combustion would take in the McGuire containments was presented by a panel which included experts on combustion phenomena and on risks resulting from severe nuclear reactor accidents. Professional Qualifications Statements, following Duke Combustion Testimony. The combustion experts included Dr. Bernard Lewis, who is the author of two very widely-used and well-recognized textbooks on the subject of "Combustion, Flames and Explosions of Gases". Professional Qualifications of Dr. Bernard Lewis, following Duke Combustion Testimony. The other combustion experts on the panel were Mr. Bela Karlovitz, who has developed the theory of turbulent flame propagation (Professional Qualifications of Bela Karlovitz, following Duke Combustion Testimony) and Dr. Edward T. McHale, who is the author of numerous publications regarding hydrogen and combustion (Professional Qualifications of Dr. Edward T. McHale, following Duke Combustion Testimony). This panel testified that there would rapid, turbulent mixing of the hydrogen-steam jet from the assumed break. Duke Combustion Testimony, p. 9. To this turbulence would be added that created by the air return fans. Id. The result would be a uniform steam-air concentration in lower containment. Id. Flow patterns, in the lower compartment, dead ended Chambers, ice condenser, and the upper compartment are discussed supra VI.B.

78. The panel testified that, with the igniters in operation, ignition and burning of hydrogen would occur by: (a) a continuous burn in the ice condenser upper plenum area, (b) a series of burns initiated in the lower containment, or (c) a combination of these two burning patterns (Duke Combustion Testimony, p. 10). Either the hydrogen-steam-air mixture in lower containment will become flammable and be ignited by the glow plugs located there or the hydrogen concentration in the upper plenum of the ice condenser will reach approximately 8.5% and a continuous burn will ensue in that region until the contentration existing the ice condenser falls below this approximate concentration. Id., p. 11. The burning of hydrogen in the lower compartment is the phenomenon modeled by CLASIX (Tr. 5084). Continuous burning in the ice condenser upper plenum, which Duke considered to be the most likely scenario, and which would be the scenario if lower compartment burns do not occur because of inerting, results in a containment pressure rise of only a few psi compared to the 16 psig modeled by CLASIX (Tr. 3173, 3174, 3177, 3353-3357, 5084, 5085)

79. Steam inerting. As noted above, steam can have the effect of inerting a hydrogen-steam-air mixture. Certain evidence in this proceeding raised a question as to whether inerting might not occur in the lower containment during generation of hydrogen. Certain of the Livermore tests, discussed above, raised the possibility of inerting at steam concentrations less than the generally reported value of about 50%. A Brookhaven National Laboratory report on hydrogen combustion during degraded core accidents at Seqyoyah in the presence of glow plugs raised the possibility of inerting of the lower containment during the hydrogen

generation stage of certain severe accident sequences studied.[34/]

80. Dr. Marshall Berman of Sandia National Laboratory, a NRC Staff consultant discussed his concerns about the placement of igniters in the upper plenum of the ice condensor on the basis that a high concentration of hydrogen could become detonable in the upper plenum, (Tr. 3153-54, CESG Exhibit 40, pp. 1-2; Staff Analysis p. 34, Tr. 4082 et seq). Such a high concentration might result from inerting in the lower compartment, from ECCS recovery or from condensation fogging, combined with a sharp pulse in hydrogen air flow to the ice condenser. (Tr. 4082-4085, 4093, 4094). Dr. Berman indicated that his views were influenced by experiements of Dr. John Lee of McGill University. Tr. 4035-36, 4083, 4095, 4199-4202. Two experiments were discussed in the record, both involved stoichiometric[35/] concentrations (propane in the first experiement, methane in the second)[36/] of gases and large tubes open at one end with periodic obstacles placed therein and resulted in substantial overpressures. Tr. 4095-97, as modified at 4243.

34/ This report was admitted for the limited purpose of establishing its authenticity, since it was a report prepared by an outside contractor to the NRC, which the staff had not yet taken action upon and as to which there was no indication of reliability. Tr. 4654, as modified by discussion at 4659, 4661, 4663. The staff did, however, make available a witness familiar with the study, who was able to discuss the relevance of the points raised by Brookhaven.

35/ A stoichometric mixture of hydrogen and oxygen would be two moles of hydrogen for every one mole of oxygen. Tr. 4286-87. In air, this translates into a concentration of approximately 29% hydrogen. Id., Tr. 3333. The farther away one gets from a stoichlometric mixtrue, the more difficult it is to achieve transition. to detonation. Tr. 4299.

36/ The stoichometric mixture in air for propane is 4% and for methane 9-1/2%.

81. The Staff put the inerting question into helpful perspective by describing three phases of a degraded core accident: Phase 1 - when large amounts of steam are injected into the lower containment, but there is virtually no hydrogen generation; Phase 2 - when large quantities of hydrogen are be-ng generated, but there are typically much smaller amounts of hydrogen being generated; and Phase 3 - when ECCS recovery might take place with the possible simultaneous generation of large amounts of steam and hydrogen. Tr. 4357-59. MARCH analyses and other independent analyses have indicated that during Phase 2 of a S2D accident the lower containment will not be inerted. Id. The recorvery stage is a matter which was not modeled in the MARCH runs used by Duke for its analysis of the S2D accident. Tr. 4357.

82. As noted above, Duke's witnesses, particularly Dr. Lewis indicated that in the event that the lower compartment became inerted, hydrogen would burn without detonation in the upper plum. He noted that with a lower compartment of some 237,000 cubic feet, it will ta some period of time (roughly one and a half minutes) for the hydrogen concentration to increase significantly in the lower compartment, above the level it was at before it became inerted. (Tr. 5051-5052, 5073, 5074, 5084, 5085). The Staff shared Dr. Lewis' view that t e lower compartment does not inert instantaneously (Tr. 4366). Dr. Lewis indicated that during this period a portion of the hydrogen air steam mix in the lower compartment will pass through the ice condenser where steam is condensed out pe mitting the hydrogen air mix to again become flammable. The hydrogen will ignite at the upper plenum igniters and burn back to the position in the ice bed at which sufficient steam has condensed to permit the mixture to be flammable. It will result in a steady burn at this point.

83. As hydrogen concentration increases the flame will simply move to the point in the ice condenser at which sufficient steam has condensed to permit the higher hydrogen concentration mixture to become flammable. Thus, concentrations in the upper plum cannot become detonable. (Tr. 5052-5054, 5084-5085). The initial ignition in the upper plenum is at a hydrogen concentration at or just slightly above the concentration at which it was in the lower compartment when the lower compartment became inerted about 8 to 9% hydrogen (Tr. 5052, 5053, 5084, 5085). Thereafter, the flame is in the ice bed at the point at which the hydrogen air mixture becomes flammable. Above that point, the mixture is no longer flammable since the hydrogen has been burned. (Tr. 5053, 5054, 5085). Thus, concentrations at or near detonable levels do not exist in the upper plenum.37/ (Tr. 5050, 5053, 5054, 5085) and detonation in this region is not a serious concern. Even Dr. Berman indicated that "I suspect that the further away you get from stoichiometric, the more difficult it would be to get transition to detonation, until ultimately you could not get it" (Tr. 4299).

84. The record also explored whether there were configurations in the ice condenser similar to those in Dr. Lee's experiments. Three regions in the ice condenser were discussed as areas in which transition to detonation might occur. These regions were (1) the areas between the ice baskets, (2) the upper plenum, and (3) the air handling ducts. The evidence demonstrates that the areas between the ice basked do not constitute confined channels and sideways spreading of the gaseous mixture rising through the ice condenser would occur. Tr. 3261-62.

37/ No evidence in the record suggests detonable concentrations anywhere near as low as 8-9% hydrogen. (Cf Staff Exhibit F p. 7 with Tr. 3295).

85. The upper plenum is an area which runs the 300 degrees around on top of the ice condensor. It is unconfined in that it has doors which open into the upper containment. Canup Testimony, p. 2. The upper plenum contains periodic structures: The intakes for the air handling ducts; and the intermediate deck doors. Dr. Berman analogized these to Dr. Lee's obstructions. Tr. 5057-58. The air handling intake units do not, however, represent a sufficiently high degree of blockage such as to create any possibility of transition to detonation and the intermediate deck doors open sideways and would not, therefore, constitute any obstacle to a flame moving horizontally around the upper plenum. Id. There was some indication that the air handling ducts,which do approximate a tube, might have a sufficient length over diameter to provide the necessary "run up" to a transition to detonation. Tr. 3263. Duke has, however, committed to trip the air handling unit intake fans coincident with actuation of the igniters. Tr. 5160, 5175. A damper on the discharge side of each air handling fan would, upon the tripping of the fan, prevent the inflow into the duct of any unburned hydrogen. Tr. 5174.

86. On the basis of the evidence developed, we find that (1) detonable concentrations of hydrogen will not be approached in the ice condenser and (2) there is no configuration in the ice condenser where a transition to detonation can occur. We do not perceive the problems associated with placement of igniters in the upper plenum that have been raised by Sandia. We, therefore, consider the placement of igniters in the upper plenum of the ice condensor as part of the interim hydrogen mitigation system for McGuire to be appropriate.

F. CONTAINMENT STRUCTURAL CAPABILITY

87. Analyses of Containment Capability - Since CESG's Contentions 1 and 2 place into controversy the capability of the McGuire containment structures to withstand the pressures associated with a TMI-2 type accident, testimony was presented on the structural capability of the McGuire containments. To put the matter into perspective, the McGuire containments were initially qualified on the basis of a design pressure of 15 psig, corresponding to the pressure calculated from the design basis LOCA. Testimony of R. B. Priory Regarding Containment Structural Integrity and Response to Licensing Board Questions, following Tr. 3654 (hereafter "Priory Testimony"), p. 2; Tr. 3745. The 15 psig pressure represented the design value for internal pressure, which was only one of the service loading conditions to which the plant had to be designed. Priory, p. 3. In accordance with NRC requirements, the containments for Units 1 and 2 were tested to establish their capability to withstand this pressure without experiencing unacceptable leak rates, but testing is not possible at pressures much higher than this level, such as those explored in this proceeding. Tr. 3757-58, 3704. Accordingly, the capabilities of the two reactor containments beyond the 15 psig design basis has to be determined on the basis of analysis.

88. Three independent analyses of containment capability were performed for this proceeding. Tr. 3655, 4951. One was undertaken by Duke and is reported in the Priory Testimony and in Duke Exhibit 5B, Chapter 4. A second analysis was undertaken by a Mr. Orr of Offshore Power Systems, acting as a consultant to Duke. Testimony of R. S. Orr Regarding the McGuire Structural Integrity, following Tr. 3654. A

third analysis was undertaken by Ames Laboratory of Iowa State University, acting as a consultant to the NRC staff. Staff Analysis, pp. 27-33.

90. The Board had been concerned about the proliferation of terms used in these analyses by the parties to describe various levels to which the containment would be expected to perform. To clarify this matter, the Board, by Memorandum and Order of January 27, 1981, posed questions to the parties regarding the calculation of containment capability. The record has now been satisfactorily clarified as to the meaning of the various terms used. Going from lowest to highest pressures the terms that have been used and their definition for this proceeding are:

1. Design Pressure, the level to which the containment was originally designed to respond to the design basis loss of coolant accident,
2. Local Yielding, the first pressure at which an outside fiber of an element in the structure reaches yield stress,
3. Membrane Yield, the point at which the stresses on a curve of elastic/plastic analysis departs from linearity (Duke Exhibit 5B, Fig. 4.2.4-4),
4. Functional Capability, the maximum point at which the containment can be reasonably assured of retaining its leak-tight integrity, and
5. Ultimate Capability, the point beyond which one could not continue to maintain equalibrium in the structure and would, therefore, expect to see cracking of the containment. Tr. 3746-49, 3694.

91. In the proceeding, the focus has been upon functional capability. The functional capability analyses have been undertaken to determine

whether the McGuire containments could withstand the pressures associated with TMI-2 type accidents. Tr 3749-50. The results of this analysis are not intended to supplant the design pressure, but to provide realistic, yet conservative, estimates of the full capability of the containments to withstand internal pressures associated with such accidents. Staff Analysis, pp. 28, 30; Priory Testimony, p. 2.

92. Both the Staff and Duke approached the problem by analyzing where in the containment the point of first failure ("critical region") would occur. Priory Testimony, p. 1; Tr. 4895. They independently come to the conclusion that the critical region would be approximately half-way up the cylindrical portion of the containment. Tr. 4895, 3720, 3737. The thickness of the steel shell in this area is 3/4", whereas it is 1" for the lower portion of the containment shell nearer the base. Duke Exhibit 5D, Fig. 4.1.1-1. Although the steel in the containment dome is thinner than in the critical region (namely, 11/16"), because of the curves in two directions in the dome the stresses on the dome plate are less than in the critical region. Id.; Tr. 3737-38, 4936-37. The Duke analysis had further determined that the point of minimum strength would be in a shell plate/horizontal stiffener configuration. Priory Testimony, p.1. Mr. Orr took this location and performed a finite element model analysis on 1/4 of a panel bounded by vertical and horizontal stiffeners. Orr Testimony, p.-1. Finite element models were also used by Mr. Priory and by Ames Laboratory. Priory Testimony, p. 1; Staff Analysis, p. 28. At this point, the Duke and Staff analyses took somewhat different routes. Although both began with actual mean mill certified properties for the steel in the containments, Staff assessment, p. 31; Tr. 3742, 3753, they were

used differently in the analyses. Staff used actual mean values for all parameters that have some variability associated with them, which would include materials properties. Tr. 3754-55. Duke took the actual mean values and reduced them in order to obtain a design margin. Tr. 3672. Based upon its analysis, Duke concluded that the functional capability of the containments is 67.5 psig.[38/] Priory Testimony, p. 2.[39/] The Ames Laboratory analysis for the staff resulted in a calculated mean functional capability of 84 psig. Staff Analysis, p. 28. A standard deviation was determined and was applied to this value to determine a lower bound functional capability value. Id. To assure high reliability of leak-tight capability at its lower bound figure, the staff reduced the 84 psig value by three standard deviations (a standard deviation being 12 in this case) to arrive at a lower bound functional capability of 48 psig. Id. Tr. 4893.[40/] 90. The probability of failure of a panel at 48 psig was calculated to be 4×10^{-5} per occurrence. Tr. 4894, 4942-43. The overall probability of failure of the vessel would be the product of the probability of occurrence of a TMI-2 type accident, and the probability of failure of the critical panel. Tr. 4943-45. If the probability of a TMI type scenario is approximately between 10^{-5} and 10^{-6} per reactor year (CESG Exhibit 61) then the overall probability of failure would be approximately between 10^{-10} and 10^{-11} per reactor year. The overall probability of

38/ There would be some increase in leakage through identified paths at this pressure, but such leakage would not result in offsite doses in excess of 10 CFR Part 100 limits. Tr. 3757-58.

39/ Mr. Orr's testimony produced a functional capability figure of 68 psig. Orr Testimony, p. 2.

40/ To put these different calculational results into perspective, it should be noted that the Staff testified that, in view of the different inputs, its analysis correlates reasonably well with the testimony presented by Duke. Staff Analysis, p. 29. Tr. 4962.

failure of the vessel associated with 67.5 psig would be somewhat higher under the same assumptions, between 10^{-6} and 10^{-8}. Id.

94. The only other calculation of containment capability discussed in the record is one by R&D Associates, (hereafter, "R&DA") which was done for the Sequoyah Plant and resulted in a calculated membrane yield of 27 psig. Tr. 3752. Both staff and Duke testified that the R&DA analysis underestimated the capability of the facility because it neglected the coordinated capability of the horizontal and vertical stiffeners to carry load and because it used minimum procurement specifications rather than actual values for materials properties. Tr. 3752-53, 4914-5. Also, the McGuire containment is approximately 1.5 times as strong as the Sequoyah containment and this differential would have to be taken into account in converting the R&DA results to McGuire. Tr. 3753. Duke calculated that if the above limitations were corrected and the Sequoyah value was converted to apply to McGuire, the resulting membrane yield was approximately 60 psig. Tr. 3752-53.

95. As noted above, the containment functional capability analyses were undertaken to determine capability of the facility to withstand a TMI 2 type of accident. As we find, infra, the peak pressures calculated for an S2D accident at McGuire (taking credit for the functioning of the igniters and all safety-grade equipment) are well below the lower valve used by the Staff of 48 psig as functional capability for the McGuire containments. Thus, we find that in the event of a TMI-2 type accident, as described above, at McGuire, the containments can withstand the

associated maximum pressures without releasing offsite doses in excess of 10 CFR Part 100 limits.

96. Containment Welds - CESG also introduced the testimony of Mr. Lanford, a former Duke structural engineer, who testified that he had observed defective welding at the McGuire Nuclear Station. Tr. 3827-29. The specific deficiency asserted was excessive grinding into the base liner plate with a resulting gouge estimated by Mr. Lanford to be 1/8" deep and several inches long. Id., 4712, 4700. Mr. Lanford testified that he brought this defect to the attention of Duke officials but that he did not know whether the weld in question had been repaired. Tr. 3827-29, 3820-1. Mr. Lanford gave his opinion that if such a gouge had not been repaired, it would be some degree weaken the design load capacity of the facility. Tr. 3832.

97. Duke testified in response that, although it was unable to identify from Mr. Lanford's trip report exactly which weld he had identified, since every weld in containment has been radiographed and accepted, such a gouge would have been repaired. Tr. 4848-51. Duke described the welding inspections conducted on its nuclear facilities (4847-48) and the QA checks that are run on this inspection process. Tr. 4852. Duke testifi. that a gouge of the size and depth described by Mr. Lanford would have been detected either on visual inspection or upon inspection of radiographs. Tr. 4850-51.

98. In response to Mr. Lanford's testimony and to a Board request, staff provided testimony by the Chief, Materials and Processing Section, Office of Inspection and Enforcement (hereafter, "IE"), Region II,

regarding the nature of the inspections conducted by IE of containment welds at McGuire.[41] Tr. 4971-72. He testified that IE does selective auditing of procedures (including those for weld rod control, radiographic examination, and qualfication of personnel), observes actual welding, observes the radiography process and reads selected film, and reviews quality assurance/quality control records. Id. Based upon his review of IE's records and his knowledge of the inspection history of the facility, he testified that IE had no knowledge of the defects identified by Mr. Lanford, but he further testified that if such a defect had existed he would have expected it to have been detected and repaired. Tr. 4972. In closing, he stated that, to his knowledge, IE was not aware of any defects in the McGuire containments. Tr. 4973.

99. Although Mr. Lanford expressed doubts as to whether the gouge which he had observed would have been detected either visually or by radiograph (Tr. 4696-98), the record establishes to our satisfaction that a gouge this size would have been detected and repaired. Tr. 4859, 4704-05. The record further demonstrates that, even had it not been identified and repaired, a gouge of this size would have an insignificant effect on containment capability due to the very ductile nature of the steel used. Tr. 4895-96. In sum, we find that the containment welds do not bring into question the reasonableness of the containment functional capability figures put forward by staff and Duke in this proceeding.

41/ The witness, Alan R. Herdt, is a registered professional metallurgical engineer and he had personally conducted some of the welding inspections at McGuire. Statement of Qualifications, following Tr. 4968, 4969.

G. EQUIPMENT SURVIVABILITY

100. In addition to the direct effects of hydrogen combustion on containment, the effects upon essential equipment also requires study. The equipment deemed essential in the face of hydrogen combustion falls into two categories: 1) systems important to maintaining containment integrity in connection with the hydrogen burn and 2) systems important to recovery from an inadequate core cooling situation. Reactor and Containment Systems Performance Assessment, following Tr. 5435 (hereafter, "Staff Performance Assessment"), p. 1; Duke Exhibit 5D, p. 6-2. The analyses of the survivability of such systems and equipment entailed considerations of both pressure and temperature. Staff Performance Assessment; Duke Exhibit 5D, Section 6. Temperature considerations further broke down into effects of the flame itself to which equipment is exposed and the gases following behind that flame. Id.; Tr. 3318, 4621-22.

101. The only system required for maintenance of containment integrity in connection with the hydrogen burn condition which appears to be susceptible to impact by hydrogen combustion is the air return fan system. Staff Performance Assessment, p. 2. The fan blades could be sensitive to pressure differences across them and to thermal expansion; the motors to overload; and the ducts to pressure differences. Id., p. 4; Duke Exhibit 5D, pp. 6-16 - 6-18. Based upon manufacturers' warranties, the fans should be able to function without deterioration when exposed to the maximum pressure differences between upper and lower containment associated with two different burning scenarios. Id. The operation of the fan blades are not expected to be adversely affected by thermal expansion. Staff Performance Assessment, p. 6. Duke has sta d that the fan motor

would be protected against damage from overload by a trip mechanism. Id. Further, since the pressure differentials would be expected to exist for only a very short period of time, there is reasonable assurance that all of the necessary components of the air return fan system will remain functional during and following a hydrogen burn. Additional verification of this conclusion will be provided as part of Duke's research program to be completed by January 31, 1982. Staff Performance Assessment, p. 4.

102. Of the equipment necessary to recovery from inadequate core cooling, the equipment located within containment is comprised in the main of instrumentation to sense the symptoms of inadequate core cooling. Id., p. 3. Because this equipment is generally smaller than the containment protection equipment discussed above and because most of this equipment is located in lower containment where it might be directly exposed to burning, it was analyzed for the effects of exposure to both the flame and hot gases, as discussed above. Id., pp. 5-9; Duke Exhibit 5D, pp. 6-14 - 6-21. The analyses were done for an assumed series of 10 burns in lower containment (as predicted by CLASIX) (Staff Performance Assessment, p. 6; Duke Exhibit 5D, p. 6-20) and assumed a reasonably slow flame speed (thus exposing the equipment to the heat of the flame for a longer than predicted period of time). Staff Performance Assessment, pp. 6-7; Duke Exhibit 5D, 6-19; Tr. 4627-28. The Staff assumed higher emissivities (thermal energy transfers) from the flame and gases to the surfaces of the equipment and greater heat absorption (also termed emissivity) by such surfaces than did Duke. Tr. 4622-23. The resulting maximum temperatures of instrumentation casing calculated by Duke was 340°F., and that calculated by the staff was 320°F. Staff Performance Assessment, pp. 6-8. The representative piece of equipment actually chosen for this analysis, a

Barton pressure transmitter, has been qualified in excess of 380°F, thus providing margin above either the staff's or Duke's calculated cumulative temperature. Tr. 4566, as modified at Tr. 4617. The Barton transmitter has been qualified for operation under such temperatures and pressures for much longer periods of time than those to which they would be exposed during a hydrogen burn in the McGuire containment. Tr. 4597, 4599, 4620-21. Because of certain failures of soldered connections in the Fenwall tests, the wiring within the transmitter has also been analyzed for its capability to withstand exposure to elevated temperatures. The wiring in Barton transmitters could not experience the type of failure noted at Fenwall, both because of its superior quality and its greater protection. Tr. 4586-89, 4600-01, 4622.

103. On the basis of the analyses which have been conducted of essential equipment, we find that there is reasonable assurance that such equipment will survive hydrogen burning associated with a TMI-2 type accident in the McGuire containments.[42/]

42/ The Staff brought to the attention of the Board and parties a separate analysis it had conducted of the environmental qualifications of safety related electrical equipment in the McGuire containments when exposed to a design basis accident. Staff Exhibit Tr. 4562, 4582. The record establishes that the only piece of equipment identified therein as requiring immediate corrective action, a solenoid valve, will be replaced prior to commencement of operation of the facility. Tr. 4630.

104. Pyrolysis of polyurethane foam - A concern was identified by CESG during the course of the proceeding with the question of whether the polyurethane foam used as insulation in the ice condenser could pyrolize (i.e., decompose) as a result of exposure to a continuous burn in or around the upper plenum. The polyurethane in question is predominantly located between the outermost panel of the air handling ducts and the containment steel shell, where it is separated from the ice condenser atmosphere by 3 inch diameter back to back downcomer and riser ducts with wall thicknesses of 1/16 inches of steel and a 1/4 inch insulating sheet of "glastrate" (manufactured by Owens-Corning) between the ducts for their entire length. Staff Exhibit P, as revised by Staff Exhibit Q, Fig. 1.[43/] Between the air handling ducts (of which there are some 75 to 80) are areas containing the fasteners which hold the entire array to the containment shell or the crane wall. Tr. 5112; Staff Analysis, p. 29; Duke Exhibit 9, Attachment 1. The polyurethane foam behind this fastener configuration is at all places separated from the ice condenser atmosphere by insulating material between steel sheets. Staff Exhibit Q; Duke Exhibit 9; Tr. 5123.

43/ Duke supplied the Affidavit W.H. Rasin, dated April 3, 1981, to verify that the glastrate sheet is in place. Although Duke did not explicitly move the admission of the affidavit, we have admitted it into the record of the proceeding and designated it Duke Exhibit 9.

105. Duke performed an analysis to calculate what temperatures would be achieved in the panels adjacent to the foam in order to determine whether such temperatures would cause the foam to pyrolize,[44/] under the conditions of sustained ice condenser or upper plenum burning postulated by Duke's Combustion witnesses. Duke's combustion experts testified that the flame from the upper plenum burn would settle back down into the ice condenser to t he point where the mixture was just flammable. Tr. 5066-67. The exact location of this flame could not be specified, but Duke assumed that the flame was located in the center (vertically) of the ice condenser, which had the effect of maximizing the heat transfer to the outermost panels for their entire length. Id., Tr. 5113-14. Under the S2D scenario analysis of Duke, the flame would burn for approximately 45 minutes. Tr. 5069, 5115. Duke assumed a 6 inch tall flame with a temperature of 1600°F. Tr. 5113. The conservatism of the values assumed for flame height and temperature (Tr. 5068, 5082) is necessary, in the Board's opinion, to compensate for the inability to determine to what extent the flame front will be moving up and down in the ice condenser.

106. Duke added to the heat-up from the flame, the contribution of radiation from metal surfaces in the ice condenser. Tr. 5114, 5190. This represents a form of double-accounting and introduces an element of conservatism into the Duke analysis. 5190. At the time that testimony on the polyurethane question was taken in this proceeding, Duke was not assuming that there was any insulation between the metal sheets in the 1/2 inch space between the ducts and their respective fasteners. Tr. 5112, 5130. The presence of insulation between the metal sheets, will tend

---

44/ The CLASIX analysis had not modeled substained upper plenum burn.

to result in a somewhat more uniform distribution of heat on the outermost panels, as was assumed by Duke Staff Exhibit Q; Duke Exhibit 9.

107. Duke's analysis resulted in a calculated rise to approximately 370°F over the entire outer panels. Tr. 5116. This temperature was provided to Dr. Leonard E. Edelman, a consultant with extensive experience in the polymer field who had developed the specifications for the polyurethane foam used in ice condenser nuclear plants, for his assessment of the potential for pyrolysis. Professional Qualifications of Dr. Leonard E. Edelman, following Tr. 5042; Tr. 5040-41. Based upon his assessment, it was estimated that a total of 250 pounds of polyurethane foam would be pyrolized. Tr. 5136. This 250 pounds represents a very small fraction of the total mass of 27,000 pounds of polyurethane foam installed behind the outermost panels. Tr. 5136.

108. The air handling ducts are not leak-tight and some of the volatalized gases from the pyrolysis are assumed to be released into the ice condenser atmosphere where they could contribute to the burning already occurring there. Tr. 5130. The heat of the combustion of the foam (12000 btu's/lb.) was used as an approximation of the energy contribution. Tr. 5118. The resulting total energy contribution to the containment would be a maximum of 3 million btu's, which should be compared to the 80 million btu's contributed by hydrogen burning under Duke's S2D scenario. Tr. 5118-19, 5215-16. We find that this additional energy contribution will not significantly increase the total pressure rise in containment. Tr. 5119, 5215-16.[45/]

45/ We have considered in reaching this conclusion the evidence adduced on the possibility of oxygen being present in the foam area, thereby permitting combustion of the foam. We find that there should be not any significant inflow of oxygen into the ducts. Tr. 5134, 5145, 5160. We also note that the pyrolysis itself does not generate free oxygen. Tr. 5139.

109. The record was closed at the conclusion of the evidentiary session on March 19, 1981, subject only to the Staff's request to be permitted to review the record on pyrolysis and, if necessary, file staff testimony on that subject. Pursuant to that reservation, Staff filed an affidavit which has been admitted as staff Exhibit Q, discussed above. The Board permitted the parties the opportunity to respond to staff Exhibit Q and, pursuant to that opportunity, Duke filed an affidavit which has been admitted as Duke Exhibit 9, also discussed above. Mr. Riley filed an affidavit on the same date as Staff filed its Exhibit Q and, obviously, not in response thereto. That affidavit touches on a number of matters in the record. Most of the information contained in the affidavit (i.e., the present bracing shut of the lower ice condenser doors, the affiant's inability to verify the existence of fiberglass at the top of the polyurethane wall panel, the existence of a plastic sheet approximately eight feet above the intermediate deck, and the capability of steel to withstand temperatures associated with burning of mixtures of 32% hydrogen) is of minimal materiality to this record. Other information offered is either cumulative of what is already in the record or simply argument to the record. We, however, take note of Mr. Riley's description of the differences between the "U-shaped member" at Sequoyah and McGuire. The precise configuration at McGuire has now been clarified by Duke Exhibit 9, Attachment 1.

H. Overall Findings on Hydrogen Control

110. On the basis of the evidence developed on this record with respect to hydrogen control, we make the following findings of fact:

(1) There is reasonable assurance that the EHM system will reliably operate to burn in a safe manner any significant hydrogen that may be generated in the event of occurrence of a TMI-2 type accident at McGuire.

(2) The conditions of burning at McGuire in such an event, and the configuration of the McGuire containment are such that detonation of such hydrogen will not occur.

(3) The pressures generated by the resulting burn in the McGuire containments will be well below the containment functional capability and will not result in any breach of containment.

(4) There is reasonable assurance that essential equipment in containment will survive burn conditions and function thereafter.

(5) The measures adopted by Duke to reduce the possibility of operator interference with automatic ECCS operation and the measures adopted by Duke, including an Emergency Hydrogen Mitigation System, to deal with hydrogen generation if a low probability loss-of-coolant accident resulting in degraded core conditions should occur, provide adequate assurance that a sequence of events involving substantial hydrogen generation and breach of containment resulting from the combustion thereof will not occur.

(6) A sequence of events involving substantial hydrogen generation and breach of containment resulting from the combustion thereof is not a credible event as that term is used in 10 CFR Part 100.

111. The Board has taken official notice of the contents of the program instituted by TVA to demonstrate by January 31, 1982 that an adequate hydrogen control system is installed at the Sequoyah facility and will perform its intended function in a manner that provides adequate safety margins. The staff has taken the position that this requirement should also apply to McGuire, and we concur that such a requirement is appropriate with respect to the matters which we have considered in this proceeding. Since the decision to be reached by January 31, 1982, however, also entails matters beyond the scope of this proceeding (e.g., consideration of results of refined CLASIX calculations, results of verifications of equipment survivability, etc.), we consider such a requirement to be within the purview of the Director of the Office of Nuclear Reactor Regulation.

VII . CONCLUSIONS OF LAW

113. This being an operating license proceeding, the Board is called upon to decide only the issues in controversy among the parties. 10 CFR §2.760a. Other matters required to be determined prior to the issuance of an amendment to the zero-power operating license for Unit 1 authorizing full-power operation or of an operating license for Unit 2 are entrusted to the Director of the Office of Nuclear Reactor Regulation. 10 CFR §§2.760a, 50.57.

114. Based upon the foregoing findings of fact, which are supported by reliable, probative , and substantial evidence in the record, and upon consideration of the entire evidentiary record in this reopened proceeding, the Board makes the following Conclusions of Law in supplementation of the Conslusions of Law reached in its April 18, 1979 Initial Decision:

(1) As to CESG Contentions 1 and 2, the design of the McGuire Nuclear Station and the procedures of the Duke Power Company provide reasonable assurance that the facility can be operated without undue risk to the public health and safety with respect to possible hydrogen generation resulting from accidents bearing a reasonable relationship to the accident at TMI-2.

(2) As to CESG Contentions 3 and 4, since the Board has found that breach of containment resulting from hydrogen generation in an accident bearing a reasonable relationship to the accident at TMI-2 is not a credible sequence of events, the premise for these contentions has not been established and there is no need to develop a record with respect to said contentions.

IX. ORDER

115. WHEREFORE, IT IS ORDERED that the stay of the Licensing Board's April 18, 1979 Initial Decision is lifted and that the Director, Office of Nuclear Reactor Regulation, is authorized, upon making requisite findings with respect to matters not embraced in the Initial Decision, in accordance with the Commission's regulations, to issue to Duke Power Company operating licenses (or in the case of Unit 1, an amendment to NPF-9, if appropriate) for a term of not more than forty (40) years, authorizing operation of the McGuire Nuclear Station, Units 1 and 2, at steady state power levels not to exceed 3, 411 megawatts thermal; such licenses may be in such form and content as is appropriate in light of such findings.

116. In view of the Commission's Rules of Practice considering the Board's jurisdiction in a contested operating license proceeding, the Board has made findings of fact and conclusions of law on matters actually put into controversy by the parties to the proceeding. In addition, the licenses will not be issued until the Director, Office of Nuclear Reactor Regulation has made the findings reflecting its review of the application under the Atomic Energy Act, which will be set forth in the proposed licenses, and has concluded that the issuance of the licenses will not be inimical to the common defense and security and to the health and safety of the public. In addition, the licenses will not be issued until directed by the Commission after the appropriate Appendix B to 10 CFR Part 2 stay review process, if such is applicable. Exceptions to the Decision and requests for stay may be filed within 10 days after the service of this Supplemental Initial

Decision. A brief in support of the exceptions should be filed within 30 days thereafter (40 days in the case of the Staff). Within 30 days after the service of the brief of appellant (40 days in the case of the Staff) any other party may file a brief in support of, or in opposition to, the exceptions.

Respectfully submitted,

Joseph F. Scinto
Counsel for NRC Staff

Edward G. Ketchen
Edward G. Ketchen
Counsel for NRC Staff

Stephen H. Lewis
Stephen H. Lewis
Counsel for NRC Staff

Dated at Bethesda, Maryland
this 13th day of April, 1981

APPENDIX A

The NRC Staff adopts the proposed list of exhibits as set forth in Appendix A to "Applicant's Proposed Findings of Fact and Conclusions of Law in the Form of a Supplemental Initial Decision," except as supplemented by the following list of exhibits:

STAFF EXHIBITS

Number	Identified	Received	Description
E	3160-61		Letter from Marshall Berman, 4441, Sandia National Laboratories, to Thomas E. Murley and Denwood F. Ross, February 9, 1981 (Appendix B), pp. 1-5.
F	3558		Memorandum for Commissioners Ahearne, Gilinsky, Hendrie and Bradford; subj: OPE Review of Hydrogen Control Measures for Sequoyah (dtd January 22, 1981), encl., "Evaluation of the Glow Plug Igniter Concept for Use in the Sequoyah Nuclear Plant, prepared by Roger A. Strehlow, Consultant ("Strehlow Report (January 9, 1981).
L	4297		Figure 7, "Obstacle Configurations" (Diagram).
N	4546, 4656		Environmental Qualifications SER, February 24, 1981.
Q	Motion to Supplement Record w/joint affidavit of staff members Noonan, Polk, Parczewski and Tinkler submitted <u>nunc pro tunc</u> on April 8, 1981		Joint Affidavit of Vincent S. Noonan, Harold E. Polk, Krysztof I. Parczewski, and Charles G. Tinkler (March 27, 1981) (submitted by staff counsel's letter of March 27, 1981 in accordance with leave granted by the Licensing Board at the close of the hearing on March 19, 1981).

INTERVENOR'S EXHIBITS

Number	Identified	Received	Description
41	3482		Affidavit of Stephen P. West, March 2, 1981
42	3782		"Analysis of the Three Mile Island Accident and Alternative Sequences", NUREG/CR-1219, pp. v-vi, 1-1 to 1-4, 2-1 to 2-8, prepared by R. O. Wooton, R. S. Denning, P. Cybulskis, Battelle, Columbus Laboratories, prepared for U.S. Nuclear Regulatory Commission (NUREG/CR-1219).
43	3782		NUREG/CR-1219, Cp. 5, "MARCH Analysis of Alternative Accident Sequences," pp. 5-1&5-18; Figs. 5.3, 5.4, 5.5.
44	3784		NUREG/CR-1219, Cp. 8, Analysis of Hydrogen Burning During the TMI-2 Accident, pp. 8-1 to 8-8.
45	3785-87		Testimony of A. D. Miller Regarding Hydrogen Production at TMI (includes Hydrogen Phenomena (Appendix HYD) NASAC-1, pp. 1-11, Figs. HYD-1 to Figs. HYD-6.
46	3786-87		Report from Harmon W. Hubbard, R&D Assoc. to Nuclear Regulatory Commission, dated August 4, 1980 with encl. entitled "Hydrogen Problems in Sequoyah Containment."
47	3787		Attachment 2, Memorandum from W. R. Butler to W. C. Milstead, "Commission Paper - SECY 80-107 'Proposed Interim Hydrogen Control Requirements for Small Containments.'"
48	3789		Figure TH10, Nozzle Locations; Fig. TH9, Primary System Reactimeter Measurement; Fig. TH11, Drain Tank Behavior.
49	3790		NSAC-1, Appendix PDS, pp. 12-14.
50	3792		Attachment 6, Memorandum for R. L. Tedesco, from W. Butler, subj: Three Mile Island, Unit 2: Analysis and Evaluation of Selected Containment Related Issues, April 25, 1979.

Number	Identified	Received	Description
51	3793		Letter from Harmon W. Hubbard to Nuclear Regulatory Commission, dated July 25, 1980 with encl. entitled, "Sequoyah Containment Analysis," July 1980, pp. 1-5, 7-22.
52	3793		Memorandum from R. Tedesco to L. Rubenstein, dated December 1, 1980.
53	3793-94		248th ACRS Meeting, Tr. 339, 388-90, 404-05.
54	3805		NSAC-1, Appendix ERV, "Electromatic Relief Valve," pp. 1-5.
55	3808		NSAC-1, Appendix PDS, "Plant Data Sources for Three Mile Island Unit 2 Accident," pp. 1-6.
56	3808		NSAC-1, Fig. OTSG-1; Fig. OTSG-2 (OTSG Level Indication) (Appendix OTSG); Fig. RCPCS-1 (Pressurizer Layout) (Appendix RCPCS).
57	3810		Science News, Vol. 118, "Nuclear Accidents: The 10-Minute Myth," p. 37 (July 19, 1980) and letter from Thomas B. Sheridan, Massachusetts Institute of Technology, Dept. of Mechanical Engineering to Mr. Jesse Riles [sic], dated February 26, 1981.
58	3818		"NRC Staff Answers to CESG Interrogatories and Requests for Documents" (January 16, 1981).
62	4881-82		Chapter 8, Accident Process Analysis.

Mr. David E. Smith
City of Charlotte
Legal Department
600 E. Trade Street
City Hall
Charlotte, North Carolina 28211

Diane B. Cohn, Esq.
William B. Schultz, Esq.
Public Citizen Litigation Group
Suite 700
200 P Street, N.W.
Washington, D.C. 20036

*Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

*Atomic Safety and Licensing Appeal Panel
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

*Secretary
U.S. Nuclear Regulatory Commission
ATTN: Chief, Docketing & Service Br.
Washington, D.C. 20555

Edward G. Ketchen
Counsel for NRC Staff

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
DUKE POWER COMPANY	)	Docket Nos. 50-369
	)	50-370
(William B. McGuire Nuclear Station, Units 1 and 2)	)	

CERTIFICATE OF SERVICE

I hereby certify that copies of "NRC STAFF PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW IN THE REOPENED LICENSING BOARD PROCEEDING REGARDING HYDROGEN GENERATION IN THE FORM OF A SUPPLEMENTAL INITIAL DECISION", dated April 13, 1981 in the above-captioned proceeding have been served on the following by deposit in the United States mail, first class, or as indicated by an asterisk through deposit in the Nuclear Regulatory Commission's internal mail system, this 13th day of April, 1981.

*Robert M. Lazo, Esq., Chairman, Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

*Dr. Emmeth A. Luebke, Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

*Dr. Richard F. Cole, Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

William Larry Porter, Esq.
Associate General Counsel
Duke Power Company
P. O. Box 2178
422 South Church Street
Charlotte, North Carolina 28242

Mr. Jesse L. Riley, President
Carolina Environmental Study Group
854 Henley Place
Charlotte, North Carolina 28207

Dr. John M. Barry
Department of Environmental Health
Mechlenburg County
1200 Blythe Boulevard
Charlotte, North Carolina 28203

J. Michael McGarry, III, Esq
Debevoise & Liberman
1200 Seventeenth Street, N.W.
Washington, D.C. 20036

Shelley Blum, Esq.
1402 Vickers Avenue
Durham, North Carolina 27707