NUREG-0011
Supplement No. 3

Safety Evaluation Report
related to the operation of Sequoyah Nuclear Plant, Units 1 and 2

Docket Nos. 50-327 and 50-328

Tennessee Valley Authority
Supplement No. 3

September 1980

Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission

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1.0 INTRODUCTION AND GENERAL DISCUSSION

1.1 Introduction

We stated in Supplement No. 2 to the Safety Evaluation Report that except for the hydrogen control measures for the Sequoyah units, all matters had been resolved to the extent that the activities authorized by the license can be conducted without endangering the health and safety of the public.

The staff is presently reviewing a recent report from TVA entitled "Report on the Safety Evaluation of the Interim Distributed Ignition System" (Volume 1 and 2) dated September 2, 1980.

This supplement provides further information and reviews on the hydrogen issue. Pending further action which may be required as a result of rulemaking, but no later than January 31, 1981, TVA shall by testing analysis show to the NRC's satisfaction that the interim distributed ignition system will function in a manner that will mitigate the risk which could stem from the generation of hydrogen.

1.2 Current Data on the TVA Hydrogen Control Program And Containment Capacity

Initial Efforts on CLASIX Verification

TVA has completed certain initial efforts to verify the computer code CLASIX, which was used to perform the preliminary containment transient analysis of hydrogen distribution and deflagration. CLASIX, which was developed by Offshore Power Systems (OPS)/Westinghouse, has been described as a code under development. Nevertheless, in order to increase confidence in the calculated results, OPS has begun a preliminary analysis to verify the code by comparison with the results of other Westinghouse dry containment codes, namely the TMD and COCO codes. The COCO code which is the Westinghouse dry containment code has been used for several years and most recently was used to perform containment pressure calculations with hydrogen burning in the Zion/Indian Point (Z/IP) studies.

Selected comparisons of results between CLASIX and COCO have shown good agreement. A comparison of results has also been made for selected cases using the TMD code. The TMD code is the Westinghouse subcompartment and short term transient ice condenser code, which has been reviewed and approved by the staff. For both two-phase and superheated mass and energy releases the CLASIX and TMD codes predict pressure transients in close agreement. In summary, the initial verification efforts for the CLASIX code using familiar codes has demonstrated that the CLASIX code adequately predicts the containment transient.

Test Results from TVA's Singleton Laboratory

Tests were conducted at TVA's Singleton Laboratory for the purpose of selecting an igniter for use in the Interim Distributed Ignition System (IDIS) for the Sequoyah Nuclear Plant, Unit 1, and assessing the endurance and ignition capabilities of the selected igniter. The igniter that was selected for extensive testing is the GMAC model 7G diesel engine glow plug; a Bosch glow plug is also being tested as an alternate. A spark plug type igniter was considered but was rejected because of potential problems with electromagnetic interference with critical plant instrumentation. However, TVA is continuing to research the problem and spark type igniters may be reconsidered.

The GMAC 7G glow plug produced a surface temperature of 1720 degrees Fahrenheit when operated at 14 volts ac, and the Bosch plug produced a surface temperature at 1700 degrees Fahrenheit when operated at 13 volts ac. TVA has therefore concluded that diesel engine glow plugs can reach and maintain a temperature sufficiently high for hydrogen ignition. Temperatures in the 1700 degree Fahrenheit range have been demonstrated to be adequate for flame initiation based upon the preliminary tests conducted at the Singleton Labs.

Although the GMAC 7G glow plug would produce a surface temperature acceptable for hydrogen ignition when operated at 12 volts ac, TVA plans to operate the plug at a slightly higher voltage to accommodate the line losses, variances in system voltage and possible plug cooling in a turbulent, steam environment.

TVA was concerned about the effects of overvoltage and extended operation at high temperatures on the life expentancy of a glow plug. A GMAC 7G (12 volt) plug was continuously operated at 14 volts ac for 148 hours and later used in the hydrogen burning tests; a Bosch (10.5 volt) plug was operated at 13 volts ac for 90 hours, cooled down for two hours, re-energized, and at the time of reporting to the NRC, had been operating continuously for an additional 5 days. The endurance tests that have been performed to date appear to confirm the durability of the two types of glow plugs tested. However, TVA plans to conduct additional endurance/acceptance tests on the GMAC 7G glow plug which has been selected for initial use in the proposed IDIS.

TVA installed a GMAC 7G glow plug in a $0.039\ ft^3$ pressure vessel to determine the feasibility of igniting lean hydrogen mixtures with the plug. The tests were conducted using an air/hydrogen or an air/steam/hydrogen environment: the glow plug was operated at 12 volts. A series of 10 tests were conducted at various initial hydrogen concentrations and ignition intervals (the time over which electrical power is applied to the igniter circuit). The test results showed essentially complete combustion of the hydrogen occurred at hydrogen concentrations of 12 to 14 volume percent. TVA concludes, and we concur, that the initial testing with the GMAC 7G diesel engine glow plug adequately demonstrates the feasibility of using a commercially available glow plug to ignite hydrogen.

Initial Testing at Fenwall, Inc.

Based on the results of the Singleton tests, TVA has developed an expanded test program using a hydrogen igniter unit of the type to be installed in the Sequoyah Nuclear Plant, Unit 1. The igniter unit essentially consists of a glow plug protruding from a steel enclosure that houses a power transformer. The tests will be conducted by Fenwall, Incorporated.

The igniter unit has been placed in a test vessel and will be subjected to a range of environmental conditions (various air/steam/hydrogenm mixtures at elevated pressure and temperature); the hydrogen ignition performance of the igniter unit will be monitored. The purpose of the tests is to demonstrate that the igniter will initiate a volumetric burn of the hydrogen for the prescribed environmental conditions, and define the hydrogen concentration range over which a volumetric burn of the hydrogen will be initiated.

The test vessel is a sphere about 6 feet in diameter. The vessel can be heated externally with electrical heaters, and is equipped with an internal fan to promote mixing and create a draft at the igniter heating surface. Instrumentation will be provided to monitor vessel pressure and surface temperature, and vessel atmosphere temperature. Sampling capability exists, and hydrogen and oxygen analyzers will be provided to measure pre- and post-burn concentrations of these gases.

The test matrix for the first series of tests will include dry air mixtures having initial hydrogen concentrations of 8 and 12 volume percent, and air/saturated or superheated steam environments, with initial pressures up to 12 psig and hydrogen concentrations of 8 and 12 volume percent. Turbulent conditions will also be simulated with the aid of the internal fan.

Further testing will be based on the outcome of the first test series. However, TVA is developing a test program to determine the effect of the hydrogen burn environment on critical safety equipment, the effectiveness of radiant heat transfer to steel and concrete structural heat sinks and the effect of spray droplet entrainment on igniter reliability.

TVA plans to submit a test report on the first series of tests by October 1, 1980. The staff evaluation of these test data, and subsequent test data, will be discussed in a future supplement to the Safety Evaluation Report.

4. Containment Capacity

Three independent analyses of the Sequoyah containment were performed by TVA, Ames Laboratory and R&D Associates to determine the capacity of the containment to withstand a postulated hydrogen burn/detonation. All three analyses were based on the use of the elementary thin shell theory with variations in assumptions to account for the stiffeners and use of material strength data (actual mill test data vs. code specified values). The results of our initial analysis based on the containment pressure at yield of the steel shell varied from 23 psia to 38 psia (reference Appendix F). On the basis of staff's review of the various analyses, the staff concluded and presented to the ACRS Subcommittee on Structural Engineering that the containment can safely resist an internal pressure of 33 psia. However, after participating in the ACRS subcommittee meeting on September 2, 1980, and observing the results of more sophisticated analysis, the staff determined that the pressure of 33 psia as originally recommended may be overly conservative and that a pressure of 38 psia as computed by TVA should be used as the limiting pressure, which is still believed to be a lower bound, and that there will be enough margin of safety to take care of the various uncertainties.

II.B.7 Analysis of Hydrogen Control

Position

Reach a decision on the immediate requirements, if any, for hydrogen control in small containments, and apply, as appropriate, to new operating licenses pending completion of the degraded core rulemaking in II.B.8 of the Action Plan.

Discussion and Conclusions

In Supplement No. 2 to the Safety Evaluation Report, we provided an analysis of hydrogen generation and control during severe accidents for the Sequoyah ice condenser type of containment. This supplement provides further details on the approaches that the staff has underway toward resolving the issues related to hydrogen control and provides an assessment of results to date.

The staff has two basic approaches underway:

1. Short-Term Approach

   Define and implement those requirements that assure no undue risk to the health and safety of the public pending further action which may be required as a result of the rulemaking proceeding.

2. Long-Term Approach

   a. Require the owners of nuclear power plants to conduct analytical and experimental studies. These studies will establish the data base for defining those design features that make plant responses to degraded/melted core accidents acceptable.

b. Establish NRC sponsored research and technical assistance programs to confirm the results obtained by LWR plant owners and to establish acceptance criteria for the anticipated design features for mitigating degraded/melted core accidents.

Details on these approaches as they affect the Sequoyah plant are provided in Appendix F as well as an assessment of the results to date.

The staff's position regarding this matter for Sequoyah and other ice condenser plants is:

> The existing provisions satisfying 10 CFR § 50.44 are sufficient near term requirements to warrant full power licensing.
>
> Accelerated programs by staff and applicant are needed to qualify and implement measures additional to those satisfying 10 CFR § 50.44. The time frame for these efforts is about four months; i.e. about December 1980.
>
> Those additional measures found effective for Sequoyah will then be implemented at other ice condenser plants.

The above position is based on the staff's from its findings relative to hydrogen generation and control during severe accidents for the Sequoyah plant. In summary, these findings are:

a. The TMI Short Term Lessons Learned (STLL) items have been implemented placing Sequoyah in same risk space as Surry and Peach Bottom;

b. Aggressive applicant and staff programs are in place to improve the hydrogen management capability at Sequoyah (time frame: 4 months);

c. Preliminary work shows the Interim Distributed Ignition System (IDIS) to be a very promising approach; and

d. Backup programs are in place, should the IDIS prove unacceptable.

On this basis we conclude that full power licensing of Sequoyah Unit 1 need not await completion of ongoing work.

APPENDIX F

HYDROGEN CONTROL

FOR

SEQUOYAH NUCLEAR PLANT, UNIT 1

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HYDROGEN CONTROL

for

SEQUOYAH NUCLEAR PLANT, UNITS 1 & 2

1. INTRODUCTION

1.1 Statement of Problem

In the case of a severely degraded core, the generation and release of substantial amounts of hydrogen to the Sequoyah containment (e.g., from a zirconium-water reaction like that which occurred at TMI-2) could under certain assumptions lead to containment failure. By contrast, a similar event in a conventional, large "dry" containment would probably not lead to containment failure. It is therefore necessary to consider whether scenarios leading to containment failure in ice condenser plants such as the Sequoyah Nuclear Plant are sufficiently likely as to pose undue risk.

1.2 Background

Prior to the TMI-2 accident, Commission regulations regarding hydrogen control (10 CFR Section 50.44); GDC 50 in Appendix A to 10 CFR Part 50) dealt with the hydrogen generated from certain design basis accidents, such as the LOCA. These relatively small amounts of hydrogen generated by a LOCA have been accommodated by the use of small capacity hydrogen recombiners or by delayed purging of the containment.

Following the TMI-2 accident, the staff prepared the "NRC Action Plan Developed as a Result of the TMI-2 Accident," NUREG-0660. Item II.B.7 of the Action Plan states that the staff is preparing interim hydrogen control requirements for small containment structures.

On February 22, 1980, the staff issued SECY-80-107, "Proposed Interim Hydrogen Control Requirements for Small Containments," in response to Item II.B.7 of the Action Plan. In SECY-80-107, the staff concluded that:

> "The 'Short Term Lessons Learned' from the TMI-2 accident have been implemented at all operating reactors and will be implemented at all plants under construction before operating licenses for them are issued. This action makes the likelihood of accidents involving substantial amounts of metal-water reaction smaller than was the case before the TMI-2 accident.
>
> A rulemaking proceeding on design features to mitigate the consequences of degraded core and core melt accidents is under consideration. Pending this rulemaking proceeding, we conclude that: 1) all Mark I containments that are not now inerted and all Mark II containments should be required to be inerted; 2) no interim requirements are required at this time for improvement in hydrogen management capability at nuclear power plants with other types of containment designs; and 3) subject to implementation of item 1, above, continued operation and licensing of nuclear power plants is justified."

A Commission briefing on SECY-80-107 was held on March 19, 1980. Following this briefing, the Commission requested that certain additional information be provided. At its response to this request for additional information, the staff issued SECY-80-107A and SECY-80-107B on April 22, 1980 and June 20, 1980, respectively.

A second briefing of the Commission was held on June 26, 1980. The Commission was advised during this briefing that the staff was preparing an advance notice of rulemaking and a proposed Interim Rule for Commission review and approval. The matters dealing with rulemaking are discussed in Section II, below.

There are a total of 10 licensed nuclear power units with ice condenser containments in the United States. Two of these, D. C. Cook, Units 1 and 2, are licensed for operation at full power. Sequoyah, Unit 1 is licensed to operate up to 5% of full power. The other seven units are under various stages of construction. Construction is scheduled to be complete at the next unit, McGuire, Unit 1, by about October 1980, and at the other six units in 1981 and later.

1.3 Summary

The present status of hydrogen control measures for the Sequoyah Nuclear Plant as of August 13, 1980 is discussed in this section. In summary, the significant new events subsequent to the background discussed above are reported and preliminary assessments are provided.

The staff's view has been that, because of the safety improvements, associated with implementation of the TMI-2 Lessons Learned items, hydrogen control measures beyond those satisfying 10 CFR Section 50.44 (i.e., redundant hydrogen recombiners) are not required for full power licensing of the Sequoyah Plant pending the upcoming rulemaking proceeding. As part of an effort to improve the safety margins at Sequoyah, TVA has proposed the use of an interim distributed ignition system pending completion of its broader studies of alternative systems for hydrogen control.

The ACRS has reviewed the interim system proposed by TVA and has reported its views on the matter (Section 2.5).

In a letter dated July 25, 1980, R&D Associates documented the results of its independent study of the ultimate strength analyses of the Sequoyah containment. We have reviewed and compared this work with similar work done by TVA and by the Ames Laboratory (Section 2.4.2). In a subsequent letter, dated August 4, 1980, R&D Associates reported the results of its analyses on hydrogen production and burning and mitigation by igniters. Our views on this work and on related work by others are reported in Section 2.4.1.4.

The staff has contracted with the Lawrence Livermore National Laboratory (LLNL) for certain experimental studies designed to evaluate the efficacy of the proposed igniter in initiating combustion of various lean mixtures of hydrogen in the presence of varying amounts of steam. We are targetting completion of this work in about three months. The staff has also issued a "Users Request," which is designed to have the NRC's Office of Nuclear Regulatory Research undertake a program of experiments and analyses to obtain information for use in the upcoming rulemaking proceeding. It calls for certain early studies of the ice condenser plants so that any additional safety requirements can be identified and implemented in a timely manner.

TVA has described a three-phase program dealing with hydrogen control and degraded core matters in general. We intend to impose, as a condition of the operating license for Sequoyah, Unit 1, the completion of a substantial study program by TVA.

We believe that there is good likelihood that the distributed igniter system will be established as a worthwhile safety measure. The distributed igniter system will serve to mitigate the consequences of a hydrogen release to the containment under degraded core accident conditions by inducing a series of controlled burns in the lower compartment of the containment to permit the active and passive heat removal mechanisms to dissipate the combustion energy and thereby maintain the pressure response within the containment structural design capability. We will expedite our review, which includes a review of the TVA assessment (to be filed by August 15, 1980) so that a regulatory decision may be made in the fall of 1980.

2. Discussion

2.1 Rulemaking

As part of Item II.B.8 of the NRC Action Plan Developed as a Result of the TMI-2 Accident, NUREG-0660, the NRC will conduct a rulemaking on consideration of degraded or melted cores in safety reviews. The first step in the rulemaking proceeding will be the issuance of an advance notice of rulemaking and an Interim Rule.

2.1.1 Advance Notice of Rulemaking

In SECY-80-357, dated July 29, 1980, the staff seeks Commission approval to publish an advance notice of proposed rulemaking. This advance notice states that the NRC is considering amending its regulations to determine to what extent, if any, commercial nuclear power plants should be designed for a broad range of reactor accidents which involve damage to fuel and release of radioactivity, including design for reactor accidents beyond those considered in the current "design basis accident" approach. In particular, this rulemaking would consider the need for nuclear power plant designs to be evaluated over a range of degraded core cooling events with resulting core damage and the need for design improvements to cope with such events.

2.1.2 Interim Rule

Pending the rulemaking proceeding referred to above, an interim rule is being prepared (and should be to the Commission in August 1980) which contains additional requirements relative to hydrogen control. Specifically, the proposed rule would require that: 1) all Mark I and Mark II containments for BWR plants be operated with an inerted atmosphere inside containment by January 1, 1981; and 2) design analyses be performed for all other plants to evaluate measures that can be taken to mitigate the consequences of large amounts of hydrogen generated within 8 hours after onset of an accident. The design analyses and a proposed design would be filed some six months after the effective date of the rule or by the date of docketing of the application for the operating license, whichever is later.

We expect to request Commission approval for publication of the proposed rule during August 1980, and allow 30 days for public comment.

2.2 Licensee Efforts

2.2.1 Short Term

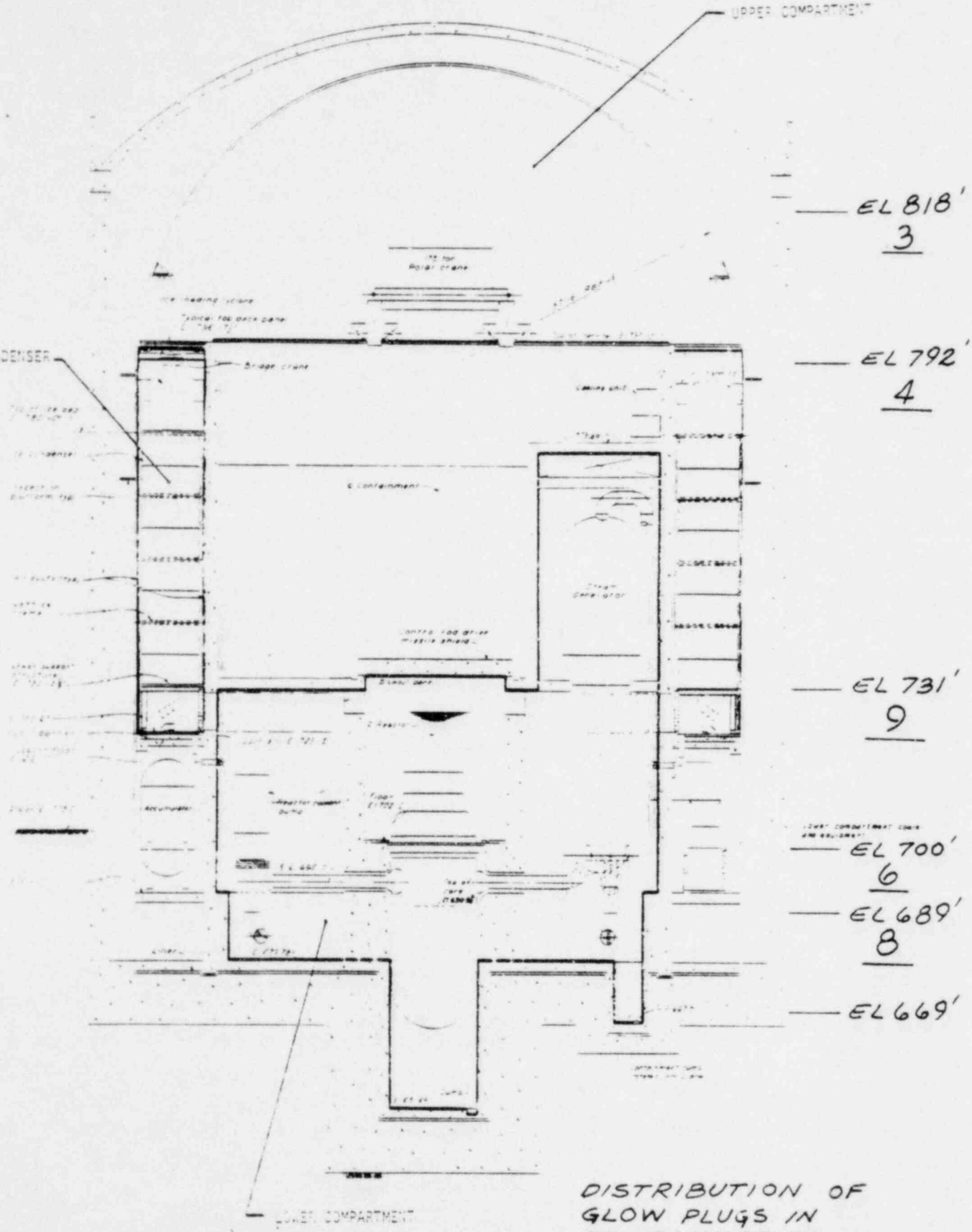
Although TVA considers the existing Sequoyah capability relative to hydrogen control to be adequate pending the rulemaking proceeding, it has taken steps to improve this capability in the near term. Specifically, TVA has proposed to install and implement an interim system of distributed igniters for controlling hydrogen combustion which should limit the effects of large amounts of hydrogen such as that generated during the Three Mile Island accident. On or before August 15, 1980, TVA will submit to the staff for review and approval the safety analysis, system design description and drawings, Final Safety Analysis Report revisions, system test requirements and igniter test results, and proposed revisions to the emergency operating instructions. The distributed ignition system will not be made operable until TVA has received staff approval.

The system will be installed and upgraded in three phases. Phase 1 is an interim effort consisting of system installation and testing, and is expected to be completed by September 15, 1980. The system will use off-the-shelf components, and the igniters will be thermal resistors (GMAC 7-G diesel engine glow plugs are currently being tested). The igniters will be powered from the emergency buses through backup lighting circuits, which are seismically qualified. The emergency diesel generators will also provide power to the backup lighting circuits in the event of a loss of offsite power. The system would be remote manually controlled from the auxiliary building.

Figure 1 is an elevation view of the Sequoyah containment and indicates the number of glow plugs TVA proposes to locate at various elevations in the containment. TVA proposes to provide a total of 30 glow plugs. Eighteen glow plugs will be located in the lower compartment; 8 at the 689.0' elevation, 6 at the 700.0' elevation and 4 at the 731.0' elevation (in the openings to the steam generator compartments). Five glow plugs will be located in the lower plenum of the ice condenser at the 731.0' elevation, and 4 glow plugs will be located in the upper plenum of the ice condenser at the 792.0' elevation. Three glow plugs will be located in the upper compartment at the 818.0' elevation.

TVA is presently testing the GMAC 7-G diesel engine glow plug to determine the appropriate operating conditions, its durability and its reliability as an ignition source in lean hydrogen mixtures. The glow plug temperature as a function of applied voltage is being determined, and TVA has informed us that glow plug temperatures of about 1700°F and 1500°F occur at 14 volts and 12 volts, respectively. TVA also stated that a glow plug specimen has continued to operate successfully after 6 days at 1700°F. At an applied voltage of 14 volts, ignition

SEQUOYAH CONTAINMENT



DISTRIBUTION OF GLOW PLUGS IN CONTAINMENT
FIGURE

FIGURE 1

was achieved in hydrogen mixtures of 12 volume percent and 7 volume percent hydrogen. TVA plans to conduct further tests by varying the hydrogen concentration and introducting a steam environment to determine the reliability of the glow plugs as an ignition source and the percent completion of hydrogen burns.

TVA, Westinghouse, and Offshore Power Systems (OPS) have performed a preliminary containment analysis using the CLASIX computer code (currently under development), which indicates that a distributed ignition system would be beneficial in mitigating the potential effects of large amounts of hydrogen. Using an accident sequence similar to the TMI-2 accident (small-break LOCA resulting in degraded core cooling), and assuming partial containment safeguards capability, the analysis indicates that the Sequoyah containment could withstand, based on ultimate strength estimates, the pressure spikes resulting from a series of initiated burns in the containment. The accident sequence assumed a hydrogen release from the reactor coolant system corresponding to about an 80% core metal-water reaction.

The analysis briefly discussed above is discussed in greater detail in Section 2.4.1.1, TVA/OPS Results. The results are preliminary. TVA is working with Westinghouse and OPS to refine and complete the analysis. The status of the staff's evaluation effort and independent analytical effort are discussed in Section 2.4.1.4., Comparison of Results.

2.2.2 Long Term

Phases 2 and 3 of the distributed ignition system installation are long term efforts.

Phase 2 improvements to the distributed ignition system will be implemented in parallel with the rest of TVA's long term (2-year) Degraded Core Task Force Program. Phase 2 will include the following improvements:

- Each igniter will have individual control from the main control room.
- More hydrogen and oxygen monitors will be installed to guide operators.
- A plant computer to warn of hydrogen concentrations reaching the detonation limit will be provided.
- Backup diesel power supply to the system will continue to be provided.
- Environmental qualification of distributed ignition system components will be determined.
- Effects of the hydrogen burn environment on components will be analysed.
- Alternate and/or additional igniter locations will be selected based on a better understanding of the characteristics of hydrogen combustion.
- Installation of hydride converters near the reactor vessel vent, PORV discharge, and air return fans will be considered.

Additional containment penetrations will be considered to facilitate an expanded hydrogen monitoring capability.

Phase 3 will consist of final modifications to the Phase 2 system and will be implemented upon completion, and based on results, of TVA's long-term program.

TVA has initiated a long-term Degraded Core Task Force Program. The Program's major tasks will involve extensive work in the following areas:

1. Controlled Ignition
2. Halon Suppressants
3. Risk Assessment
4. Core Behavior, Hydrogen Generation and Transport
5. Hydrogen Burning and Containment Responses
6. Containment Integrity
7. Equipment Environmental Qualifications
8. Radiation Dose Code
9. Hydride Converter, Fogging and Other Mitigation Schemes
10. Rulemaking and State of the Art

This effort is to be performed over a two-year period.

The foregoing discussion of TVA's proposed distributed ignition system and companion efforts is based on discussions with TVA and a review of preliminary information concerning their ongoing design, test and analysis activities, and longer term efforts.

Staff conclusions on the overall efficacy of the proposed distributed ignition system in limiting the effects of large amounts of hydrogen resulting from a degraded core accident will be developed following formal submittal by TVA and completion of the staff review of the system design, supporting test results and analyses, and detailed discussions of subsequent phases of TVA's efforts.

2.3 NRC Efforts

2.3.1 NRR Short-Term

2.3.1.1 Igniter Tests at Lawrence Livermore National Laboratory (LLNL)

In order to evaluate the efficacy of the distributed ignition system to be installed by TVA in the Sequoyah plant the staff has obtained technical assistance to gather information through both experimental and analytical efforts.

The staff, through LLNL, will test hydrogen igniters, identical to those to be installed at Sequoyah. An effort will also be made to test the igniters in the configuration or mounting arrangement identical to those proposed by TVA for installation. The experimental test program will determine the efficiency of the TVA igniters by examining their performance under a spectrum of test conditions. The test matrix will serve to gather data on igniter performance in atmospheres with varying hydrogen and steam concentrations since the effect of large steam concentrations on hydrogen combustion in these situations is not well understood.

A schematic of the test assembly is shown in Figure 2. The general procedure will be to start with dry air at ambient conditions inside the test vessel and then add hydrogen until the pre-selected concentration is reached. Steam will then be injected into the vessel at a given temperature. The steam concentration will decrease slowly as a result of condensation on the cooler test vessel wall. As condensation occurs the volume fraction of hydrogen and air will increase slightly until the conditions of interest are achieved. Intermittent or continuous testing of igniters can proceed with appropriate gas sampling continuing up to and just after ignition. By gas sampling we can determine the degree of combustion, i.e., how much of the hydrogen initially present burned after ignition. Instrumentation in the test vessel will also allow for measurement of pressure and temperature conditions.

Another objective of the program at LLNL is to study current hydrogen analyzers utilized in nuclear power plants, including the analyzer type used to measure hydrogen concentrations within the Sequoyah containment. The program at LLNL is expected to be completed within approximately 3 months. Further testing of ignition devices is expected to continue with investigation into the effects of containment spray operation on igniter performance.

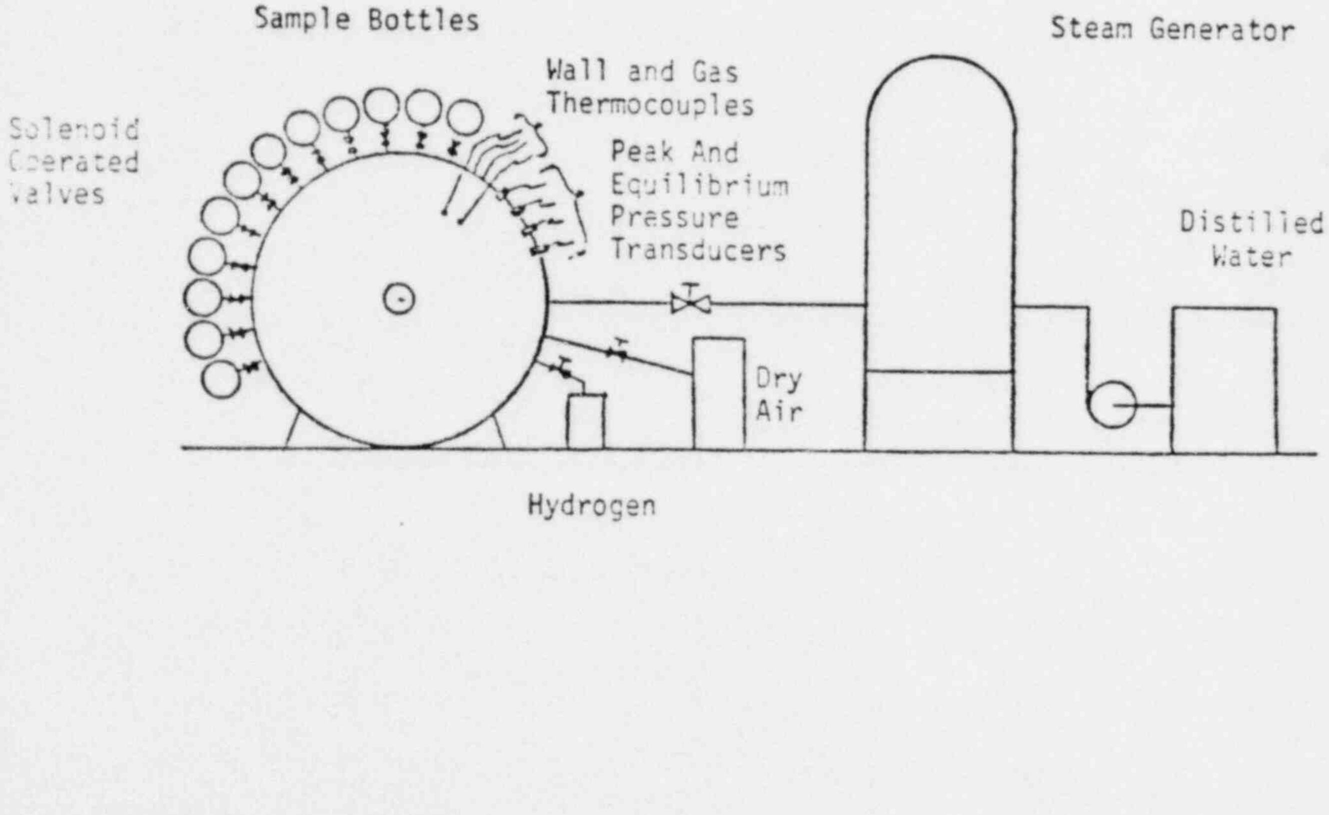


Figure 2. Schematic View of Igniter Test Apparatus

2.3.1.2 Analyses at Battelle-Columbus Laboratory

The staff has also obtained technical assistance from Battelle-Columbus Laboratory (BCL) to study through analysis the effects of igniter performance in the degraded core post-accident environment. The purpose of the analytical effort is to estimate the role and relative worth of igniters in reducing the containment pressure and maintaining containment integrity for accident scenarios where a large amount of core degradation and concomittant hydrogen generation is expected.

Battelle will use the MARCH code to perform the analysis of hydrogen generation and the containment pressure and temperature response. The MARCH code, which was developed by Battelle, has the capability of modeling a multi-volume containment including both active and passive heat removal mechanisms including the ice condenser. Details of preliminary BCL analyses are discussed in Section 2.4.1, Assessment.

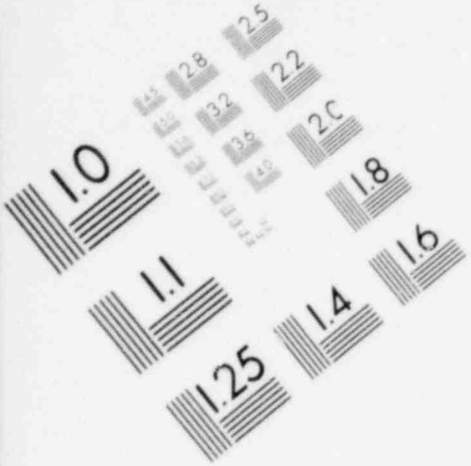
2.3.2 NRR Long-Term

As a result of the accident at Three Mile Island, the TMI Action Plan (NUREG-0660), at item II.B.8 calls for a rulemaking proceeding on consideration of degraded or melted cores in safety reviews. To support the staff's participation in the rulemaking we have requested a safety research program that is to provide a basis for evaluating safety systems intended to mitigate the consequences of degraded/melted core accidents for the generic classes of LWR containment designs. The containment types to be studied are the BWR pressure suppression containments, and ice condenser, subatmospheric and dry containments. A significant portion of this progarm will be devoted to assessing various hydrogen control systems for the different containment designs. Among the hydrogen control measures to be studied are: halon systems, gas turbines, inerting, large capacity recombiners, water fog system and distributed ignition systems. The evaluation of hydrogen control techniques will be based on criteria which include large scale implementation feasibility, economics, reliability and consideration of potential adverse impact. As a matter of priority, the staff has identified the ice condenser and BWR Mark III containment designs as those to be first investigated with regard to mitigation systems.

2.3.3 RES Long-Term

RES is developing a research program plan for Severe Accident Phenomenology and Mitigation to support rulemaking proceedings on Degraded Core Cooling, Siting and Emergency Planning, which are called for in the TMI Action Plan (NUREG-0660) at Items II.B.8, II.A.1, and III.A and III.D, respectively. The objective of the research program is to develop the technical bases for Commission decisions during the rulemaking activities. It is the goal to have major aspects of the work completed in 4 years.

As noted above, the RES research program will incorporate the NRR long-term needs.



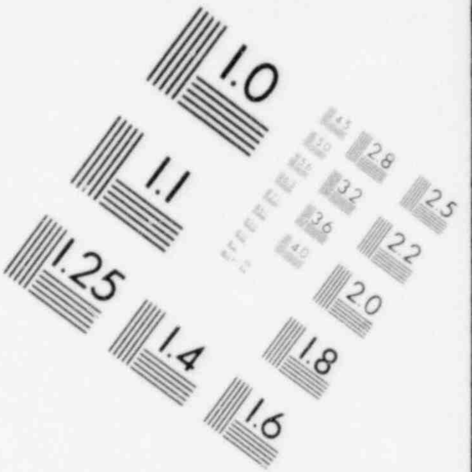


IMAGE EVALUATION
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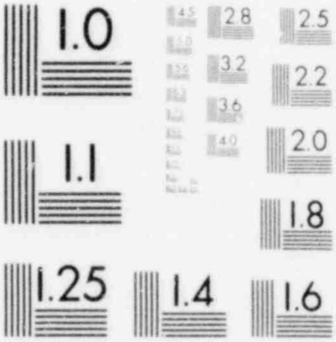
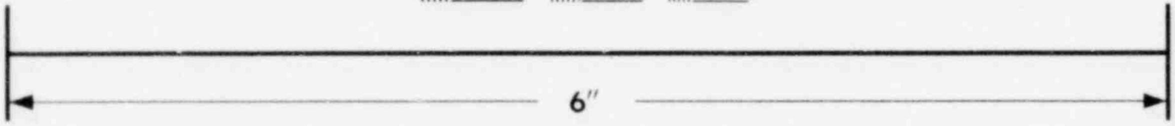
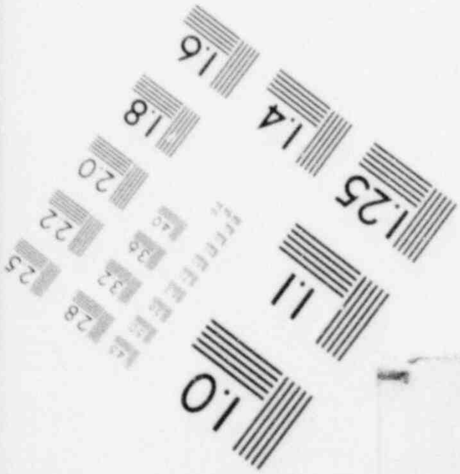
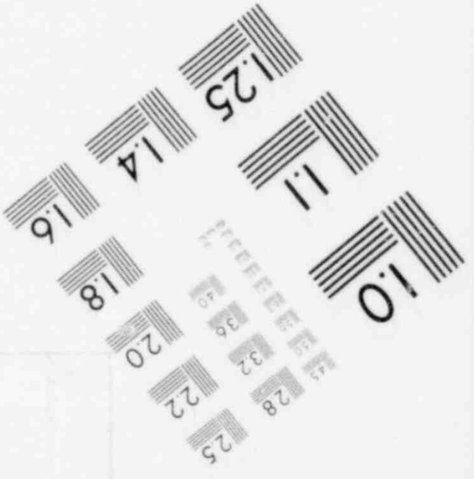
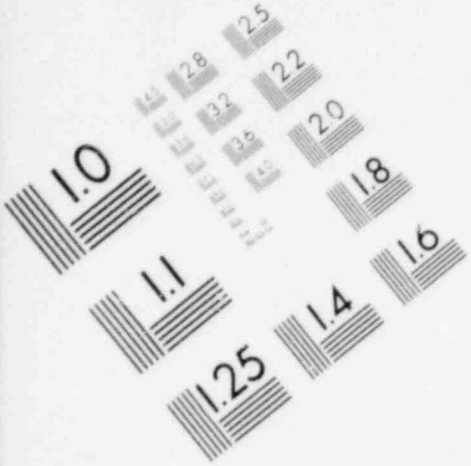




MICROCOPY RESOLUTION TEST CHART







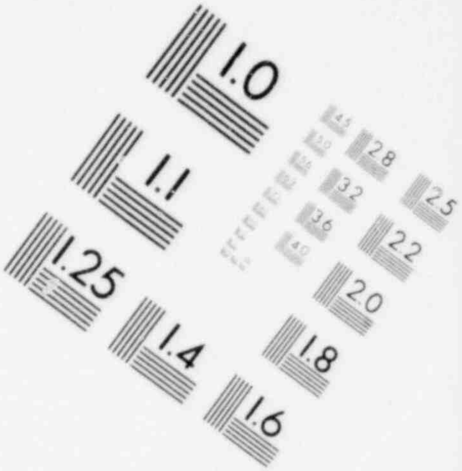
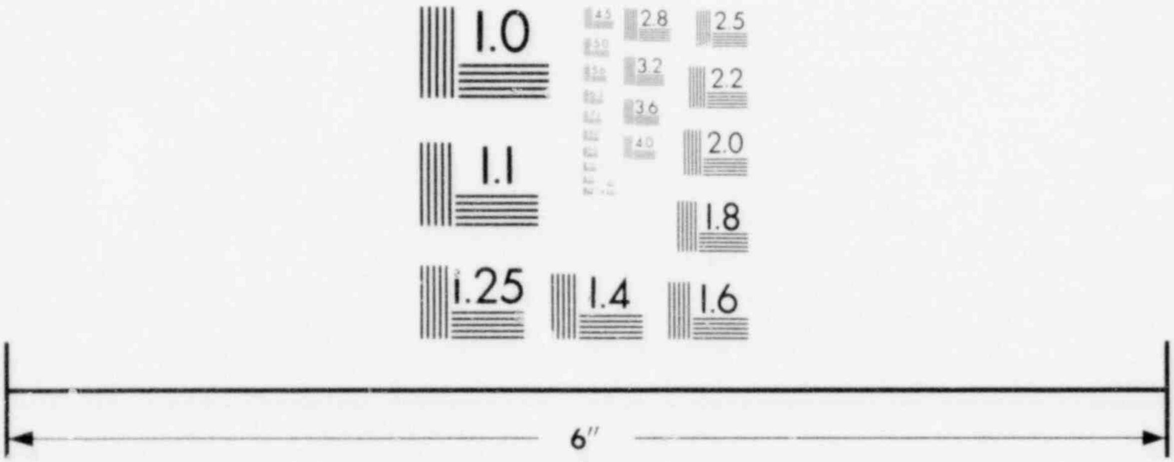
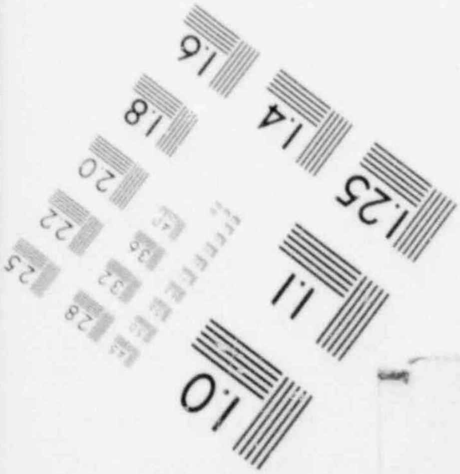
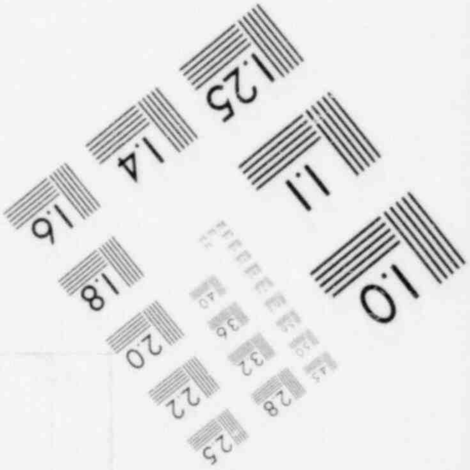


IMAGE EVALUATION TEST TARGET (MT-3)



MICROCOPY RESOLUTION TEST CHART





2.3.4 Relationship to Zion/Indian Point Studies

A study has been undertaken of the containment response associated with the combustion or detonation of hydrogen for the Zion and Indian Point (Z/IP) plants under degraded core or core melt conditions.

The Z/IP effort involves the estimation of the threat to containment from hydrogen combustion or detonations, and the establishment of performance requirements for systems (other than inerting) to mitigate or eliminate the threat. The hydrogen can develop from metal-water reactions (e.g., Zr/H_2O, Cr/H_2O), radiolytic decomposition and reactions of molten core materials with concrete in degraded core/core melt accidents. The investigation has been underway since January 1980, and has comprised three principal areas:

1) Estimate of the amount and possible behavior of hydrogen in applicable accident sequences, including the possibilities and types of non-uniform distributions, the rise and fall time of pressure pulses from the combustion and/or detonation, and how these might add to existing pressure stresses from other sources.

2) Estimate of the response of structures, vessels and vital equipment to the pressure-temperature pulses associated with hydrogen burning/detonations. The in-house effort in this area has been augmented by LASL.

The Z/IP structures studies are not directly applicable to ice condenser plants, except insofar as the same codes and methodologies can be used.

3) Sandia Laboratories has investigated, for RES, the possible problems that the presence of hydrogen might contribute to features of a filtered venting system. Sandia has prepared a compendium on hydrogen burning, detonation and control methodology. The scenarios of accidents leading to the production of hydrogen have also been reviewed.

Some of the results of this program which have applicability to ice condenser plants and other plants include:

1) Codes for the analysis of dynamic loading of containments from hydrogen burning or explosion pressures.

2) A survey and collection of information on combustibility of hydrogen-air-steam mixtures; information on methods of suppression or prevention of hydrogen fires; and ignition information.

3) A summary of the technology for detection of hydrogen.

4) Descriptions of presently used hydrogen recombiners and the problems encountered in their development.

5) Descriptions of other hydrogen control devices and procedures.

As a result of studying accidents more severe than degraded cooling, i.e., accidents involving core melt progression ex-vessel, the Z/IP studies have tended to reiterate previous conclusions on the generation of hydrogen from concrete. Experimental and analytical studies on this interaction of molten core materials with concrete are continuing at Sandia Laboratories.

2.4 Assessment

2.4.1 Containment Loading

2.4.1.1 TVA Results

In order to evaluate the role of igniters in accident mitigation, TVA and the staff have initiated separate programs to analytically and experimentally determine the effectiveness of distributed ignition systems in reducing the threat to containment integrity due to the combustion of hydrogen generated following postulated degraded core accidents.

TVA is currently engaged in an analytical program designed to investigate the consequences of igniter operation in the Sequoyah plant in an accident environment. It is expected that thorough analyses including sensitivity studies on critical parameters for a range of accident scenarios will continue for approximately one year. The analytical work will be performed using the CLASIX computer code which is being developed by Westinghouse/OPS. 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 atmopshere constituents oxygen, nitrogen, hydrogen and steam. Figure 3 shows an example of an ice condenser model for the CLASIX code. The code also has the capability of modeling containment sprays but presently does not 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 burning of hydrogen is calculated in the code with provisions to vary the conditions under which hydrogen is assumed to burn and conditions at which the burn will propagate to other compartments.

As previously stated, TVA is at the beginning of its program to analytically evaluate the effectiveness of their hydrogen ignition system. However, TVA has provided the results of interim calculations performed with the CLASIX code to analyze the response of an ice condenser containment with an operating ignition system. These interim calculations were performed for the accident scenario designated S2D in WASH-1400, which is a small break loss

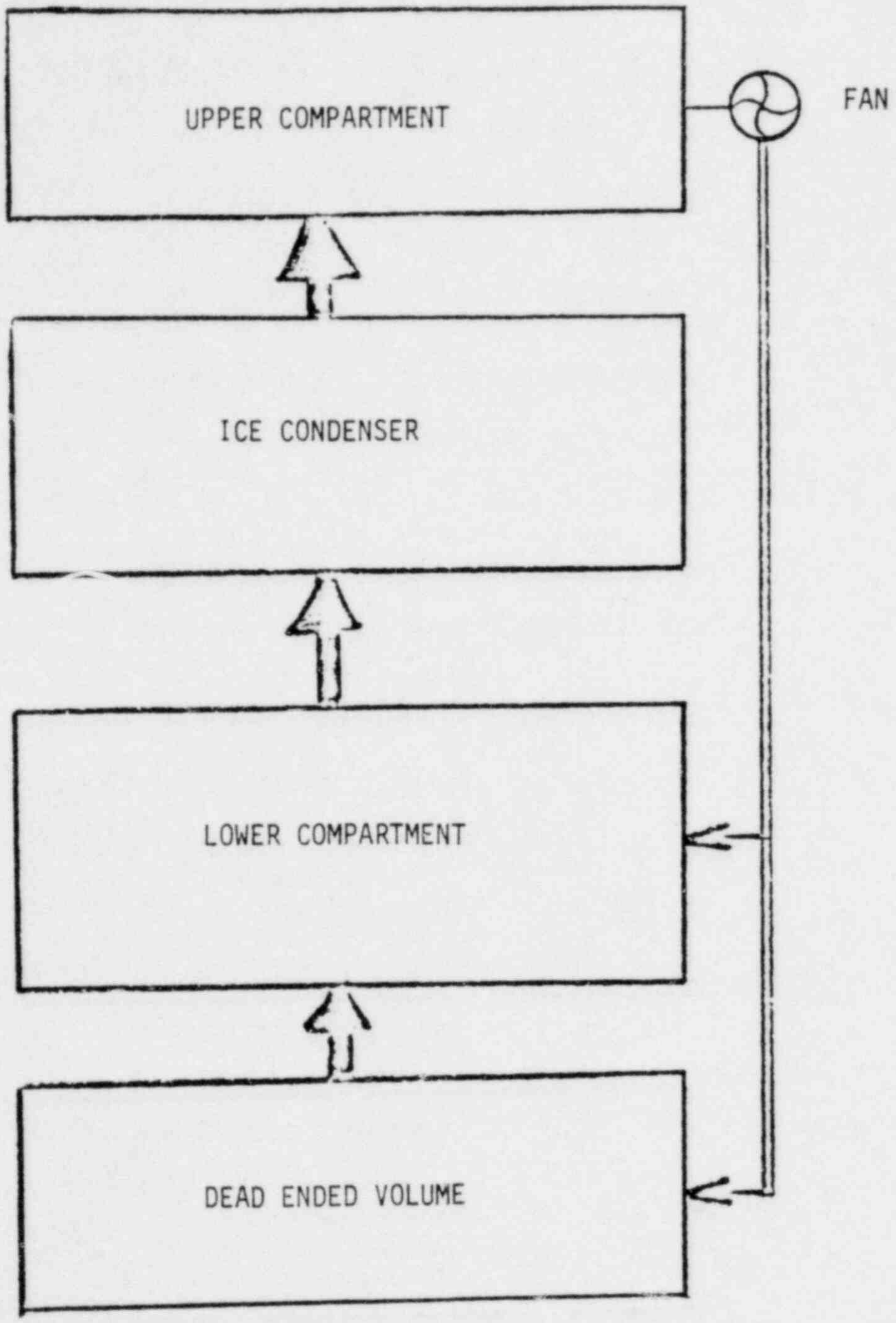


FIGURE 3. CLASIX MODEL OF ICE CONDENSER CONTAINMENT

of coolant accident accompanied by the failure of emergency core cooling injection. The S2D sequence leads to the production of hydrogen from the zirconium-water reaction as a result of the degraded core conditions, i.e., lack of core cooling. The rate of hydrogen production and release to the containment for the interim calculations was based on calculatons by BCL using the MARCH code. The conditions inside the containment prior to the onset of hydrogen generation were determined from LOTIC analyses; LOTIC being the Westinghouse long term ice condenser analysis code previously reviewed and approved by the staff. The CLASIX calculations then begin at the onset of hydrogen production, which occurs at approximately 3500 seconds following onset of the accident. Table 1, which presents the parameters used in the base case CLASIX analysis, shows that hydrogen ignition was assumed to be initiated at a 10% hydrogen concentration and that burning is assumed to propagate to other compartments with a 10% hydrogen concentration. Hydrogen burning was assumed to occur with a flame speed of 6 ft/sec.

Figure 4 presents the integrated hydrogen release input to CLASIX that was calculated for the S2D transient using the MARCH code. The hydrogen release to containment was terminated, for the containment analysis, after approximately 1550 lbs of hydrogen were released. This mass of hydrogen

BASE CASE PARAMETERS

1. INITIAL CONDITIONS:	VOLUMES	LOTIC CODE
	TEMPERATURES	
	PRESSURES	
	ICE MASS	
	ICE HEAT TRANSFER AREA	
2. BURN PARAMETERS:	H_2 FOR IGNITION	10 V/O
	H_2 FOR PROPAGATION	10 V/O
	O_2 FOR IGNITION	5 V/O
3. AIR RETURN FANS:	NUMBER OF FANS	2
	CAPACITY OF EACH FAN	40000 CFM
4. SPRAY SYSTEM:	FLOW RATE	6000 GPM
	TEMPERATURE	125 F
	HEAT TRANSFER COEFFICIENT	20 BTU/HR FT^{2}F
5. ICE CONDENSER DRAIN TEMPERATURE		32 F
6. BREAK RELEASE DATA		MARCH CODE

TABLE 1

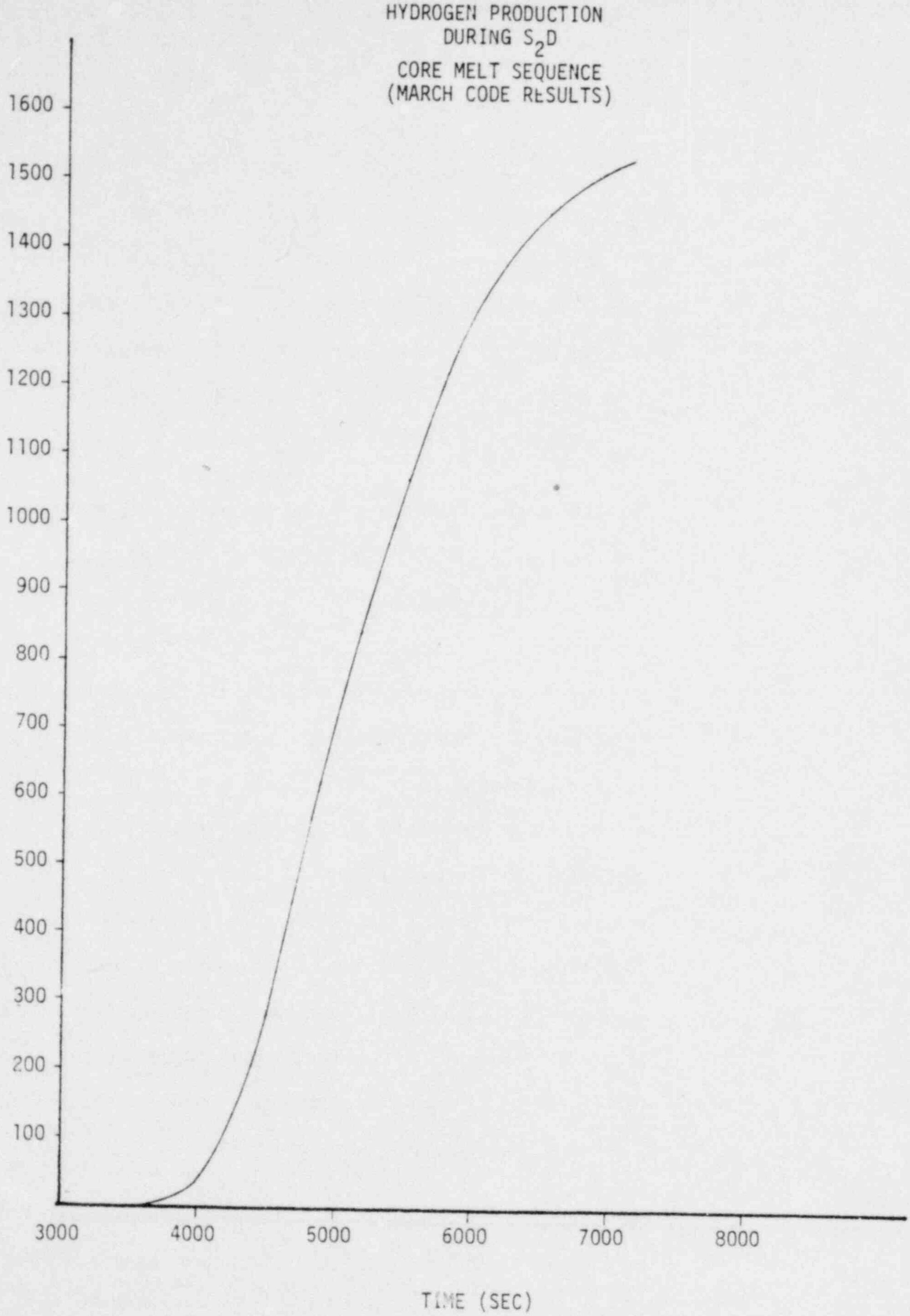

HYDROGEN PRODUCTION
DURING S_2D
CORE MELT SEQUENCE
(MARCH CODE RESULTS)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
3000
4000
5000
6000
7000
8000
TIME (SEC)

FIGURE 4

corresponds to the reaction of approximately 80% of the total zirconium mass in the core. At this point in the scenario the core is dry, thus there is no steam to produce a further zirconium-steam reaction. Extending the accident scenario to the point of reactor vessel melt through will be the subject of future analyses in conjunction with TMI Action Plan Item II.B.8.

Results of the CLASIX base case analysis are shown in Figures 5 through 10. The results of the base case analysis indicate that the hydrogen will be ignited in a series of nine burns in the lower compartment. One of the burns propagates upward into the ice condenser as can be seen by the temperature transient shown in Figure 6. The total interval over which the series of burns occurs is approximately 3300 seconds. For the first burn a peak pressure of 26.5 psia was calculated in the lower compartment, and 28.5 psia for the ice condenser and upper compartment. The pressure in the containment before the first burn was approximately 22.5 psia. Subsequent burns resulted in successively lower pressure spikes. Peak temperatures of 2200°F 1200°F and 150°F were calculated in the lower compartment, ice condenser and upper compartment, respectively.

As a result of the action of engineered safety features, such as the ice condenser, air return fans and upper compartment

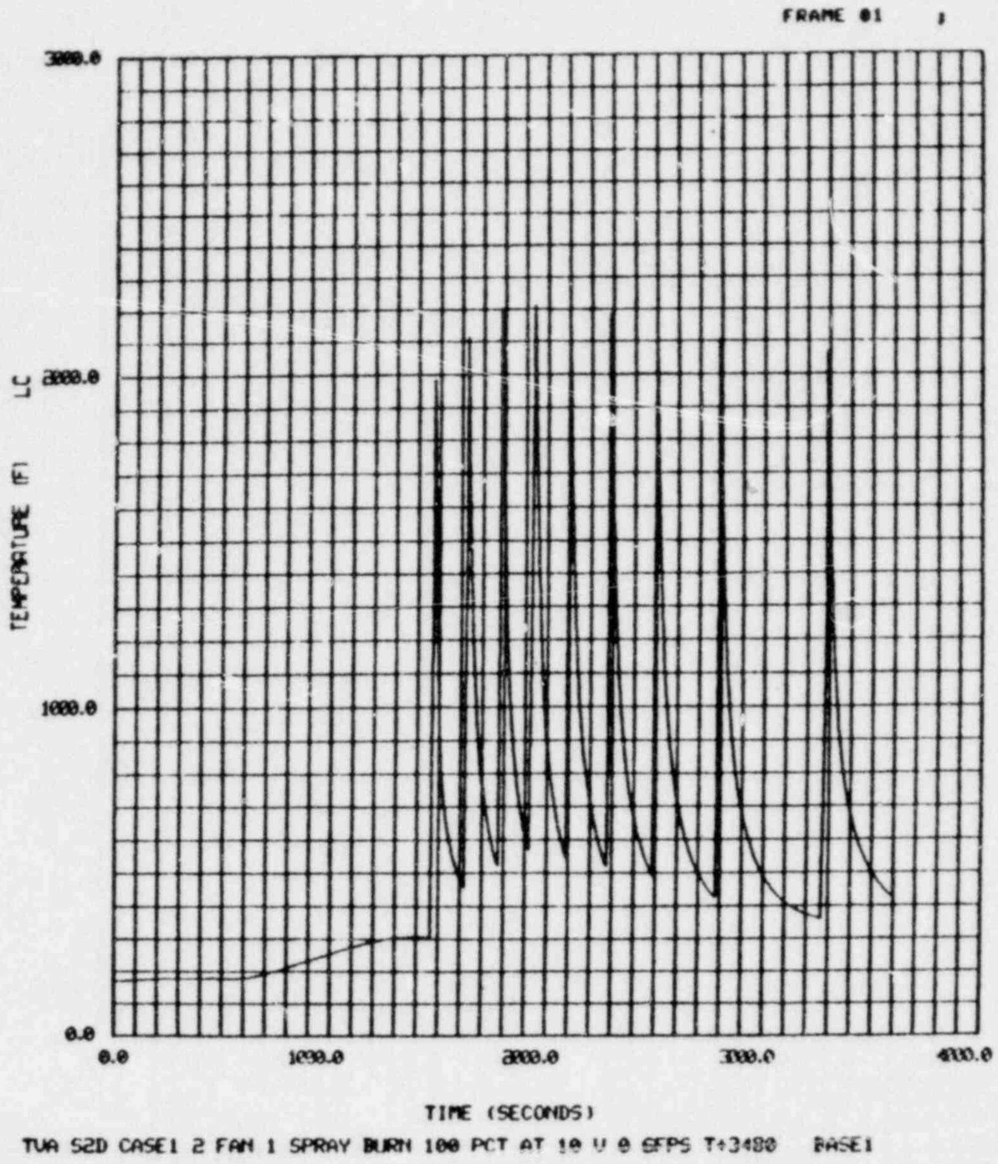


Figure 5. Base Case Lower Compartment Temp. (°F)

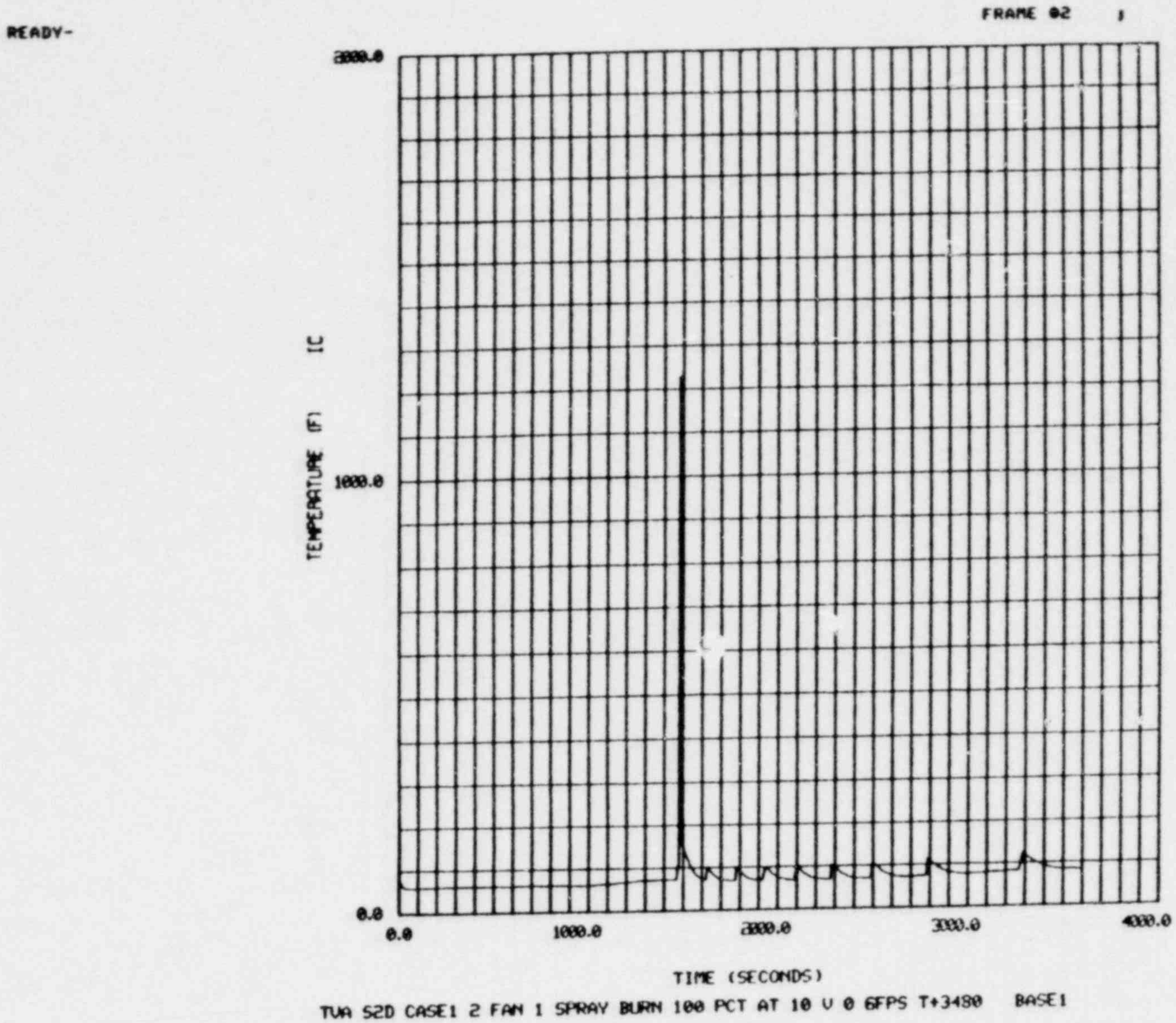


Figure 6. Base Case Ice Condenser Temp. (°F)

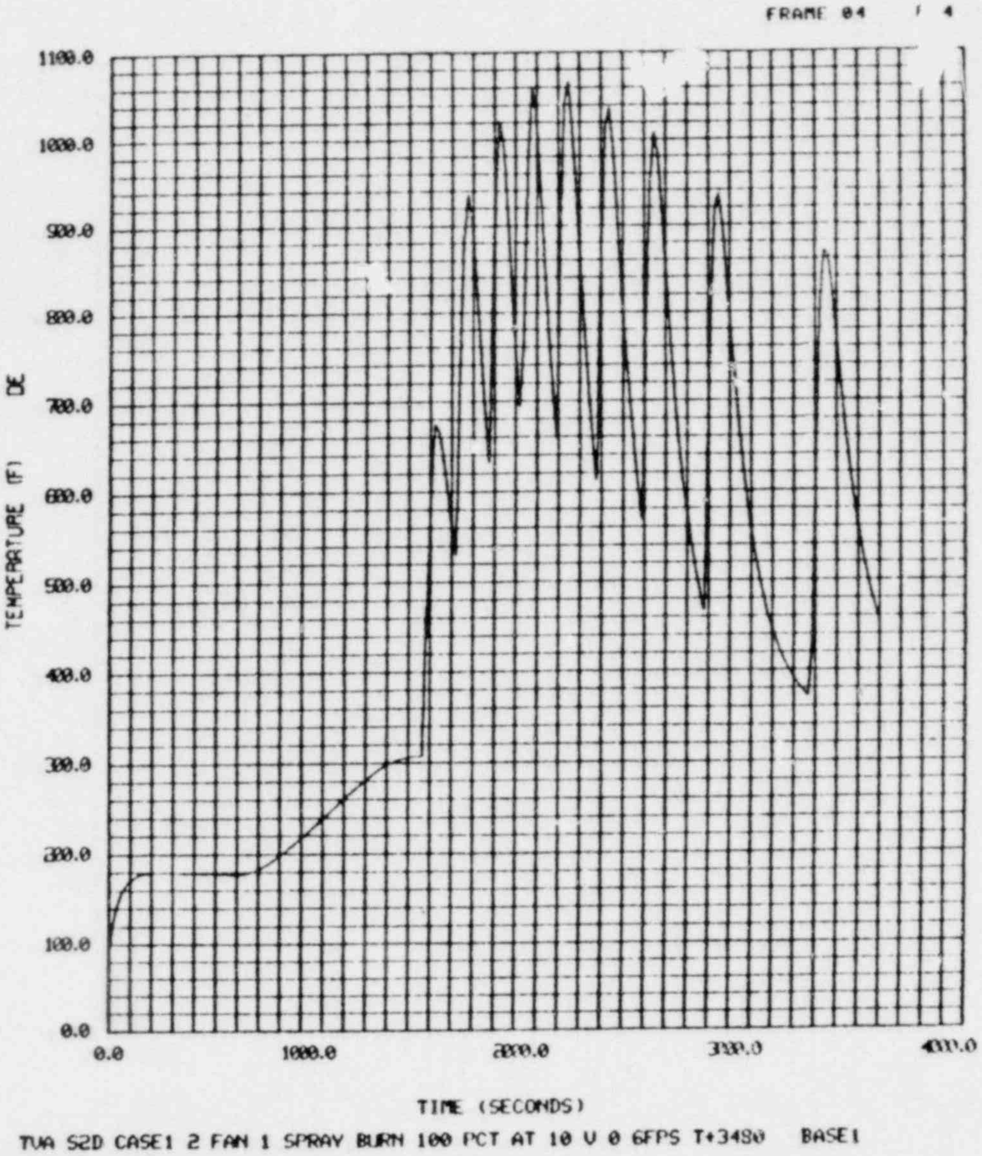


Figure 7. Base Case Dead Ended Volume Temp. (°F)

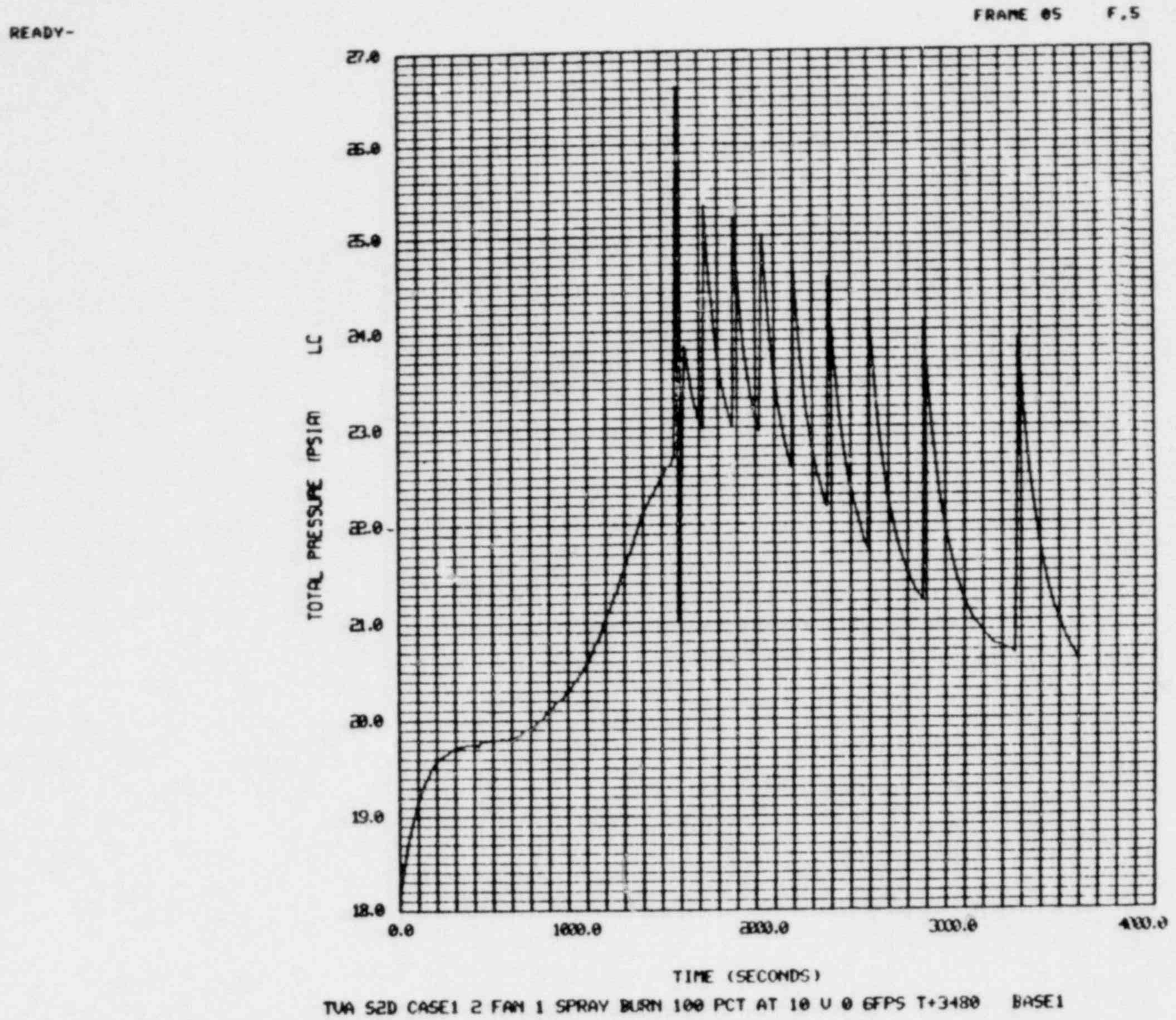


Figure 8. Base Case Lower Compartment Pressure

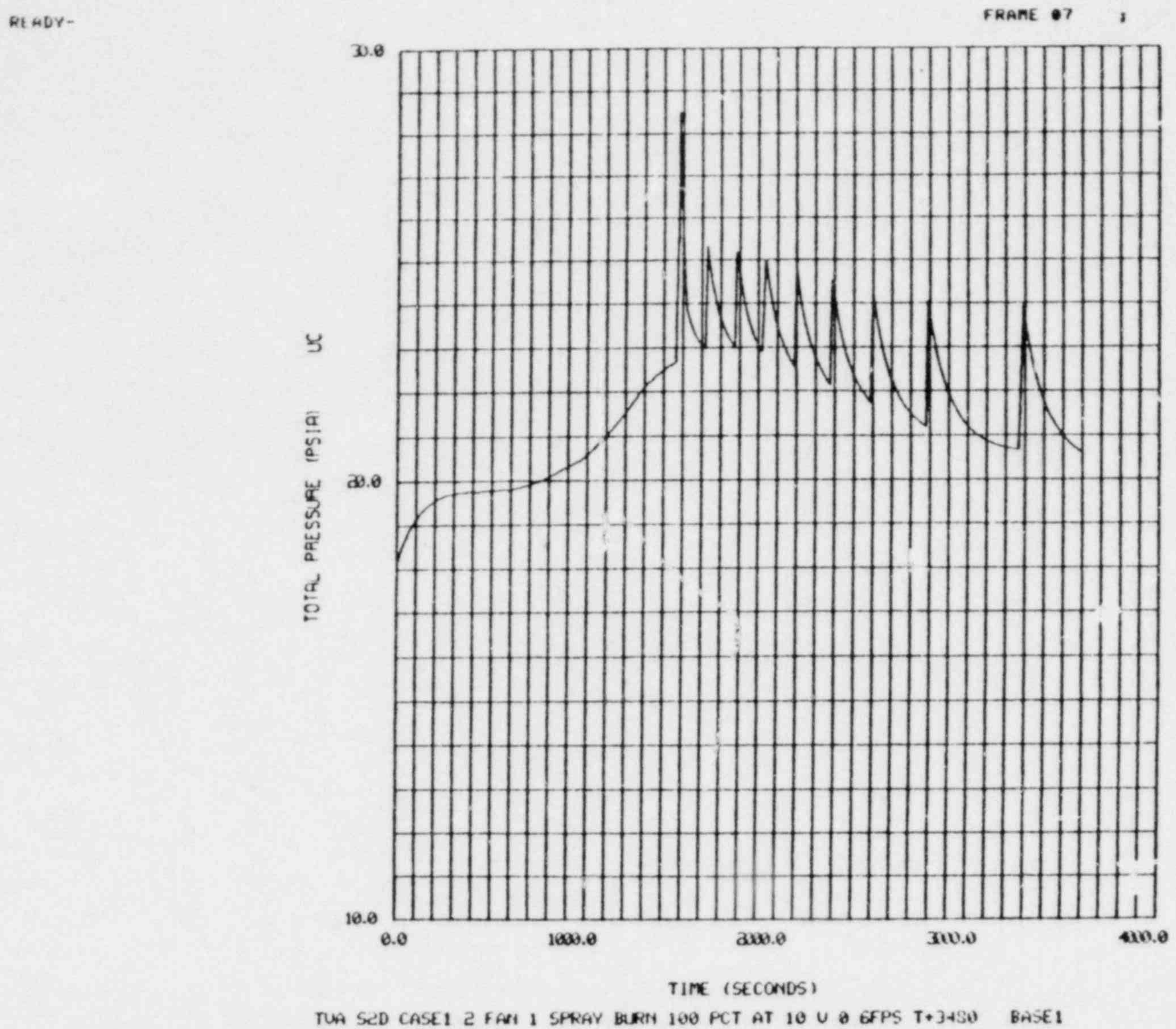


Figure 9. Base Case Upper Compartment Pressure

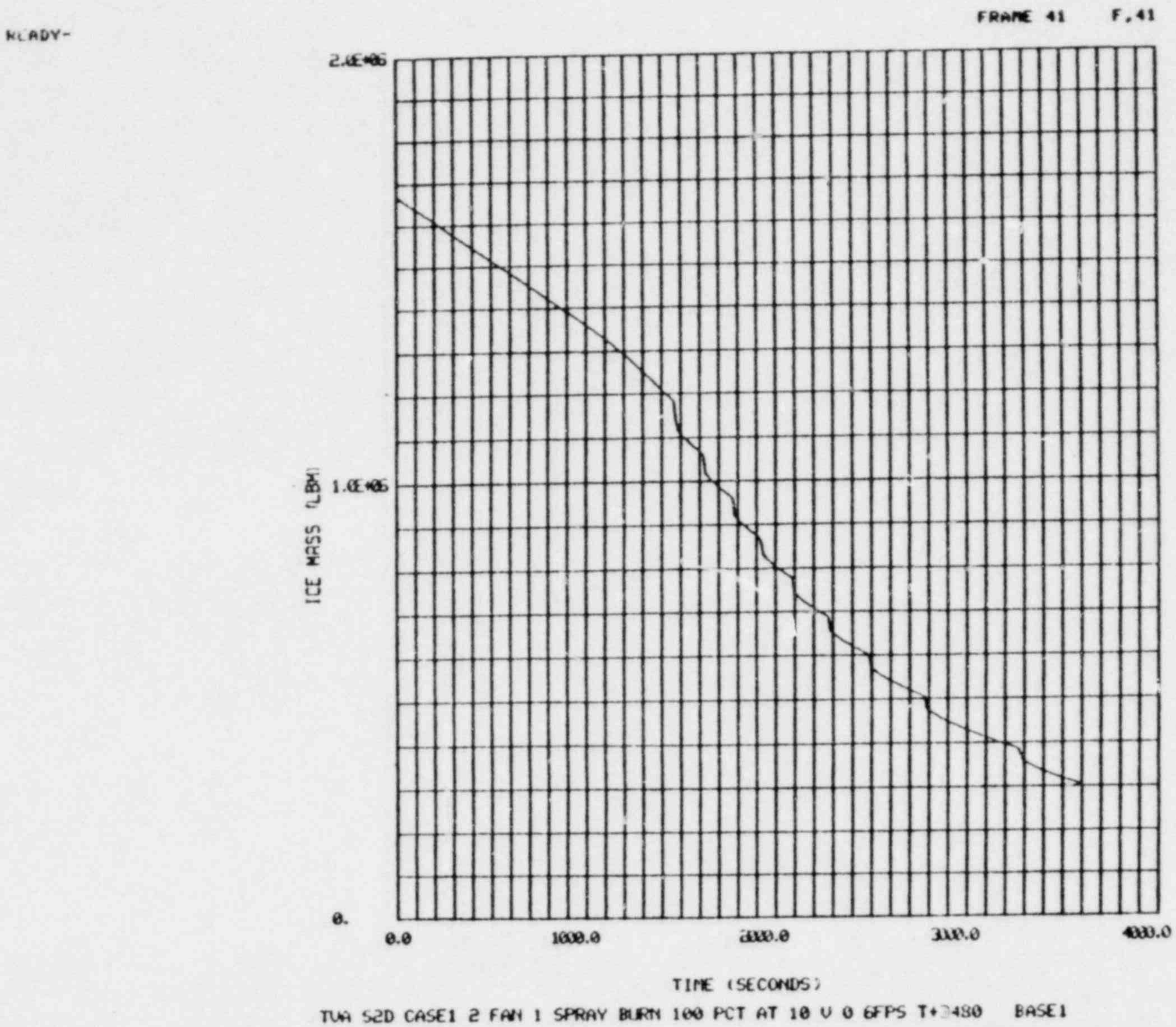


Figure 10. Base Case Ice Mass

spray, the pressure and temperature spikes were rapidly attenuated between burns. The pressure was decreased to its pre-burn value roughly 2 minutes after the burn occurred. After the last ignition of hydrogen, which occurs approximately 6800 seconds after the accident is initiated, there was roughly 300,000 pounds of ice left in the ice condenser section (representing at least $40x10^{6}$ Btu's in remaining heat removal capacity).

In summary, the results of the TVA base case analysis show only a modest increase in containmment pressure, on the order of 4-6 psi, with the containment remaining well below the estimated failure pressures. The burning criterion used in the analysis caused virtually all of the burning to occur in the lower compartment, thereby gaining the advantage of heat removal by the ice bed. It should also be noted that each burning cycle involved the combustion of only 100 pounds of hydrogen, or roughly $6x10^{6}$ Btu's of energy addition. By burning at a given concentration in the lower compartment (where one might naturally assume hydrogen concentrations to be higher since this is the area of hydrogen release) there is also the advantage of burning less total hydrogen at a time since the lower compartment volume is only around 1/4 of the total containment volume which allows for expansion of the hot gases to the rest of the containment free volume.

TVA has also performed preliminary sensitivity studies to determine the effects of ignition criteria and safeguards performance on the containment response. Results of several of these studies are shown in Table 2.

The sensitivity analysis performed to date demonstrates that 1) the ignition criterion, at least within the bounds chosen, has little effect on the containment pressure; 2) partial vs full operation of the air return fans makes little difference; 3) ice condenser heat removal is effective in reducing pressure; and 4) without any fan operation to assure mixing, the containment pressures due to burning rise dramatically to the point where containment loses structural integrity. It should be noted that the case which considered only enough ice exists to reduce the pressure spike for two burns (out of seven) is non-mechanistic; i.e., it is not representative of the actual S2D scenario. However, it does importantly demonstrate that even without ice, the containment pressure, with the assumed igniter operation, remains below the estimated failure pressure. This serves to indicate some insensitivity to whatever accident scenario is chosen.

TVA has also provided an estimate of the containment shell temperature rise for two of the cases analyzed, the base case and the case where no ice remains in the ice bed afte

TABLE 2 PRELIMINARY CONTAINMENT ANALYSIS SENSITIVITY STUDIES

	Total H_2 Burned (lb)	Peak Temp. (°F)			Peak Press (Psia)	
		Lower Compartment	Ice Bed	Upper Comp.	Lower Comp.	Upper Comp.
1. Base Case	900	2200	1200	150	26.5	28.5
2. H_2 Ignition and Propagation @ 8%	1050	1200	700	260	28.5	30.5
3. 1 Air Fan	900	2200	1350	160	26.5	29.5
4. No Ice*	850	2400	2000	270.	41	41
5. No Air Fans	1200	2370	2580	1090.	46.4	92.4

* Ice exists only for the first two of 7 burning cycles.

the first two burns. The calculation assumed that the atmosphere loses heat to the containment shell by radiation and convection and to the ice condenser when ice exists. Due to the relatively low temperature of the atmosphere in the dead ended compartment, it was assumed that only the water vapor emitted and absorbed radiation. Simple finite difference equations were used to represent the heat balances for the containment shell and atmopshere for a time increment, Δt. The gas and shell temperatures were updated at the end of each time step and the calculation repeated until thermal equilibrium was reached. For the base case analysis the mean temperature of the shell was estimated to increase by approximately 72°F. For the transient with limited initial ice mass the total temperature rise in the containment shell was estimated to be 101°F. An estimate of the temperature distribution through the shell was made using the TAP-A computer program to model transient heat conduction. The temperature difference calculated across the wall for the base case and limited ice mass case was approximately 21°F and 32°F, respectively.

TVA has also provided information regarding the consequences of a detonation occurring in the upper compartment of the containment. For the assumption of a 100% zirconium-water reaction in the core, the upper compartment would have the following composition: hydrogen - 23 v/o, air - 63 v/o, nitrogen - 14 v/o (from the accumulators). This mixture is detonable since the hydrogen concentration is greater than 19 v/o.

A detonation will produce two coupled effects on the containment structure. First the detonation shock wave will deliver an impulse loading to the containment wall. This dynamic loading will quickly decay to a somewhat sustained pressure pulse from the expanding gas that has undergone adiabatic heating. Further heat transfer from the gas to the wall and to internal structures will eventually cause decay of this secondary pressure pulse.

TVA has extrapolated the results of detonation calculations appearing in WASH-1400 (for a dry containment) to the case of an ice condenser containmment, on the basis that the hydrogen concentration is similar and assuming that the nitrogen from the accumulators plays a similar role in the detonation process as the post-accident water vapor present in a dry containment. Following a procedure of WASH-1400, containment failure is predicted to occur if $I\Delta t \geq 0.32\ P_D T$, where I is the time of detonation (sec), P_D is the load that produces the maximum elastic deflection for the structure (psia) and T is the natural period of the ice condenser containment. For the ice condenser containment, $0.32\ P_D T$ is equal to 0.38 psia-sec. Based on the impulse loads from WASH-1400, $I\Delta t$ values more than an order of magnitude lower are obtained.

TVA concludes, therefore, that containment failure due to a detonation shock wave is not expected to occur.

The analysis performed to date by TVA is preliminary in nature. TVA plans to refine the analytical models in the CLASIX code, do other parametric analyses and evaluate other accident sequences, in assessing the effectiveness of a hydrogen ignition system. These additional analyses will be discussed in a future report.

2.4.1.2 NRR/Battelle-Columbus Results

As previously discussed in section 2.3.1, under NRR Short Term Efforts, the staff has obtained technical assistance from BCL to analyze the containment response to the combustion of hydrogen for the small loss of coolant accident scenarios (S2D). The calculations were performed using the MARCH code with a 2-volume model of the Sequoyah containment. The MARCH code model consisted of a lower and upper compartment, with the ice bed modeled as a junction and not as a separate volume due to code constraints. Code features include models for ice bed heat removal, structural heat sinks, return air fans and containment sprays. The sprays in the ice condenser model, however, are presently assumed, due to code constraints, to have heat removal capacity only after the ice is completely melted.

The results of analyses performed by Battelle using the MARCH code are summarized in Table 3. The calculations are preliminary and do not represent final confirmatory analyses of hydrogen igniter performance. All of the results presented were from analyses based on the S2D transient, the same accident sequence as that assumed in the TVA analysis. The containment peak pressure values shown in Table 3 are the pressures calculated due to hydrogen burning up until the time reactor vessel head failure occurs. Results beyond this time are the purview of studies into core melt accident transients and are not relevant to degraded core accident analysis. The actual containment peak pressure value given is that pressure calculated assuming heat removal mechanisms (e.g., ice bed, sprays) function to reduce the energy addition and subsequent pressure rise. The adiabatic pressure given for each case is the pressure calculated to exist assuming no heat removal occurs during the hydrogen burn. By comparing the values for each case one can identify the relative effectiveness of the heat sinks, knowing that the initial containment pressure prior to burning was approximately 20 psia.

As can be seen from the table, the pressure rise following a hydrogen burn is approximately 3 psi when ice remains in the containment. As noted in Table 3, case 6 was performed using the non-mechanistic assumption that the ice

Table 3. BATTELLE ANALYSIS OF H_2 BURNING IN SEQUOYAH CONTAINMENT

Case	H_2 Ignition Setpoint (%)	H_2 Burn limit (%)	Burn Time (sec)	Containment Peak Pressure (Psia)	
				Actual	Adiabatic
1	10	0	1	≈ 23	58.
2	10	0	25	≈ 22	58.
3	12	0	1	≈ 24	64.
4	8	0	25	≈ 22	51.
5	8	4	1	≈ 22	36.
6	10	0	1	≈ 31	79.

Case 6 - Ice Bed Melted Before Burning Occurs.

bed was melted before the onset of hydrogen burning. For this case the containment peak pressure was seen to increase to 31 psia, demonstrating that the upper compartment sprays are also effective in removing the combustion energy addition.

The shape of the pressure transient calculated using MARCH was similar to that calculated by TVA using CLASIX in that hydrogen combustion was calculated to occur in the lower compartment in a series of burns. Following each burn and concomitant pressure spike, the containment pressure was rapidly reduced until the next burn was calculated to occur.

Although the analyses performed at Battelle are preliminary, they provide further support that given certain conditions igniters will function to limit the containment pressure increase due to hydrogen combustion such that the containment structural integrity will be maintained. What remains to be investigated by further analysis is how wide a range of accident conditions the igniter system will serve to mitigate.

2.4.1.3 R&D Associates Results

In addition to the analyses provided by TVA and BCL, we have received a letter report (dated August 4, 1980) prepared by R&D Associates on hydrogen combustion in the Sequoyah containment. The R&D Associates report is included as Attachment 1.

The R&D Associates report addresses two concerns (stated below) that were part of their overall assessment of the ultimate strength analysis of the Sequoyah containment. The two concerns are:

1. How would the analyses and results be altered if the stresses are caused by ignition/detonation of 300-600 Kg of hydrogen distributed uniformly and nonuniformly in the containment.

2. To what extent can distributed ignition sources mitigate the effects of hydrogen?

In their discussion, R&D Associates contends that (a) the complete adiabatic combustion of 300 Kg (660 pounds) of hydrogen uniformly mixed in the containment would result in containment failure; (b) a non-uniform distribution of the hydrogen could lead to detonable mixtures which would also result in containment failure; and (c) the use of igniters constitute an uncertain means of pressure control when considering the uncertainties in the rate of hydrogen generation and the rate and extent of mixing in the containment.

TVA has responded to the R&D Associates report. TVA agrees with the analysis of the adiabatic burning of 300 Kg (660 pounds) of hydrogen, and points out that they have previously reported that an ice condenser containment can accommodate the adiabatic burning of approximately 450 pounds of hydrogen.

TVA further states that calculational techniques have progressed beyond the overly conservative assumption of adiabatic burning and that more mechanistic analyses are being performed. For example, the CLASIX code accounts for the rate of hydrogen release from the reactor coolant system, the transport of constituents (hydrogen, oxygen, nitrogen, steam) throughout the containment, the effects of heat removal mechanisms and the performance of a distributed ignition system, to arrive at a more realistic assessment of the containment response.

TVA's developmental program includes igniter tests and containment analysis to overcome technical difficulties and determine the efficacy of the proposed distributed ignition system as a viable means for hydrogen control. Furthermore, TVA has studied, and is actively studying, alternative hydrogen mitigation schemes, including continuous inerting of the ice condenser containment and the injection of halon as a post-accident inerting agent.

TVA has also analyzed the consequences of detonation loads on the containment structure. A 100 percent zirconium-water reaction was assumed which gives a hydrogen concentration of about 25 percent by volume. Based on the results of their analysis, TVA concluded that failure of the containment due to a detonation shock wave is not expected to occur. However, TVA states that the resulting relatively long term pressure due to the oxidation of a large amount of hydrogen would exceed the ultimate capability of the containment. This same conclusion would also obtain from a calculation of the adiabatic burning of 600 Kg of uniformly mixed (18 v/o) hydrogen.

TVA however did conclude that the containment can withstand, within the ultimate capability of the containment, both the detonation load and the long term pressure from the adiabatic burning of 18 volume percent hydrogen distributed uniformly in the lower compartment.

2.4.1.4 Comparison of Results

In evaluating the results of the various analyses, the point to remember is that the calculations performed to date are preliminary in nature and do not represent the final analytical assessment of hydrogen ignition systems.

The TVA results using CLASIX are based on an unverified, unreviewed code, which is still under development. This calculational technique, in the staff's opinion does hold considerable promise for estimating the containment transient reponse due to hydrogen combustion since it already contains many basic features necessary to perform the calculation. Furthermore, the results from CLASIX tends to be confirmed by the results from the MARCH code.

The MARCH code is also largely unverified but does provide the capability to estimate the transient response due to hydrogen combustion within containment. The MARCH code, which has not been formally released and documented, does not appear to have the capability of the CLASIX code with regard to containment calculations. This is understandable since containment calculations are only one aspect of this code, which also models the reactor coolant system. Nevertheless, the code represents a substantial improvement over hand calculations which conservatively assume the burning of hydrogen and containment pressurization to be an instantaneous adiabatic process.

With regard to the R&D Associates report included as Attachment 1, our comments are presented below.

Part (a) of the report indicates that containment failure is likely if 300 kg of hydrogen were assumed to burn instantaneously (or adiabatically) inside the containment. This corresponds to approximately a 35% (based on Zr mass of 43,000 pounds) of core-cladding reaction.

The assumed burning of 600 Kg with twice the energy addition to containment is also shown to result in containment failure.

The staff generally concurs with these conclusions, considering the basis of the calculations, and cites that similar conclusions were reached in the staff's Commission paper, SECY-80-107 (February 22, 1980). Specifically, the staff concluded that calculations based on the instantaneous, adiabatic burning of hydrogen would demonstrate that an ice condenser could only tolerate a cladding reaction of 25%.

At this time the staff feels that the simplified analysis contained in the R&D Associates report does not lend itself to assessment of the mitigation potential of TVA's distributed ignition system. Although there are areas where information is lacking, the staff and TVA are pursuing these concerns both experimentally and analytically.

Part (b) of the report is technically correct but it may be overly conservative to evaluate the effects of such large pockets of concentrated hydrogen without examining the likelihood and timing of their formation.

The postulated 300 Kg of hydrogen (118,000 cu/ft at standard conditions) represents a pocket of 247,000 cu/ft when diluted with air to its detonation limit. This represents half of the volume of the lower compartment. It is difficult to conceive how such a large volume could form without contacting some of the igniters to be distributed in this region of the containment.

The mixing of air in the lower compartment can be expected to take place on a time scale governed by recirculation fan capacity, which provides for a change of air in the lower compartment every five minutes. Hydrogen evolved on a time scale longer than this can be expected to be reasonably well mixed by the time it leaves the lower compartment.

In the illustrations given in the R&D Associates report, the rate of introduction of the hydrogen (1% reaction per minute) leads to concentrations in the lower compartment below 10% at equilibrium. It takes over ten minutes to approach equilibrium and with effective igniters present, ignition would be likely before a 10% concentration was reached. The hydrogen concentration in the lower compartment would then revert to a lower level and the buildup would start again, resulting in a series of small burns.

The fact that the hydrogen would be free of oxygen at its point of introduction and then become diluted with oxygen as it is distributed throughout the lower compartment suggests that relatively small masses of hydrogen may be ignited near the upper flammability composition limit if constant sources of ignition are present. These ignitions would take place before there is much buildup of hydrogen throughout the lower compartment. When the staff takes these additional aspects of heterogeneity into consideration, we feel that igniters are a promising hydrogen control feature.

2.4.2 Structural Response

Three independent analyses of the Sequoyah containment were performed by the licesnee (TVA), Ames Laboratory and R&D Associates to determine the containment capacity to withstand a postulated hydrogen burn/detonation. All three analyses were based on use of the elementary thin shell theory with variations in assumptions to account for the stiffeners and use of material strength data.

The TVA analysis neglected the presence of the stiffeners and adopted the actual strength (lowest tested strength) of the steel material instead of the minimum code specified yield strength. TVA concluded that the vessel capacities at yield and ultimate strength of the material were 33 psig and 43.5 psig, respectively. The TVA study also concluded that based on the 43.5 psig ultimate strength, it could withstand the consequences of a postulated hydrogen combustion equivalent to 25% metal-water reaction. This analysis is simple and conservative in not accounting for the strength contribution of stiffeners. However, use of the actual mill-test strength data rather than the code specified minimum gives a greater containment structural capacity.

At the request of NRC staff, Ames Laboratory conducted a preliminary quasi-static analysis of the ultimate strength of the Sequoyah containment. The analysis concluded that gross yielding of the shell, including stiffeners, would occur at a static pressure of 36 psig. The total ring and stringer stiffener areas were smeared to form an equilvaent shell for stress calculations. In effect, this amounts to assuming that the rings and stringers are equally effective as the shell membrane at the yield load. An ultimate burst analysis was also performed, however, the result of such an analysis is not considered appropriate because of the uncertainty about the limiting ductility of the shell.

Ames Laboratory also concluded a preliminary analysis with simplifying assumptions of the ultimate dynamic strength of the Sequoyah containment subject to a postulated hydrogen detonation in a lower compartment. Since the loading due to such a localized detonation is not axisymmetric, circumferential bending is assumed to occur and the behavior of the stiffened shell will most probably be dominated by the rings adjacent to the compartment. A typical ring is analyzed with material and geometric nonlinearities included. The dynamic loads are idealized as (1) an initial impulse which approximates the detonation phase and (2) a venting dynamic pressure which decays linearly from a maximum to zero in 0.030 seconds. The ANSYS computer code was used to obtain onlinear transient solutions. By conservatively assuming that the ductility capacity of the vessel (maximum strain divided by yield strain) is two, the maximum value of the venting pressure is found as 31 psig.

Ames Laboratory's quasi-static analysis gives a capacity value similar to that of TVA (36 psig versus 33 psig). Because of its use of the smearing assumption, the 36 psig value is more optimistic than the 27 psig obtained in the R&D Associates' analysis discussed below. The ultimate dynamic strength analysis referred to above is based on several unconfirmed assumptions. The result of such an analysis (i.e., 31 psig) is best viewed as a reasonable estimate of the likely containment capacity due to a localized hydrogen detonation.

After reviewing the Ames Laboratory's quasi-static analysis of the Sequoyah containment and performing its own analyses, R&D Associates concluded in its report that gross yielding of the shell would occur at about 27 psig. The rationale employed by R&D Associates was that the stringers are only partially effective and the rings are totally ineffective in resisting internal pressure in the linearly elastic range. Locally high bending stresses were calculated to exist near the rings and stringers but were not considered to affect the vessel capacity for one-time loading. In essence, therefore, the 27 psig (based on Von Mises Failure criterion) represents the theoretical strength of an unstiffened 690 inch radius by 1/2 inch thickness cylinder of infinite length.

Of the three analyses, the work performed by R&D Associates gives the most conservative result because code specified minimum material yield value were used and only partial effectiveness of the stringer stiffeners was assumed. Simplified individual panel analyses were also performed by R&D Associates but were not considered to be meaningful with respect to the evaluation of overall containment capacity. A refined finite element analysis modeling the entire structure is presesntly underway as a part of the ongoing Ames Laboratory effort.

With regard to potential gross vessel leakage at stresses above the design stress and up to yield stress, while no experimental data are available at this time to provide a basis for precluding such leakage, it is our considered opinion that as long as stresses are kept below or at the yield range, the above mentioned gross leakage should not occur up to the lower-bound vessel capacity (i.e., in the range of the 27, 33 and 36 psig) estimated by the three independent analyses.

Another simplified Sequoyah containment analysis was performed by the staff of the Office of Nuclear Regulatory Research. The study predicted a capacity of 34 psig at gross yield of the vessel. Since the study is also based on a set of unconfirmed assumptions, it does not significantly add credence to the overall capacity estimates provided by the three previously discussed analyses. Having reviewed the R&D Associates' analysis, TVA concurred with the results of the analysis except for the use of material minimum yield strength. TVA also noted that the flat plate analysis and testing programs proposed by R&D Associates might not be useful. This is consistent with our view on the same subject discussed above.

In summary, the Sequoyah containment has been calculated to have a lower-bound internal pressure capacity ranging from 27 psig to 36 psig, compared to its design pressure of 10.8 psig (equivalent safety factors of 2.5 to 3.3). For the case of localized hydrogen detonation considered, a 31 psig vessel capacity was estimated based on several unconfirmed assumptions(an equivalent safety factor of 2.8). The vessel was qualified by actual test to 13.5 psig (1.25 design pressure).

2.4.3 Role of Distributed Ignition System

TVA proposes to install a distributed ignition system in the Sequoyah containment for additional hyrogen control, in advance of any rulemaking decision on degraded core accidents. The system will consist of glow-type igniters distributed throughout the upper and lower compartments of the containment. They will be activated (and remain activated in the event of a LOCA). It is TVA's intention that the system will serve to initiate controlled burning of lean hydrogen mixtures in the containment.

It is also considered desirable to initiate combustion in the lower compartment since the affected containment volume is only a small fraction of the total containment volume and the concommitant energy release from a hydrogen burn may be more readily accommodated by heat removal in the ice bed and by the containment spray. As discused above, TVA will test the igniters to determine their behavior and effectiveness in post-accident environments, and analyze the containment response to quanity benefits and identify any risks associated with the installation of a distributed ignition system.

TVA has also committed to evaluate the effectiveness of the hydrogen monitoring system, and expand the system to provide information on the concentration of hydrogen throughout the containment for the accident duration. As discussed previously in Section 2.2.2, TVA has committed to study alternative hydrogen control systems as part of their overall longer term effort.

2.4.4 Additional Views

We have received additional views from Charles N. Kelber, Assistant Director, Advanced Reactor Safety Research (DRSR) (Section 2.4.4.1), and Robert M. Bernero, Chief, Probabilistic Analysis Staff (RES)(Section 2.4.4.2). The viewpoints of these individuals are quoted below.

2.4.4.1 Consideration of Hydrogen Igniters at Sequoyah

> "In the context of considering accidents involving only partial degradation of the core, as at TMI-2, with intermittent operation of safety systems, it is my view that the deployment of hydrogen igniters should be carefully reviewed by a containment systems analysis to make sure that their use will be effective and that there will be no negative effect on safety. The chief considerations are that the burning be controllable with sufficxient accuracy to assure that undesirable flame propagation, e.g., downward propagation, does not occur, and that the atmosphere be well enough mixed that unstable burns, such as turbulent deflagration, that can lead to high overpressures, are highly unlikely. In addition, the strategy of operation of the system should assure that heat removal sources such as the Ice and the Containment Sprays are active, effectrive, and available at the time of burning.
>
> "As I see it, the requirements are that the operator know the concentration of hydrogen is below 9%, that burning should not, however, strt until the concentration is somewhat above 4%, that if the intention is to burn in the lower compartment, means be provided to assure good mixing in that compartment, and that appropriate interlocks be provided to assure heat removal.
>
> "Such a containment systems analysis should also compare the utility of alternative control methods, such as Halon injection, or a water fog generated by modify8ing a spray header to produce very find droplets (of the order of a few to ten microns in diameter) which will then remain suspended in the lower and upper compartments and effectively quench a hdyrogen fire.
>
> "In the wider context of core melt accidents, such as may be required by a degraded core cooling rulemaking, consideration may have to be given to means of presure relief, most likely via a filtered venting system. While it may be premature at this time

to enter into such considerations in any detail, the igniter system, or its equivalent, should be such as not to preclude or adversely affect the proper functioning of such a system if it is decided in the future to employ one."

[illegible].4.2 Overall Risks and Hydrogen Control in the Sequoyah Plant

"The Sequoyah Plant has undergone a unique form of analysis in parallel with the OL review. Sequoyah was one of four plants selected for probabilistic risk analysis (PRA) in the Reactor Safety Study Methodology Applications Program (RSSMAP). The Sequoyah Plant was the first of the four to be analyzed and a draft report on this analysis was prepared in late 1978. Work on the other three plants shows areas where the Sequoyah work might be refined but the other work did not develop any knowledge that would invalidate the Sequoyah RSSMAP results. Reports on all four of the RSSMAP studies are not in final preparation for publication in September 1980.

" A comparison of the overall risk of the Sequoyah design was presented to the Commission in SECY-90-283, dated June 12, 1980, as part of the Indian Point Tsk Force report. Figure 7 from SECY-80-283, attached, presents the early fatality risk profiles for several designs including Sequoyah if one compares them all at the same site (Indian Point). That analysis, based on the Reactor Safety Study (WASH-1400) and RSSMAP shows the overall risk of the Sequoyah design to be about the same as the Surry PWR design.

"The Sequoyah RSSMAP study identified interfacing systems LOCA and emergency cooling and containment recirculation failure scenarios as the dominant risk sequences. Steps have already been taken by the owner to suppress these dominant accident sequences by reducing the probability of the occurrence. An analysis of the RSSMAP results which was discussed in Enclosure, SECY-80-107B dated June 20, 1980, showed that a risk reduction of about a facator of four could be achieved by inerting the continment. This would esliminate the rapid combustion of hydrogen as a substantial contribution to containment failure from overpressure in the dominant accident sequences. It appears that approximately the same level of risk reduction could be achieved if measures were taken to assure combustion of hydrogen as it was released to the containment. Slow combustion of the hydrogen would provide more time for available heat sinks to absorbe the heat of combustion. Removal of the hydrogen and oxygen by combustion would reduce their partial pressures somewhat cancelling the effect of the heat of combustion in raising containment pressure. There is nothing in the RSSMAP analysis to suggest that controlled ignition of the hydrogen in containment could substantially increase risk in the Sequoyah design, although a specific analysis would be needed to assess the matter. This presumes, of course, that the installation and control of igniters does not somehow compromise the operation of some other safety system."

2.4.4.3 Preliminary Assessment of the Use of Igniters as a Method of Hydrogen Control in the Sequoyah Nuclear Plant

The staff has had certain members of the Brookhaven National Laboratory (BNL) working for several months on assessments of hydrogen control measures for the Zion and Indian Point plants. To benefit from expertise developed in conjunction with that work, we requested their review of the proposed use of igniters at the Sequoyah Nuclear Plant.

Because of the short duration of the BNL review, they were not able to arrive at our definitive conclusions. Their future involvement in this effort is expected to be more useful. A copy of the BNL report, dated August 8, 1980 is provided in Attachment 2.

2.5 ACRS Views

The ACRS has considered the general question of the need for improved hydrogen management capability at nuclear power plants and the specific question regarding acceptability of the interim distributed ignition system proposed by TVA.

In its "Report on TMI-2 Lessons Learned Task Force Final Report," dated December 13, 197, the ACRS stated that:

> "The ACRS suppots this recommendation. However, the Committee believes tht the recommendation should be augmented to require concurrent design studies by each licensee of possible hydrogen control and filtered venting systems which have the potential for mitigation of accidents involving large scale core damage or core melting, including an estimate of the cost, the possible schedule, and the potential for reduction in risk.
>
> The ACRS agrees with the recommendation made by the Lessons Learned Task Force in NUREG-0578 that the Mark I and Mark II BWR containments should be inerted while further studies are made of other possible containment modifications in accordance with the general recommendations in this category. The ACRS also recommends that special attention be given to making a timely decision on possible interim measures for ice-condenser containments."

The ACRS also considered the interim distributed ignition system proposed by TVA during the July 1980 meeting. The ACRS concluded that "Though the work accomplished to date is limited in scope, these studies are definitely responsive to the Committee's recommendations on these points." The Committee further stated in its letter of July 15, 1980, that in its opinion, "...their present incomplete status need not delay the issuance of a full power operating license."

3. CONCLUSION

The NRR conclusions relative to hydrogen control measures for the Sequoyah Nuclear Plant are detailed below.

The implementation of the short term Lessons Learned items at the Sequoyah Nuclear Plant and other operating nuclear plants has significantly reduced the likelihood of a degraded core accident which results in large releases of hydrogen.

TVA has proposed to further improve safety margins relative to hydrogen control by designing and installing an interim distributed ignition system. We believe the proposed system has the potential for improving the hydrogen control capability in ice condenser plants and plan an accelerated review of the proposed system. We expect to complete our review of the system by November 1980.

In view of the potential for safety improvements associated with the proposed distributed ignition system, there are several options available at this time. These options and the option recommended by NRR are detailed below.

Option A: Hold at 5%

Under Option A, TVA would be restricted to its present 5% power limit until such time as the NRC review and approval of the distributed ignition system (or other mitigative measures, should the igniters prove to be unacceptable).

Option B: Nominal 50% Limit

The maximum power level of the reactor should be limited to 50% of full power until questions concerning the net safety benefit of the distributed ignition system proposed by TVA are resolved to the satisfaction of the NRC.

If the licensee requests authorization for short periods of power operation above 50% to meet testing requirements or for other reasons, such requests would be considered on an individual case basis.

Option C: Limited 100%

Under this option, TVA would be authorized (in terms of H_2 control) to proceed to 100% power, with a license condition that, if the NRC has not concluded by 1/1/81 (date is exemplar) that distributed igniters are sufficient (or that some alternative is), then the full-power operation would cease.

Option D: Unlimited 100%

Under Option D, 100% power would be authorized without a time limit.

Of these four options, we recommend Option B. In our opinion, short-term operation at 50% power poses no undue risk and has a considerable benefit to TVA in checking our various phases of its steam cycle. TVA plans a two-week outage after the initial 50% test. We expect to have completed the major portion of our review of TVA's safety analysis by that time. The only remaining aspect would be completion of the confirmatory ignition studies at LLNL. At present, we believe that a complete safety evaluation by the staff will not be available until November 1980. This allows one month to evaluate the LLNL work. Thus, under Option B, Sequoyah could possibly operate about two to three months at 50% power, without a final staff position on additional H_2 control systems. We believe that there is reasonable assurance of no undue risk for this mode of operation, on the basis that:

1. application of remedial measures since TMI-2 have lessened the likelihood of a degraded core;
2. long-term operations above 50% power would not be considered until we had reached a firm conclusion whether the distributed ignition system had a high likelihood of NRC approval; and,
3. any limited operations above 50% power would be authorized on a very limited time basis.

R & D ASSOCIATES
Post Office Box 9695
Marina del Rey,
California 90291

4 August 1980

Nuclear Regulatory Commission
1717 H Street, N.W.
Washington, D. C. 20555

Attention: Commissioner Victor Gilinsky

Dear Victor:

Enclosed is the second part of our report on ice condenser plant containment response to hydrogen production and burning and mitigation by igniters. If you have any questions or comments, please call. We expect to see you and John Austin on Friday.

Best regards,

Harmon

Harmon W. Hubbard

HWH/dl

Enclosure: "Hydrogen Problems in Sequoyah Containment," August 1980.

ATTACHMENT 1

HYDROGEN PROBLEMS IN SEQUOYAH CONTAINMENT

INTRODUCTION

This letter report completes the RDA response to a request from the Nuclear Regulatory Commission to critique the ultimate strength analysis of the Sequoyah containment. This second report deals with the last two tasks of the work statement.

1. How would the analyses and results be altered if the stresses are caused by ignition/detonation of 300-600 Kg of hydrogen distributed uniformly and nonuniformly in the containment?
2. To what extent can distributed ignition sources mitigate the effects of hydrogen?

A preliminary discussion of these topics was attended by Commissioner Gilinsky and Dr. John Austin at RDA on 18 July 1980.

RESULTS

1. a) 300 kg of H_2 gas mixed uniformly with the air and steam (if less than 40 percent steam) in the Sequoyah containment volume following an accident would be completely combustible if ignited (see Figure 1). This complete combustion could occur so rapidly as to exceed the capacity of the available heat removal processes, and could produce a pressure as high as 5.5 atmospheres, thus rupturing the containment (see Table 2). The combustion of 600 kg of H_2 would of course have more severe consequences.

   b) A nonuniform distribution of 300 kg of H_2 present in the containment would consist of parcels of gas richer in H_2 than the uniform distribution. If these separated parcels formed while the blowers were operating, they would probably be mixed, combustible and perhaps detonable. If they were all detonable and all ignited, the damage to the containment would be worse than that due to ignition of a uniform mixture. If the gas parcels were not detonable, the pressure upon combustion would probably be at least as high as the uniform distribution. Under some circumstances, it would be possible to collect pockets of gas too rich in H_2 to burn. As the outer edges of such pockets mix with air, partially combustible mixtures would form. The results of igniting such a distribution would clearly depend on the sizes of the parcels and the timing.

It should be noted that harmless mixtures of H_2, air and steam may become highly combustible or detonable as steam is condensed out (see Appendix B). Thus one mechanism employed for removing heat from the containment also removes the combustion inhibitor from the containment.

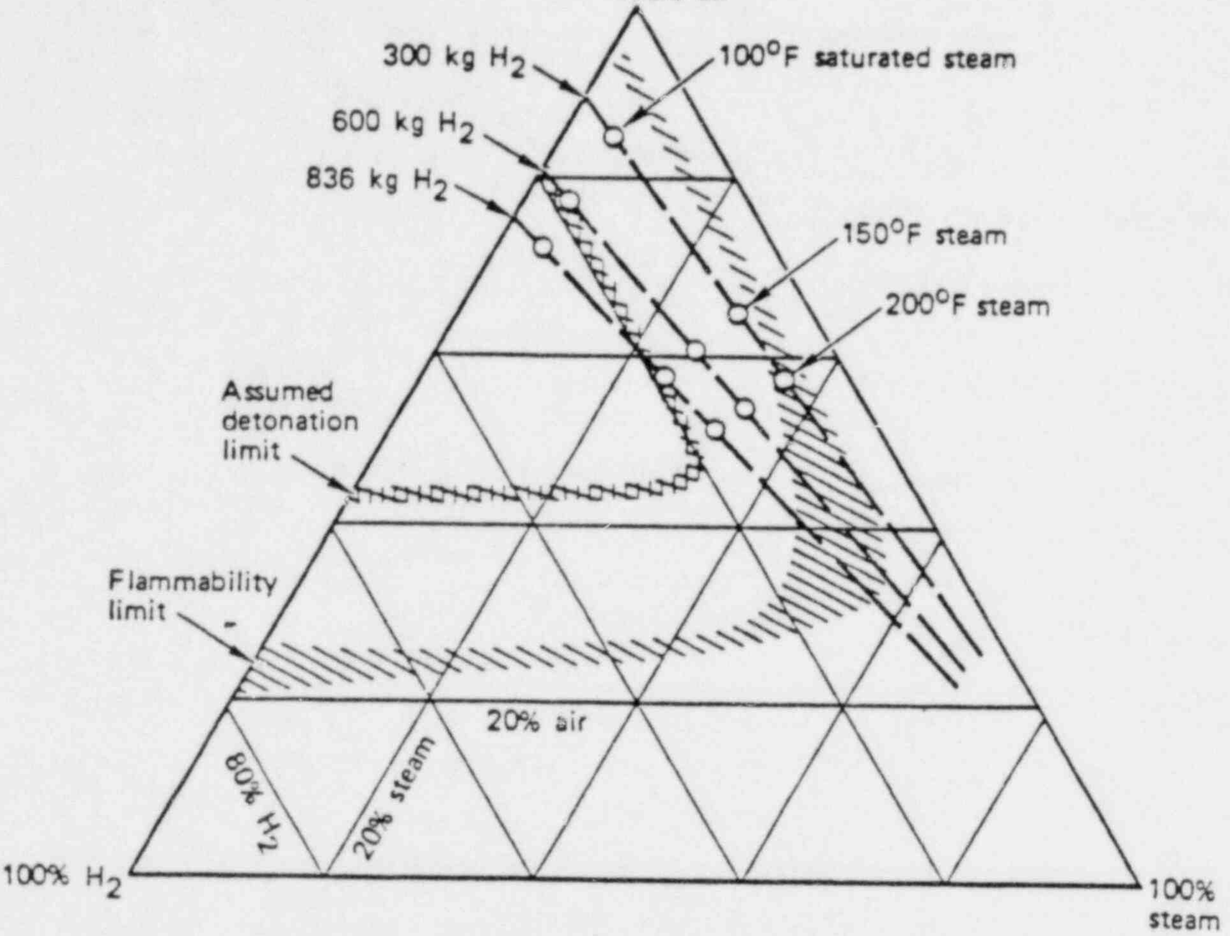
2. If the rate of hydrogen formation is sufficiently low, and the mixing of H_2 is complete and rapid so that all the gas in the containment gradually increases in H_2 concentration, then the presence of enough igniters could prevent overpressurizing the containment. This would be accomplished by releasing the heat of combustion at low concentrations over a long enough period of time to be handled by the heat removal equipment. However, if the Zr reaction rate is high relative to heat removal processes, then igniters might only delay containment failure. Table 3 shows that a 1 percent per minute Zr reaction rate, accompanied by the burning of hydrogen at its rate of formation, would match the steady-state heat removal capacity of the RHR equipment.

If the H_2 is not thoroughly mixed, then there is a possibility of igniting a detonable pocket of gas with an igniter. If left to its natural end, such an H_2-rich pocket could disperse below the detonation limit (~20 percent H_2) when its ignition would cause less of a problem.

Since the possible rates of generation of H_2 following an accident and the rate, place, and degree of mixing with air are highly uncertain, the use of igniters can only be an uncertain means of pressure control. Improper use might be detrimental rather than helpful. On the other hand, if it is assumed that there are many unavoidable ignition sources in the containment, it is certainly true that control of the time and place of ignition is preferable to chance. In this sense the use of igniters seems beneficial.

COMMENT

It is our opinion that the uncertainties in H_2 generation and mixing are so dependent on hardware details and scenarios that they are unlikely to be greatly reduced by further work. For this reason we believe it may be a better use of resources to explore thoroughly the feasibility of using an inert atmosphere in the containment, so as to avoid the hydrogen burning problem.



Limits of flammability and detonation based on Shapiro and Moffette WAPD-SC-545, as reproduced in WASH 1400.

Figure 1. Uniform mixtures in the Sequoyah containment vessel.

TABLE 1. INPUT DATA FOR SEQUOYAH PLANT

1.	Free volume of containment vessel(a)	3.2×10^4 m^3
	Weight of contained air at 27°C, 1 atm.	3.7×10^4 kg
	Gram moles of air	1.3×10^6
	Gram moles of oxygen	2.7×10^5
2.	Weight of zirconium in core(b)	1.9×10^4 kg
	Gram moles of zirconium	2.1×10^5
3.	Yield of 100% Zirconium-water reaction	
	Weight of hydrogen	836 kg
	Gram moles of hydrogen	4.2×10^5
	Heat of reaction(c), Zr + H_2O	1.1×10^{11} joules
	Heat of H_2 burn(d) (to form liquid H_2O)	1.2×10^{11} joules
	Total heat of reaction + burn	2.3×10^{11} joules

4. Molar quantities and partial air pressure of saturated steam in containment

At 100°F (38°C) vapor = 8.1×10^4 moles = 0.06 atm.
150°F (66°C) = 5.9×10^5 moles = 0.25 atm.
200°F (93°C) = 8.4×10^5 moles = 0.78 atm.

NOTES:

(a) Sequoyah Nuclear Plant, Preliminary Safety Analysis Report (PSAR), Table 5.2-1 gives the total containment active volume as 1,142,000 ft^3, comprised of 730,000 in the upper compartment, 125,000 in the ice compartment, and 287,000 in the lower compartment.

(b) Sequoyah PSAR, Tabel 1.3-1, gives the clad weight as 41,993 lb.

(c) G. W. Keilholtz, ORNL-NSIC-120, Annotated Bibliography of Hydrogen Considerations in Light-Water Power Reactors, Feb. 1976, Table 1, Heat of Reaction = 122 to 137 kcal/mole Zr.

(d) Lewis and Von Elbe, p. 685, 68.3 kcal/mole H_2O.

TABLE 2

	H_2 Quantity		
	300 kg	600 kg	836 kg
1. Percent Zr Reaction	36%	72%	100%
2. Moles H_2	1.5×10^5	3.10^5	4.2×10^5
3. Partial Pressure @ 300°k (atmospheres)	0.12	0.23	0.32
4. Molar Ratio $\frac{H_2}{Air}$, Uniform Distribution	0.11	0.23	0.32
5. Detonatable (D) or Combustible (C)[a] Mixture, no steam present	C	D	D
6. H_2 Concentration Multiplier Required relative to uniform mixture[a]			
a) to reach detonation regime	2.0	1.0	1.0
b) to reach stoichiometric ratio of 0.42:1 for H_2:air	3.8	1.8	1.3
7. Steam Vapor Pressure Required:[b]			
a) to prevent detonation of uniform mixture	0	0.1 atm	0.4 atm
b) to prevent combustion of uniform mixture	0.9 atm	2.0 atm	2.3 atm
8. Energy Release in 100% Combustion, Joules (liquid water product)	4.3×10^{10}	8.6×10^{10}	1.2×10^{11}
9. Final Absolute Pressure in Adiabatic Combustion (Initial Air Partial Pressure 1 atm, Initial Temperature 300°k)[c]			
a) No steam, 100% combustion	5.5 atm	10.0	13.3 atm
b) No steam, 50% combustion	3.3	5.8	7.3
c) Steam @ 190°F, 50% combustion	4.1	6.5	8.3

NOTES:

(a) Approximate, based on regimes outlined in Figure 1.

(b) Approximate, based on regimes outlined in Figure 1, plus molar concentrations of saturated steam as a function of pressure.

(c) Assuming products of combustion behave as ideal gases, and assuming a constant-volume reaction.

TABLE 3. HEATING AND COOLING RATES IN SEQUOYAH CONTAINMENT

Time when Fission Product Heat (Cumulative) Equals Total Heat of Reaction	3000 sec
Rate of Heating at the 1% per min Zr Reaction Rate	
Zr Reaction	18.0 MW
H_2 Burning	20.0
Total	38.0 MW
Rate of Fission Product Heating at 2 hours (when ice has been melted in DBA)	27 MW
Steady-state Cooling Capacity of the 2 RHR Heat Exchangers[a]	67 MW
Net Margin of Cooling Capacity (Beyond Chemical Reactions @ 1%/min and Fission Product Heating)	2 MW

NOTES:

(a) Sequoyah PSAR, Table 6.3-2 cites 2 heat exchangers, each having a capacity of 1.15×10^8 BTU/h at specified conditions.

APPENDIX A

LITERATURE SEARCH ON EXTENT OF HYDROGEN BURNING AND FLAMMABILITY LIMITS FOR MIXTURES OF H_2, AIR, AND STEAM

In considering the effects of 300 kg to 600 kg H_2 in the Sequoyah containment vessel, questions of lean mixture flammability limits and the extent of combustion are important. The 1976 literature survey by Keilholtz (1) provided citations for most of the sources used in this brief study, and provided much of the available data on flammability and extent of combustion.

EXTENT OF COMBUSTION

Keilholtz states that combustion of 100 percent of the hydrogen will not occur until the hydrogen comprises about 10 vol percent of the H_2-air mixture. A partial combustion data point of 50 percent combustion is quoted for a 5.6 vol percent H_2 mixture in air. This point is attributed to Shapiro and Moffette (2), a reference that we were unable to obtain in the available time. However, Furno, et al. (8) indicate about 90 percent combustion for an initial mixture of 8.5 percent H_2 as compared with 5-10 percent combustion for mixtures of 6.9-7.4 percent H_2. If 300 kg H_2 were uniformly distributed throughout the active volume of the Sequoyah Unit 1 containment vessel, it would constitute a 10 vol percent mixture with air (neglecting steam), and hence could burn completely.

FLAMMABILITY LIMIT

The lean mixture threshold of flammability is given by Keilholtz as 4.1 vol percent H_2 in air but at this concentration, Egerton (3) as well as Keilholtz point out that the flame front is not coherent, and flame propagation is upward only.

Downward propagation begins with a hydrogen concentration of about 9 vol percent (1), (3). Drell and Belles (4) state that a 9 percent mixture will burn completely (a point to be compared with the Keilholtz 10 percent mixture for 100 percent combustion). Even the lean mixture non-coherent flames are postulated to burn a mixture that is richer than the original mixture, because the high diffusion rate of H_2 permits access of additional H_2 to the flame (4). The diffusion rate of H_2 is also important to the dispersal of segregated pockets of hydrogen, and will be discussed later.

STEAM DILUTION

The effects of dilution by steam are potentially important. Drell and Belles (4) state that inert diluents have scarcely any effect on the lean-mixture limit of flammability, where 300-600 kg of H_2 in Sequoyah would be, if uniformly distributed. They claim water vapor has effects similar to CO_2, and they show data of Coward and Jones (5) (which we were unable to obtain) such that only after more than half the mixture is CO_2 does the fraction of H_2 required for flammability begin to increase. These findings are consistent with the ternary mixture chart of Shapiro and Moffette for H_2, air, and steam, wherein the lean mixture flammability limit is at a nearly constant H_2 fraction as the steam content increases from zero to about 50 vol percent.

DETONATION

Shapiro and Moffette indicate a triangular shaped detonation regime in their ternary mixture chart, a regime bounded approximately by a 19 vol percent H_2 line at the lean mixture boundary and a 45 vol percent air line at the rich mixture boundary. Although the original reference was not available to us, it appears that the authors constructed the detonation regime by extrapolating from data on dry mixtures of H_2 and air. We note that Drell and Belles show the range of detonability of H_2 in air from 18.3 vol percent to 50 vol percent H_2. We could find no information on the effects of inert diluents on the detonability of hydrogen-air mixtures, and we note the caption on the Shapiro-Moffette ternary mixture chart: "Assumed Detonation Limits." We conclude that the effects of steam on detonability of H_2-air mixtures are essentially unknown. The nearest information we could find was cited by Keilholtz, and this pertains to detonations in Knallgas-team mixtures (6). Knallgas is a stoichiometric mixture of H_2 and 0_2. In reference (6), experiments indicated that a minimum of about 65 vol percent Knallgas in saturated steam at 100°C was required for detonation. This would correspond to about 44 percent H_2.

The occurrence of detonation is also influenced by the size and configuration of the vessel, and the nature of the walls (4,7), which further complicates efforts to predict detonation precisely.

REFERENCES

1. G. W. Keilholtz, "Annotated Bibliography of Hydrogen Considerations in Light-Water Power Reactors, ORNL-NSIC-120, Feb. 1976.

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3. Sir Alfred C. Egerton, "Limits of Inflammability," Fourth Symposium (International) on Combustion, the Williams and Wilkins Co., Baltimore, 1953, pp. 4-13.

4. I. L. Drell and F. E. Belles, "Survey of Hydrogen Combustion Properties," National Advisory Committee on Aeronautics Report 1383, 1958.

5. H. F. Coward and G. W. Jones, "Limits of Flammability of Gases and Vapors," U. S. Bureau of Mines, Bulletin 503, 1952.

6. J. A. Luker and E. C. Hobaica, "Effect of the Initial Mixture Density on the Formation of Detonation in Knallgas Saturated with Water Vapor," Journal of Chemical and Engineering Data, 6, 2 April 1961, pp. 253-256.

7. L. B. Adler, E. C. Hobaica, and J. A. Luker, "The Effect of External Factors on the Formation of Detonation in Saturated Knallgas-Steam Mixtures," Combustion and Flame, 3, 481, 1959.

8. A. L. Furno, E. B. Cook, J. M. Kuchta, and D. S. Burgess, "Some Observations on Near-Limit Flames," Thirteenth Symposium (International) on Combustion, 1971.

APPENDIX B

HYDROGEN-AIR MIXING BY FAN

Air recirculation fans are provided in the Sequoyah containment for returning air to the lower compartment after a postulated blowdown. Two such fans are provided, each having a rated capacity of about 40,000 cfm. The purpose of the fan-induced recirculation is to convey steam produced by residual heating to the ice condenser, if the emergency core cooling system should fail (failure of the ECCS is also a situation that could permit a zirconium-water reaction and hydrogen generation). The design basis for the recirculation system is an air flow rate of 40,000 cfm, corresponding to the operation of one fan. Some parameters related to mixing and burning of hydrogen in an air flow of 40,000 cfm have been calculated, and are presented in Table 4.

The air velocities in the ice condenser and upper plenum are low. Nevertheless, the flow would be turbulent in the upper plenum of the ice compartment, so the flow entering the upper compartment should be well mixed. If hydrogen were being generated by a 1% per minute reaction of zirconium (as an example), the rate of hydrogen flow would be about 10% of the air flow, giving a mixture containing about 9% H_2. This would be combustible, according to the literature cited elsewhere in this report.

A reference calculation is illustrated in Figure 2, where mixtures of 40,000 cfm air and the hydrogen yields of various rates of zirconium reaction are plotted on the ternary mixture chart. Each reaction rate corresponds to a straight-line locus, with steam rate determining the position on any line. The one point plotted on each line is for a steam rate that corresponds to the heat release rate of the $Zr-H_2O$ reaction and the latent heat of vaporization of water. It can be seen in Figure 2 that the yield of Zr-H_2O reaction rates in excess of 2% per minute can produce detonable mixtures with 40,000 cfm of air if the steam content is sufficiently low. Rates of several percent per minute were calculated for some accident scenarios in WASH 1400.

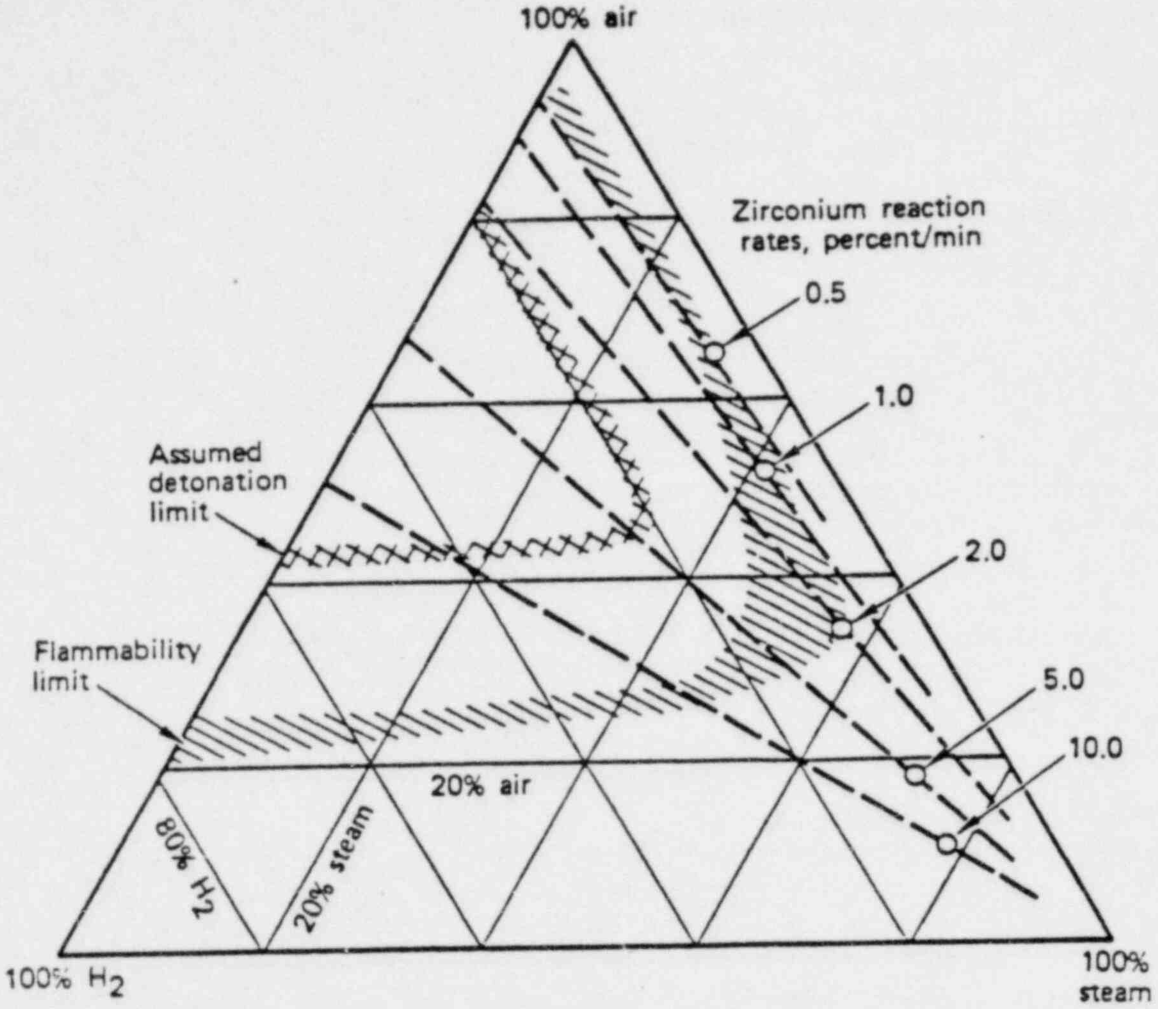
Table 4. Air Circulation Parameters

Design Data From Sequoyah PSAR

Number of Blowers		2
Capacity of Each Blower		40,000 cfm
Ice Condenser:	Flow Area (net)	1,326 ft^2
	Height	48 ft
	Annular Thickness	11 ft
	Effective Circumferential Length	267 ft
Lower Compartment Active Volume		2.87×10^5 ft^3
Total Containment Active Volume		1.24×10^6 ft^3

Derived Parameters, for One Blower Operating

Air Velocity:	a) In Ice Bed	30 ft/min
	b) In Upper Plenum of Ice Compartment	14 ft/min
Air Reynolds Number in Upper Plenum (kinematic viscosity of air @ 50°C = 1.15×10^{-2} ft^2/min)		2.6×10^4
Air Residence Time in:	Ice Compartment	1.6 min
	: Lower Compartment	7.2 min
	: Total Active Volume of Containment	31 min



Limits of flammability and detonation based on Shapiro and Moffette WAPD-SC-545, as reproduced in WASH 1400.

Figure 2. Locus of state points for mixtures of 40,000 cfm air with the hydrogen yield of various Zr reaction rates.

BROOKHAVEN NATIONAL LABORATORY

ASSOCIATED UNIVERSITIES, INC.

Department of Nuclear Energy

Upton, New York
(516)345-2629

August 8, 1980

Mr. Denwood F. Ross, Director
Division of Systems Integration
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Denny:

As per your request, the BNL "hydrogen team" has performed a preliminary assessment of the use of igniters (glow plugs) as a method of hydrogen control in the Sequoyah Nuclear Plant. This assessment is based on our present understanding of the igniter scheme proposed by TVA. This understanding, in turn, is based only on conversations held with NRC personnel during the past week.

It is our understanding that TVA proposes to use approximately thirty glow plugs which will be distributed uniformly around the containment building (upper and lower compartments) and that they will be used to mitigate the consequences of a hydrogen release to containment which derives from a degraded core accident (but not necessarily a full core meltdown). TVA will initially include one or two hydrogen detectors as part of this scheme, but the specific locations of both the detectors and the igniters are unknown to us. They will rely on the return air fans, which are intended for design basis accident accommodations, between the upper compartment and the lower compartment to ensure a distributed mixture of hydrogen, air, and steam. Their intended strategy is to burn hydrogen in the lower compartment with the aid of the glow plugs and to remove heat and reduce pressure with the available containment heat sinks. It is our understanding that TVA has performed an analysis which supports this scheme for a selected accident scenario (small pipe break with failure of emergency coolant injection) and that they have used their newly developed code CLAS-IX to compute inter-compartment flows and pressure and temperature histories in both compartments.

Although it is difficult for us to develop a firm position on the use of igniters as proposed by TVA without the benefit of a fuller description of their overall plan, we can say, based largely on our own studies of possible hydrogen control approaches for Zion and Indian Point, that the exclusive use of igniters as a means of controlling hydrogen for a wide spectrum of accident scenarios (insofar as hydrogen release as a function of time, space, and accident environment is concerned) may not be prudent. As far as the use of glow plugs or any similar form of igniters in Sequoyah is concerned, we have several concerns and reservations, as is noted below.

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ATTACHMENT 2

1. With regard to the use of igniters in the lower compartments, it may be possible that some igniters will be in the noncombustible regime, while other igniters may be in the deflagratable or detonable regime. Activation of igniters may thus initiate combustion phenomena (explosions/detonations) which entail larger pressure rises than expected on the basis of stoichiometries which exist in the neighborhood of the few diagnostic probes.

2. The potential for focusing effects related to detonations in geometrically converging regions in the containment building should be assessed.

3. It would be important to know the combustion-associated pressure and temperature histories of the lower compartment. These prescribe the flow rates through the ice chest. In turn, this determines heat loss to ice and flow rates and modes of melted ice. Further, the amount of uncondensed combustion products reaching the upper chamber is also so determined. Finally, this determines the pressure rise of concern.

4. With regard to hydrogen ignition in the lower compartment vs the upper compartment, it is not clear to us that lower compartment ignition and hydrogen consumption will always be obtained without concern for upper compartment ignition. If upper compartment ignition does occur, can the resulting pressure and temperature be tolerated?

5. Several concerns arise in connection with the ice chest performance in the presence of hydrogen combustion.

   (a) For a given scenario it would be important to know how much ice is lost to steam and how much ice then remains to cool the combustion products that are generated in the lower compartment.

   (b) Is the ice chest susceptible to combustion-generated effects which can challenge its structural integrity?

   (c) We have a particular concern for the ice chest's foam insulation and its surrounding cover. We have not been able to identify (from the Sequoyah FSAR) the material compositions of the foam and cover, but it may be that these materials are flammable. There appears to be on the order of twenty tons of foam surrounding the ice chests. Combustion of this material could engender serious pressure and temperature conditions within the containment structure. It is apparent that an ignition of hydrogen could serve as an initiator of the foam cumbustion. It is important to identify the compositions of the foam cover in order to assess their roles in relation to the course of events during a degraded core accident in the ice condenser plant.

6. In order to perform a detailed evaluation of the igniters, it would be important to know the precise design function(s) of the igniters. Their ability to "perform" can only be measured against their intended design function(s).

7. With regard to NRR-sponsored experiments at Livermore Laboratory, it would be important to have a more precise and complete characterization of the conditions of the experiments in order to judge whether useful, pertinent and complete ignition information will be obtained for a range of expected accident conditions. In particular, it will be important to know whether or not flow effects and possible droplet quenching will be accounted for.

8. The secondary purpose (stated in the Sequoyah FSAR) of the Air Return Fan System is to limit hydrogen concentration in potentially stagnant regions in the lower compartment by ensuring a flow of air from these regions. Without onsite electrical power, a flow of air from these stagnant regions could not be ensured. We are concerned that a local detonation or explosion could cause a failure of the non-return valves which normally isolate the air return paths between the lower compartments. A failure of these valves would produce a direct path between the compartments which bypasses the ice chest.

I hope that this inforamtion will be useful to you. If you have any questions on the foregoing, please do not hesitate to contact me.

Warm regards,

/s/ Bob

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Supplement No. 3 to the Safety Evaluation Report of Tennessee Valley Authority's application for licenses to operate its Sequoyah Nuclear Plant, Units 1 and 2, located in Hamilton County, Tennessee, has been prepared by the Office of Nuclear Reactor Regulation of the U.S. Nuclear Regulatory Commission. This supplement provides further information on the hydrogen control measures for Unit 1.

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