ATTACHMENT TO AEP:NRC:0500I
STATUS SUMMARY REPORT ON THE ADEQUACY OF THE
DISTRIBUTED IGNITION SYSTEM
DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

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I. Introduction

Prior to the accident which occurred at the Three Mile Island Nuclear Plant Unit No. 2 (TMI-2) on March 28, 1979, the United States Nuclear Regulatory Commission's (NRC's) position regarding hydrogen control in light water reactor containment buildings was expressed in General Design Criteria 50, "Containment Design Basis," of 10 CFR 50 Appendix A, "General Design Criteria for Nuclear Power Plants," and in 10 CFR 50.44, "Standards for Combustible Gas Control System in Light-Water-Cooled Power Reactors." These regulations dealt with calculated amounts of hydrogen generated from specific design basis accidents, such as a Loss-of-Coolant Accident (LOCA). In the case of the Donald C. Cook Nuclear Plant Unit Nos. 1 and 2, small capacity hydrogen recombiners were licensed to control the relatively small quantities of hydrogen expected to be released as a result of a LOCA.

The TMI-2 accident, however, involved a large amount of clad metal-water reaction in the core, resulting in hydrogen generation in excess of the amounts specified by the NRC in 10 CFR 50.44. As stated in Reference (1), metal-water reactions in the range of thirty (30) to fifty (50) percent of the core clad had been estimated for the TMI-2 event. Most, if not all, of the hydrogen generated during the accident was released to containment where it ignited. The resultant containment pressure, as recorded on a control room pen recorder, increased dramatically to about twenty-eight (28) pounds per square inch gauge (psig), then decreased to about four (4) psig over the next fifteen (15) seconds (Reference (2)).

Because the Donald C. Cook Nuclear Plant has an ice condenser containment of smaller volume than a large dry Pressurized Water Reactor (PWR) containment, the TMI-2 event indicated a need to reevaluate containment integrity and systems and equipment operability during degraded core accidents involving generation of large quantities of hydrogen. To this end, the American Electric Power Service Corporation (AEPSC) consolidated efforts with the Tennessee Valley Authority (TVA) and Duke Power Company in 1980, and began a reevaluation of hydrogen control measures for ice condenser containments.

Since inception of the consolidated AEPSC/Duke/TVA program, the major emphasis of the joint program has been on (a) funding research and studies dealing with prospective containment hydrogen control systems and concepts, and (b) funding development of a computer code to model ice condenser containment response to hydrogen combustion events. In early 1981, the Electric Power Research Institute (EPRI) joined the ice condenser containment utilities in evaluating hydrogen combustion, and aided in the organization and funding of four (4) research programs at Hanford Engineering Development Laboratory, Factory Mutual Research Corporation, Whiteshell Nuclear Research Establishment, and Acurex Corporation. The ice condenser owners further contracted with Westinghouse/Offshore Power Systems of Jacksonville, Florida, to obtain the CLASIX computer code for the modeling of hydrogen deflagrations in containment.

As a result of the ice condenser owners' work and a review of work performed at various national laboratories, a Distributed Ignition System (DIS) was selected by AEPSC as an adequate method of hydrogen control through combustion of lean mixtures for the Donald C. Cook Nuclear Plant. Although evaluation of the DIS has not been completed yet (survivability of equipment is still being reviewed), information available as of the present time indicates that the DIS will successfully perform its intended function. A DIS has also been selected by TVA and Duke Power Company for utilization in their ice condenser containment facilities.

This report describes the Donald C. Cook Nuclear Plant DIS, presents the results of the AEPSC/Duke/EPRI/TVA research program on hydrogen combustion and control, outlines the results of the CLASIX computer code development for use in evaluating Donald C. Cook Nuclear Plant containment integrity, and discusses the present status of AEPSC's DIS evaluation program. This report is intended to summarize and substantiate AEPSC's present position relative to DIS adequacy.

II. Selection of the Distributed Ignition System Concept

AEPSC has selected a hydrogen control system consisting of thermal igniters for the Donald C. Cook Nuclear Plant. This system is expected to cause reliable, periodic ignition of lean hydrogen-air mixtures throughout the containment building. Such periodic ignitions are expected to result in a moderated energy addition rate to the containment, thereby allowing the containment heat sinks to absorb the heat of combustion more effectively and minimizing containment pressurization.

Selection of the thermal igniter concept for the Donald C. Cook Nuclear Plant occurred as a result of numerous studies performed by AEPSC, Duke Power Company, and TVA. In particular, prior to the installation of an Interim DIS (IDIS) at the Sequoyah Nuclear Plant during the summer of 1980, TVA personnel conducted a study of various concepts to prevent or minimize the effects of hydrogen combustion in containment. This initial study considered preinerting with nitrogen, postinerting with Halon, controlled ignition, and increasing containment capacity for overpressure events through venting or increased atmospheric cooling. Each of these mitigation strategies was evaluated for effectiveness, technical feasibility, reliability, and cost. As a result, TVA staff proposed the implementation of a controlled ignition system, at least on an interim basis.

Additional studies performed by the ice condenser owners considered the potential electromagnetic interference effects of spark igniters, controlled combustion with catalytic combustors, the effects of catalyst poisoning by fission products, oxygen removal from containment utilizing a gas turbine, and postinerting with carbon dioxide. A conceptual design study of a Halon 1301 injection system was also performed, with the corrosive effects of Halon decomposition on stainless steel being demonstrated later by TVA at the

Singleton Materials Engineering Laboratory (see Chapter 2 of Reference (3) for additional information on the ice condenser owners scoping studies). After evaluating the results of these studies, all of the ice condenser owners selected a controlled ignition system utilizing thermal igniters. A description of the Donald C. Cook Nuclear Plant DIS is presented below.

The Donald C. Cook Nuclear Plant DIS utilizes seventy (70) GMAC-7G glow plug igniters within containment, distributed throughout the various containment compartments. These durable glow plugs were selected because of their high reliability at igniting hydrogen concentrations near the lower flammability limit. As noted in Reference (4), these glow plugs are of low power density, and require a heat-up period of about twelve (12) to twenty (20) seconds before reaching the hydrogen ignition temperature. At that temperature, the glow plugs are capable of emitting about one hundred fifty (150) to two hundred twenty (220) watts per square inch (W/in^2) over a surface area of about 0.6 in^2, depending upon the input voltage.

Additionally, each glow plug installed in the Donald C. Cock Nuclear Plant has undergone a preoperational test of at least a five hour duration, with the applied voltage stepped-up from about 3 Vac (15 minutes) to 6 Vac (15 minutes) to 9 Vac (15 minutes) to 14 Vac (4 hours 15 minutes). One hundred sixty-four (164) of the igniters so tested were then deenergized and allowed to cool to ambient temperature, and subsequently reenergized to 14 Vac for an 8 hour duration. A separate set of twenty (20) igniters were likewise deenergized, but subsequently reenergized for a period of about forty-seven (47) hours. The glow plug sheath temperature was monitored intermittently at 14 Vac, and glow plugs with a surface temperature of 1550°F or greater were considered acceptable for installation. These preoperational tests, along with the results of the research and development experimental programs utilizing type GMAC-7G glow plugs, provide reasonable assurance that the igniters installed in the Donald C. Cook Nuclear Plant will maintain surface temperatures in excess of the required minimum for extended periods, initiate combustion, and continue to operate in various combustion environments.

As noted above, there are seventy (70) igniters installed within containment at the Donald C. Cook Nuclear Plant. Table I provides a listing of igniter locations for the Donald C. Cook Nuclear Plant Unit No. 2; these positions may also be considered typical for Unit No. 1. Figures 1 through 4 present the basic layout of the ice condenser containment, and indicate in sectional view where the igniters listed in Table I are located. These igniters have been positioned to assure adequate spatial coverage in those areas of containment to which hydrogen could be released or to which it could flow in significant quantities. The general criteria for placement of igniters in the Donald C. Cook Nuclear Plant are as follows:

- The igniters are located above the maximum floodup level within containment.

- At least two igniters, controlled and powered redundantly, are located in each region or compartment of concern.

- Igniter locations are in areas which should be well mixed by the air recirculation/hydrogen skimmer system and/or by blowdown forces.

- With the exception of the igniters in the upper plenum, it was generally intended to place igniters about one third of the way up a wall within a given containment compartment, in order to maximize the amount of hydrogen combusted via upward propagation in a lean mixture. In practice, this was modified to keep igniters away from areas with concentrations of instrumentation. Additionally, igniters were placed in the dome area of the upper compartment to account for the possibility of hydrogen concentration gradients.

- Placement of igniters in the upper plenum of the ice condenser involved somewhat different considerations. It is believed that hydrogen volume percent concentrations in the upper plenum will be higher than at the entry to the ice condenser, due to steam removal/condensation produced in the ice bed. In addition to the high temperatures and pressures which may be produced by a hydrogen burn in the upper plenum, the amount of hydrogen escaping into the upper compartment was of concern. For hydrogen concentrations on the order of eight volume percent, it was believed that downward propagation was also probable, especially due to the turbulence in the flow stream upon exit from the ice condenser. In order to take advantage of both the upward and downward propagation characteristics of postulated flow streams, thereby limiting hydrogen leakage into the upper compartment, it was determined that placement of the igniters about two thirds of the way up the wall in the upper plenum was acceptable.

Following a degraded core accident in which hydrogen is released to the lower compartment inside the crane wall, twenty-four (24) igniters in the lower compartment are expected to provide the first level of defense against hydrogen collection and hydrogen concentration increases in excess of lean mixture limits. Twelve (12) of these igniters are mounted on the primary shield wall, with one train of six (6) igniters located about nine or ten feet above the second train of six (6) igniters. The top train on the primary shield wall is located just a few feet below the operating deck structure, near the lower compartment spray headers. Two (2) igniters, one from each train, are located in each steam generator enclosure and in the pressurizer enclosure. These ten (10) igniters have been positioned near the top of the enclosures to account for potential pocketing concerns. Two (2) igniters have also been positioned near the Pressurizer Relief Tank (PRT) in case the PRT rupture disk blows and provides a possible hydrogen escape route from the primary system.

It is expected that the lower compartment igniters will not result in the burning of all hydrogen in that compartment, either due to inerting of the atmosphere from high steam/chemical spray concentrations or, more probably, the inefficient burn completeness of lean mixtures. In such a case, it is likely that a hydrogen/air/steam mixture will enter the lower plenum of the ice condenser and pass into the ice bed. The ice bed is then expected to "scrub" the mixture, condensing the steam and thereby increasing the volume concentration of the hydrogen. For this reason, mixtures that were nonflammable in the lower plenum or lower compartment may become flammable by the time they reach the ice condenser upper plenum. This phenomenon is supported by the CLASIX containment analysis code, which predicts numerous sequential burns to occur in the upper plenum of the ice condenser (see Reference (5)). Controlled burning in the upper plenum of the ice condenser is considered preferable to burns in other compartments, since the amount of hydrogen consumed by each lean limit burn in the upper plenum is low (predicted values on the order of 15 to 20 lbm hydrogen) and the energy addition rate to the containment is thereby moderated.

It has also been concluded, based on the expert opinion of Bernard Lewis and Bela Karlovitz, that there is no realistic potential for a transition to detonation in the upper plenum of the ice condenser (see Attachment 1 to Reference (20)). This considered opinion is, in turn, based on the lack of an available detonation initiation source, the belief that the entering mixtures will be near the lower limit of hydrogen flammability, and the lack of sufficient geometrical confinement either above or below the region of combustion.

For the reasons noted above, a total of fourteen (14) igniters (seven (7) from each train) have been installed in the upper plenum. Additionally, twelve (12) igniters have been installed in the dome area of the upper compartment. As indicated in Table I, these twelve (12) igniters have been evenly divided between two elevations, with the top array of six (6) igniters located within a few feet of the top of the containment dome. These igniters are expected to aid in the control of hydrogen flowing into that area if it bypasses the ice condenser upper plenum, and may additionally handle any hydrogen which may "pocket" in the dome area (this is not a major concern as long as the hydrogen skimmer system is operable).

Additional control of hydrogen during air recirculation is afforded by ten (10) igniters mounted on the exterior of the steam generator and pressurizer enclosures (two (2) igniters per enclosure) in the upper compartment, four (4) igniters mounted in each of two (2) fan/accumulator rooms, and two (2) igniters mounted in the instrument room.

The components of the DIS are expected to maintain their functional capability under Main Steam Line Break (MSLB) and Loss-of-Coolant Accident (LOCA) conditions. GMAC-7G igniters have been used in various test programs, and have performed successfully throughout numerous hydrogen burn transients. The igniters in the Donald C. Cook Nuclear Plant are not expected to become

submerged, as they are located above the maximum predicted containment floodup level. DIS cables which are routed below the containment floodup level are routed in floodup tubes. The effects of spray impingement on the igniters have also been examined experimentally, and galvanized sheet metal plates have been mounted on the installed igniter assemblies to protect the glow plugs from direct spray impingement. The effect of burn temperature transients on DIS cables has previously been reviewed by the ice condenser owners, and theoretical and experimental means have found that even bare cables will stay fire resistant during burn transients. Although the DIS is not required to be a Seismic Class IE system, many portions of the design reflect installation to Class IE standards. The DIS circuits, conduit, splice boxes, and igniter assemblies have been seismically mounted to existing steel supports inside containment, and have been found to induce negligible additional stresses in the supporting steel. The glow plugs and igniter assemblies themselves, however, are not Class IE items.

The normal and emergency power sources for each train of igniters meet Class IE specifications, and electrical train separation criteria commensurate with a Class IE system are maintained. The DIS is a manual system controllable from the main Control Room. Two control switches per train are located on auxiliary relay panels A7 and A8 in the Control Room, and are of the two-position type (i.e., "on" and "off"). Red and green indicating lights are provided above each switch to indicate system status. It is expected that the DIS will be actuated early in an event so as to promote combustion of lean hydrogen mixtures.

Surveillance testing proposed for the DIS consists of energizing the system and taking voltage and amperage readings for each circuit. These readings may be used to determine if any igniters have failed on a circuit. The glow plugs are also visually inspected to ensure that they glow red. If the glow plugs are not glowing, then they may still be considered acceptable if a direct measurement of surface temperature is made and the temperature is so determined to be at least 1550°F. If any glow plugs fail this direct temperature measurement test, they are replaced with stored glow plugs which have undergone a preoperational test of at least five hour duration.

Based on the above, it is concluded that the Donald C. Cook Nuclear Plant DIS design is adequate to perform the intended design function of reliably igniting lean hydrogen mixtures within containment. It is believed that the DIS will continue to perform its intended design function in a post-accident environment, assuming the loss of one train of igniters. The proposed surveillance measures are considered adequate for the purpose of identifying igniter failures and signaling the need for replacement installation.

III. Supporting Research and Development Programs

Extensive research has been sponsored by AEPSC, TVA, Duke Power Company, and EPRI during the last few years in order to study hydrogen combustion, mitigation, distribution, and control. The research programs were designed to be confirmatory in nature, and they were necessarily limited in scope and depth due to time constraints imposed by the Sequoyah Nuclear Plant operating license conditions and the availability of test facilities. The programs focused on the engineering applications of hydrogen combustion technology in support of a controlled ignition system.

AEPSC, TVA, and Duke Power Company sponsored combustion experiments at Fenwal Incorporated. TVA, Duke, AEPSC, and EPRI sponsored research at the Whiteshell Nuclear Research Establishment in combustion phenomena and igniter development, at the Factory Mutual Research Corporation in combustion and mitigation, at Acurex Corporation in combustion and mitigation, and at the Hanford Engineering Development Laboratory in hydrogen distribution within containment. TVA conducted experiments at the Singleton Materials Engineering Laboratory in equipment survivability and igniter development. These tests, which confirmed judgments made by the ice condenser owners in the analysis and design of their ignition systems for use inside containment, are described below.

A. Fenwal Incorporated

A two-phase experimental program was undertaken at Fenwal Incorporated to demonstrate the ignition characteristics and reliability of the GMAC-7G igniter. The test vessel was a 134 ft^3 steel sphere that was heated and insulated. Phase 1 consisted of a series of premixed combustion tests with hydrogen concentrations of 8, 10 and 12 volume percent. The effects of fan-induced turbulence and steam addition were investigated in several tests. The performance of the GMAC igniter in initiating hydrogen burns was demonstrated to be reliable. In addition, comparison of such test results as pressure rises and ignition limits with previously published data showed good agreement.

The Phase 2 follow-on tests consisted of further premixed tests with hydrogen concentrations between 5 - 10 volume percent, tests where hydrogen was continually injected into the test vessel, and a series of tests using water sprays. The most important result of the Phase 2 program was the ability of the igniter to reliably ignite lean hydrogen mixtures under adverse conditions, including the presence of steam and water sprays, and to continue to operate. No detonations were observed during the tests, even when pure hydrogen was being admitted to the vessel during the transient tests. The minimal pressure rises experienced during the continuous injection tests indicated the igniter's capability to initiate local combustion of hydrogen mixtures just as they become flammable.

B. Factory Mutual Research Corporation (FMRC)

One of the hydrogen control methods which has been considered is a water fog system which may be used in conjunction with a DIS. The water fog system would be expected to fill the containment volume with a high density fog prior to and during controlled combustion of hydrogen by the DIS. This high density fog should then absorb much of the energy released during hydrogen combustion, thereby limiting the resultant temperature and pressure to acceptable values. The adiabatic, isochoric combustion calculations of Berman, et. al. (Reference (6)), which include fog droplet evaporation effects, indicate that fog concentrations on the order of 10^{-4} g-water/cm^3-gas-mixture can significantly reduce containment pressures, as compared to combustion of dry hydrogen mixtures.

In order for a water fog system and DIS to be compatible, however, the fog should neither inert the hydrogen-air mixture nor quench a propagating flame front. Fog inerting or quenching requires rapid droplet vaporization. The vaporization rate calculations of Berman, et. al. (Reference (6)), indicate that droplets with a diameter less than approximately eight microns will vaporize entirely within the flame zone and, therefore, are capable of inerting.

The FMRC project was the first of a two-part experimental program to investigate the pressure suppressant effects of a water fog system. The major purpose of the FMRC project was to experimentally identify, in small scale, a set of nominal microfog conditions for investigation in the Acurex intermediate scale hydrogen combustion studies (see Section III.C. below). Since the interest here was in the pressure suppressant effects of a water microfog, the FMRC project was necessary in order to avoid inadvertent inerting of the Acurex test vessel. For this reason, the approach taken by FMRC to achieve the project objective was to experimentally determine the water microfog requirements for inerting hydrogen-air mixtures, and then to recommend to Acurex a set of microfog conditions that should not induce inerting. Emphasis was placed on visually dense microfogs with number mean droplet diameters on the order of 1 - 100 microns.

A laboratory-scale fog inerting apparatus was constructed to acquire inerting data. Figure 5 presents a schematic view of the FMRC test setup. Tests were conducted in a Plexiglas tube approximately 3.5 feet long with a 6 inch inner diameter. A 2.8 Joule spark served as the ignition source. Several tests were also conducted with a GMAC-7G glow plug as the ignition source to verify the applicability of these tests to installed distributed ignition systems. Successful ignition was monitored by three chromel-alumel thermocouples and by actuation of pressure relief discs at the top of the inerting tube.

The FMRC tests were conducted with gas mixtures containing 4.0 volume percent hydrogen to 8.7 volume percent hydrogen, at temperatures ranging from 20°C to 70°C. The dense water fogs were generated within the inerting tube by using a series of five different fog nozzles (i.e., a SPRACO #2163-7604 impingement-type nozzle, a SPRACO #2020-1704 hollow cone nozzle, a SPRACO #1806-1605 hollow cone misting nozzle, a SPRACO #1405-0604 impactor-type nozzle, and a Sonicore Model 35H air-driven fog nozzle). These nozzles produced volume average drop diameters of 20 - 115 microns at water pressures of 10 - 40 psig. Prior to the inerting tests, fog drop size and concentration data were obtained with a hot wire probe located at the igniter position in the inerting tube.

Conclusions of this series of tests, which are described in additional detail in Reference (7), are as follows:

- Dense water fogs applied to hydrogen-air mixtures cause only a marginal increase in the hydrogen lower flammability limit (LFL) concentration at room temperature. Four (4) different fog nozzles used in the FMRC program caused the hydrogen LFL for upward flame propagation to increase from 4.0 volume percent hydrogen (for a dry hydrogen-air mixture) to 4.4 - 5.3 volume percent hydrogen. Fog generated from the air-driven nozzle (which generated much smaller droplets than the hydraulic nozzles) resulted in a hydrogen LFL of 7.2 volume percent hydrogen at 20°C.

- Increasing temperature causes a greater increase in the hydrogen LFL in the presence of water fogs. For a typical hydraulic type fog nozzle used in the project, the hydrogen LFL increased from 4.8 volume percent hydrogen to 7.2 volume percent hydrogen and to 7.6 volume percent hydrogen, as temperatures increased from 20°C to 50°C to 70°C. This increased inerting was apparently due to (a) water vapor dilution and (b) liquid phase water heat sink effects associated with rapid vaporization of the smaller drops at elevated temperatures.

- Fog densities required to achieve a given level of hydrogen inerting were found to be strongly dependent on the characteristic size of the microfog. Indeed, fog densities required to inert hydrogen mixtures increased by an order of magnitude (from 10^{-4} gm/cm^3-gas to 10^{-3} gm/cm^3-gas) as volume mean microfog drop diameters increased from about 20 to 100 microns.

C. Acurex Corporation

Acurex Corporation experimentally investigated the deliberate ignition approach to hydrogen control. The Acurex project consisted of two phases. Phase 1 investigated the effect of igniter location within an enclosed compartment, whereas Phase 2 comprised the second phase of the water microfog investigation begun by FMRC (see Section III.B. above). Several key parameters which could affect hydrogen combustion characteristics, including hydrogen and steam flow rates, igniter locations, water sprays, and water fogs, were identified and investigated by Acurex in both dynamic and quiescent experiments.

A facility was built for the Acurex project near Livermore, California, utilizing a test vessel of approximately 630 ft^3 volume. The vessel was approximately 17 ft high with a 7 ft inside diameter. A schematic of the Acurex facility is presented in Figure 6. Igniter assemblies for use in the tests were supplied by the Duke Power Company, and are identical to those assemblies installed in the McGuire Nuclear Station. These igniter assemblies utilized GMAC-7G glow plugs which are identical to the glow plugs utilized in the Donald C. Cook Nuclear Plant. Thermocouples were used to detect flame front location and vessel atmosphere temperature. Strain gauge and piezoelectric pressure transducers were used to measure the vessel pressure. Gas concentrations within the vessel were determined by sampling the vessel atmosphere, passing the sample through a cold trap and a silica gel trap to remove moisture, and utilizing a gas chromatograph.

Several series of tests, both quiescent and dynamic, were conducted during this program. The first series of tests (Phase 1) included two modes of operation. In the first mode, a GMAC-7G igniter was energized to initiate combustion of a quiescent mixture of hydrogen, air, and steam. In the second mode, an igniter was energized prior to the introduction of hydrogen. Igniter assemblies were located near the top, at the center, and near the bottom of the test vessel. Hydrogen and steam concentrations were varied during the test series, and in some cases a spray nozzle representative of those used within an ice condenser containment was utilized.

The second series of tests (Phase 2) utilized an array of nine (9) SPRACO pinjet nozzles, which produced drop sizes about an order of magnitude smaller than a containment spray nozzle. Again, both quiescent and dynamic tests were performed, and microfog droplet size and hydrogen and steam concentrations were varied. In all experiments the vessel was preheated to about 160°F prior to each test.

Flow rates of hydrogen and steam in the dynamic injection tests were commensurate with typical analyses for degraded core accidents. The highest hydrogen flow rate and the highest steam flow rate correspond to about 50 and 1000 lb/min, respectively, when scaled by volume to a 300,000 ft^3 compartment. The greatest overpressure observed in the dynamic tests due to a single combustion event was 28 psi, for a test which utilized a flow of 0.035 lbm/min hydrogen and no steam injection. The presence of steam injected with the hydrogen, however, normally lowered the maximum pressure. Indeed, for a steam injection test basically similar to the 28 psi overpressure case cited above, the burn overpressure was reduced to about 13 psi. Combustion overpressures and temperatures were very low in the dynamic injection tests utilizing spray or microfog; a single burn overpressure for such tests never exceeded 5 psi. In some spray tests, pressures were so low that the burn was

confirmed only by post-test gas sample analysis which indicated low hydrogen and/or oxygen content. For the quiescent tests, combustion was virtually complete when hydrogen concentrations of 7.5 and 10.7 volume percent were used. The largest burn overpressure experienced during the quiescent tests was about 49 psi, for a 10.7 volume percent hydrogen case.

Two distinct types of burning were evident in the Acurex studies, based on pressure and flame front detector data. These two types of burns have been described as "discrete" and "intermittent" burns. A typical discrete burn experienced during the Acurex tests would sweep through the flammable region of the test vessel, lasting approximately one (1) second, depending upon test conditions. Such discrete burns caused rapid pressure rises which varied in magnitude, and were observed in both the quiescent and the dynamic tests. A discrete burn was responsible for the test series maximum overpressure of 49 psi. Discrete burns were also called "global" or "local", depending upon the extent to which the burn engulfed the vessel atmosphere.

By comparison, repeated intermittent burns occurred only during dynamic injection tests. Intermittent burns often appeared as burns occurring near the hydrogen injection nozzle, and thus occurred in the same general region within the vessel. Accompanying pressure rises were usually lower in magnitude than for discrete burns. Intermittent burns lasted for longer times than discrete burns and, like the discrete burns, were found to be global or local in nature.

The conclusions of the Acurex Corporation hydrogen control studies, which are described in additional detail in Reference (8), are as follows:

- The largest overpressure in a dynamic injection test, 28 psi, occurred with the igniter located near the bottom of the vessel, without steam in the flow stream. The severity of the burn transient appeared to be primarily a function of the igniter location relative to the hydrogen flow stream characteristics and source location. Overpressures were least severe when the igniter was located downstream of the hydrogen/air mixing region during the tests.

- Water sprays and microfog dramatically reduced combustion overpressure in dynamic tests. For the quiescent tests utilizing 7.5 and 10.7 volume percent hydrogen, microfog had little effect on burn overpressure; however, sprays caused a slightly more rapid depressurization following a burn.

- Peak combustion overpressures during quiescent tests agree with previously published data from similar tests. A limited number of such tests were performed with nominal hydrogen concentrations of 5, 7.5, and 10.7 volume percent, and a maximum overpressure of about 49 psi occurred for a 10.7 volume percent hydrogen case.

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- The GMAC igniter assemblies survived over five cumulative hours of exposure to combustion test environments. The assembly and power cable continued to operate without failure.

- Although the test vessel was not specifically instrumented to obtain flame speeds, it was possible to calculate "average" global flame speeds from the pressure rise data of several transient and quiescent tests. The calculated flame speeds in the dynamic tests varied between 1 - 2 ft/sec with steam present and either top or bottom ignition, to 4 ft/sec with no steam present and bottom ignition. Flame speeds from the quiescent tests varied from 3 - 8 ft/sec as the hydrogen concentration was increased from 5 to 11 volume percent hydrogen. Thus, it is concluded that these values support the flame speed ranges used in the CLASIX analyses.

- The nature of combustion was always deflagration rather than detonation, even when a hydrogen-rich mixture was entering the vessel.

- The pressure rises during all of the transient tests in both Phases 1 and 2 were dramatically less than during the quiescent tests (with the exception of one very lean mixture quiescent test). From this contrast, it is concluded that caution must be used in the direct application of data from quiescent tests to the investigation of transient conditions. However, since the expected containment post-accident environment would more closely resemble the transient (i.e., dynamic injection) test conditions, it follows that the pressure rises from repeated intermittent combustion within containment should be relatively benign from the standpoint of overpressure.

D. Whiteshell Nuclear Research Establishment (WNRE)

Two research efforts were undertaken at WNRE. One pertained to investigating the effectiveness of the glow plug igniter in a detailed and comprehensive manner; the Tayco igniter utilized by TVA in the Sequoyah Nuclear Plant Permanent Hydrogen Mitigation System (PHMS) was also studied. The second effort, a multifaceted large scale segment aimed at enhancing the ice condenser owners' understanding of basic combustion phenomena, included static and turbulent tests for varying pre-mixed hydrogen mixtures.

Igniter tests were performed in a 17-liter, quasi-spherical vessel to provide further evidence of the capability of both GMAC-7G and Tayco thermal igniters to reliably ignite lean hydrogen mixtures. Numerous tests were conducted to determine the LFL and igniter surface temperature for various premixed hydrogen-air-steam mixtures. Hydrogen concentrations were varied between about 4 and 15 volume percent, and steam concentrations were varied between about 0 and 60 volume percent. The measurement of igniter surface

temperature required for ignition showed that the igniter at its normal operating temperature had considerable margin even for high steam concentrations.

The hydrogen combustion tests were performed in the WNRE Containment Test Facility (CTF) using a 223 ft^3 heated and insulated metal sphere and, for some tests, a 20 ft long by 1 ft diameter attached pipe. These tests were grouped into four principal areas:

- Extent of reaction of lean mixtures.
- Laminar spherical deflagration.
- Effects of fan and obstacle induced turbulence.
- Extended geometry (sphere and attached pipe).

The lean mixture tests were performed in the sphere to investigate the extent of reaction under various steam concentrations; the effect of fan induced turbulence was also studied. Hydrogen concentrations were varied between 5 and 11 volume percent and steam between 0 and 30 volume percent. Fans were activated in several of the tests. The test results were in agreement with previously published data on the flammability of lean mixtures. Results also showed that the addition of relatively large (over 30 volume percent) amounts of steam reduced the burn overpressure, apparently due to the added heat capacity. This indicates that the pressure rise data from dry tests may be extremely conservative and, perhaps, nonrealistic for application to plant environments with high steam concentrations. Results also showed that turbulence increased the rate and magnitude of pressure rise for a given concentration by increasing the burn completeness. This indicates that burning at a relatively lean hydrogen concentration could be promoted by the post-accident turbulent atmosphere which is expected to occur in an ice condenser plant.

The laminar spherical deflagration tests were performed in the sphere to compare the actual pressure rises with the corresponding theoretical adiabatic pressure rises, and to confirm that detonations would not result, even at high concentrations of hydrogen. Hydrogen concentrations were varied between 10 and 42 volume percent and steam between 0 and 40 volume percent for these tests. Fans were activated in several tests. Results again showed that the addition of large amounts of steam reduced the burn overpressure. The actual pressure rise was always less than the theoretical adiabatic pressure rise, with the margin increasing as the hydrogen concentration was increased. No detonations were observed, even at stoichiometric and higher concentrations of hydrogen, which are classically considered to be detonable.

Tests were performed in the sphere to investigate the effects of turbulence induced by fans and gratings on the extent and rate of combustion. In these tests, hydrogen concentrations were varied between 6 and 27 volume percent. One

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test was run with 10 volume percent steam. Results showed that, for rich hydrogen mixtures, forced turbulence did not increase the overall pressure rise, but did decrease the pressure rise time slightly. In lean mixtures without fans, the presence of gratings tended to increase the magnitude and rate of the pressure rise. At high concentrations or with fans, the gratings reduced both the magnitude and rate of pressure rise by acting as heat sinks. These results indicate that no unanticipated pressure effects result from forced turbulence, even at high concentrations of hydrogen.

Additional information on the WNRE experiments is contained in Chapter 2 to Reference (3), and in Reference (9).

E. Hanford Engineering Development Laboratory (HEDL)

During a degraded core accident sequence, it is important to know how the hydrogen released from the primary system is going to be distributed within the multi-compartmented reactor containment building. The importance of hydrogen mixing, distribution, and stratification cannot be ignored when analyzing for potential gas pocketing areas which may lead to combustion at hydrogen concentrations at other than lean conditions.

The major objective of the HEDL investigation was to determine the extent of hydrogen mixing and distribution in a simulated ice condenser containment lower compartment, and to provide an experimental data base to evaluate analytical methods used to predict hydrogen distribution. Evaluations of such analytical methods are contained in References (10), (11), (12), and (13). The HEDL tests also allowed for the determination of the adequacy of the CLASIX computer code assumption regarding well mixed (i.e., homogeneous) containment compartment conditions.

The HEDL Containment Systems Test Facility was selected because its relatively large size (i.e., about 30,000 ft^3) allowed for a reduction in scaling effects, and because its interior could be customized to represent the structures of an ice condenser containment. Helium was used as a simulant for hydrogen in most of the tests due to safety considerations.

Since the upper compartment of all the ice condenser containments owned by the three involved utilities is expected to be well mixed by containment sprays, the lower compartment was chosen for modeling emphasis in the HEDL facility. It is noted, however, that the Donald C. Cook Nuclear Plant also has a lower compartment spray system, which should provide an additional atmospheric mixing mechanism in that region. The divider deck, reactor cavity, refueling canal, air return fans, and ice condenser lower inlet doors were all represented in the 0.3 linear scale HEDL test facility (see Figures 7 and 8). The tests were scaled using non-ideal similarity modeling to simulate a small break LOCA and were based on MARCH computer code analyses performed for the Sequoyah Nuclear

Plant. Two release scenarios were modeled — a 2" break with a horizontal jet orientation and a 10" PRT rupture disk opening with a vertically upward jet orientation. Atmospheric temperatures, velocities, and gas concentrations were measured at several distributed sample points during the tests.

The HEDL test results, which are described in detail in Reference (14), showed that mixing was very good, even without forced circulation by air return fans. The maximum hydrogen concentration difference at any time between two sample points in the scaled lower compartment was about 2 - 3 volume percent; it is noted, however, that there were two anamolous test results which are not considered typical of plant post-accident conditions (see "Response to Question 9," contained in Attachment 3 to Reference (15)). It has been concluded from the HEDL test series that a combination of mixing processes can be anticipated to be in operation in an ice condenser lower compartment during a small break LOCA. More specifically, gas entrainment in the high velocity jet is expected to provide the dominant mixing mechanism, with natural convection and forced air recirculation aiding in the mixing process. As noted above, these mechanisms may be expected to keep the hydrogen concentration within the volume from varying by more than about 3 volume percent between any two points. After the gas release period, however, natural and forced convection is expected to provide an even more uniform gas concentration within the lower compartment. The HEDL tests did not indicate a potential for pocketing of rich hydrogen mixtures, and thus the CLASIX assumption of homogeneous compartment conditions is supported.

F. Singleton Materials Engineering Laboratory

Tests have been conducted at TVA's Singleton Materials Engineering Laboratory to determine the effects of glow plug igniter operation in lean mixtures (i.e., 4 volume percent hydrogen in air) on the durability of the igniter and its ability to perform its intended design function. In particular, a 24-hour lean mixture exposure test has been performed, with the igniter subsequently demonstrated to initiate combustion in an 8 volume percent hydrogen mixture. Additionally, the igniter was cycled to determine its surface temperature characteristics and was examined visually for surface degradation. All three test methods indicated that exposure of the igniter for long periods to lean hydrogen mixtures did not degrade igniter durability or performance.

Before the 24-hour test, the glow plug igniter was energized for five minutes, then deenergized and allowed to cool to ambient temperature. Three such cycles were repeated at both 12 Vac and 14 Vac, while the igniter surface temperature was measured and recorded for comparison after the 24-hour test.

The 24-hour lean mixture test was conducted in a combustion chamber fabricated from a 4 ft section of 4" diameter schedule 40 pipe. The pipe was placed horizontally with the igniter mounted through an end plate at the centerline. The lean mixture was maintained at a constant 4 volume percent

hydrogen in air for 24 hours by passing a stream of the desired concentration through a mixing chamber and into the combustion chamber. The hydrogen mixture was added to the combustion chamber at a point near the glow plug and allowed to flow out of the pipe at the other end. The hydrogen concentration was monitored with a gas chromatograph that sampled the flow stream at the inlet to the combustion chamber. The igniter was energized at 14 Vac for 24 hours, while the surface temperature of the igniter and the chamber temperature approximately 1" above and below the igniter were monitored.

Following the lean mixture exposure test, the test apparatus was allowed to cool to ambient temperature. An 8 volume percent hydrogen mixture was then passed through the combustion chamber, and the igniter was reenergized for about two hours. The surface temperature of the igniter and the chamber temperature was again monitored. The atmospheric temperatures observed both above and below the igniter in the 8 volume percent hydrogen test were higher than those observed during the 4 volume percent hydrogen test. Additionally, the atmospheric temperature above the igniter exhibited a transient behavior that suggested periodic combustion. It was concluded that the overall higher temperatures, coupled with the transient profile observed above the glow plug, indicated that the igniter was still able to perform its intended design function following the 24-hour lean mixture exposure test.

Following the two-hour test, the igniter was again cycled through three 12 Vac and three 14 Vac cycles as were performed prior to the lean mixture exposure test. Comparisons revealed only slight differences in the peak temperature (approximately 1%) that were within the accuracy of the thermocouple used in the measurement. These results indicate that the igniter was still able to reach comparable peak surface temperatures following the 24-hour and 2-hour tests.

Upon completion of all other testing, the igniter was removed from the combustion chamber and visually examined. Some discoloration and surface roughness was evident, neither of which seemed to inhibit the proper operation of the glow plug. Both the discoloration and surface roughness were removed by light sanding.

In conclusion, the TVA tests conducted at the Singleton Materials Engineering Laboratory demonstrated that sustained exposure to lean hydrogen mixtures does not affect the subsequent ability of the glow plug igniter to perform its intended design function. Additional testing performed by TVA at Singleton with regard to equipment survivability is described in Attachment 4 to Reference (16) and in Section IV.B. below.

IV. Supporting Analyses

Numerous analyses have been performed by the ice condenser owners in order to study the effects of hydrogen combustion on ice condenser containment structures and equipment. Calculations of containment atmospheric pressures and temperatures resulting from hydrogen ignition and deflagration have been performed with the CLASIX computer code. The ability of the Donald C. Cook Nuclear Plant containment structure to maintain its integrity during a degraded core accident involving hydrogen combustion has been assessed. The survivability of required equipment has been previously addressed by TVA and Duke Power Company, and AEPSC has maintained that these analyses were, in general, applicable to the Donald C. Cook Nuclear Plant. The equipment survivability analyses are, however, under review by a consultant to determine if any areas need to be addressed in additional detail. Furthermore, AEPSC has previously identified a potential concern relating to the survivability of the air return/hydrogen skimmer fan system under postulated deflagration induced differential pressures. This matter is presently under review, as is the possible rerouting of the reactor vessel head and pressurizer high point vent system. It is believed that, upon resolution of these two concerns, the Donald C. Cook Nuclear Plant DIS will constitute the final hydrogen combustion and control system, and should perform its intended design function in a manner that provides for adequate safety margins.

A. Structures

Containment pressures and temperatures resulting from postulated degraded core accidents involving hydrogen deflagration have been calculated using the CLASIX containment analysis code. This computer code, which was developed by Westinghouse/Offshore Power Systems of Jacksonville, Florida, is described in Reference (17).

The ice condenser containment has been modeled in CLASIX through the use of commonly accepted techniques, such as the assumption of homogeneous nodal volumes connected by a few flow paths. Effects which may be considered more specific to degraded core accidents, such as hydrogen deflagration, were also modeled in the CLASIX program. Indeed, hydrogen combustion was represented in CLASIX as a simple model that added the heat released during burning to the surroundings when specific flammability criteria (i.e., burn initiation hydrogen fraction, oxygen availability, etc.) were met in a region. More elaborate combustion models, including those which attempt to account for such factors as nonuniform flame propagation, were judged to be unnecessary for the CLASIX computer code application and were not used.

As described in Appendices A and B to Reference (17), Westinghouse/Offshore Power Systems has performed comparisons of CLASIX with other computer codes. In particular, CLASIX has been compared with TMD, an NRC-accepted ice condenser containment subcompartment analysis code, and with COCOCLASS9, a degraded core

accident program based on the NRC-accepted COCO computer code. These comparisons indicated good agreement between CLASIX and the other programs. Furthermore, Appendix C to Reference (17) describes the work performed by Westinghouse/Offshore Power Systems with regard to using CLASIX to model certain hydrogen combustion tests performed at Fenwal Incorporated and at the Lawrence Livermore National Laboratory. For all tests which were representable by a single uniform hydrogen burn, CLASIX predicted conservative values for peak pressures. As a result, Westinghouse/Offshore Power Systems concluded that the CLASIX-test comparisons provided a high degree of confidence in the CLASIX burn model, heat transfer to passive heat sink model, heat transfer to sprays model, and the use of room temperature values for the constituent gas specific heats. Therefore, it is believed that the CLASIX computer program is adequate to use for conservative predictions of ice condenser containment response to degraded core accidents involving hydrogen deflagration.

One set of CLASIX input parameters required to model a degraded core event included the hydrogen and steam release rates into the containment. These rates were specifiable in the CLASIX input to allow for dependence upon the accident sequence being analyzed. A small break LOCA with failure of safety injection (S_2D) was chosen for the Donald C. Cook Nuclear Plant CLASIX analyses because this sequence is similar to the TMI-2 accident. Recovery of core cooling was assumed to occur prior to core slump and reactor vessel failure, and the cladding reaction was terminated at about 75% of the cladding inventory for a typical PWR core. Additionally, TVA utilized the MARCH computer code to predict the hydrogen release rates for a number of other accident sequences; these release rates were found to be bounded by either the S_2D base case or one of TVA's sensitivity studies (see Attachment 1 to Reference (16)). Indeed, it was determined by TVA that the accident scenario chosen resulted in more than twice as much hydrogen generation prior to core slump than was found in the other postulated scenarios.

Other CLASIX input parameters were required to describe hydrogen deflagration characteristics. These parameters included the LFL of each containment subcompartment, the fraction of burn completeness in each region, the burn time or duration, and the volume fraction of oxygen required to initiate a burn. In the latest CLASIX analyses performed for the Donald C. Cook Nuclear Plant, reported via Reference (5), the conservative assumptions used in the base case analysis included an LFL of 8 volume percent hydrogen, a burn completeness fraction of 85%, and a flame speed of 6 ft/sec. Burn time within each compartment was calculated from the assumed flame speed and igniter locations. In various sensitivity studies for the Donald C. Cook Nuclear Plant, the LFL has been varied between 6 and 10 volume percent hydrogen, the burn completeness fraction between 60 and 100%, and flame speeds between 1 ft/sec and 6 ft/sec. As noted in Reference (5), however, additional analyses have been performed by Duke Power Company and TVA for the McGuire and Sequoyah Nuclear Plants, respectively. These sensitivity studies included parametric variations

of flame speed, ignition limits, burn completeness fractions, hydrogen source terms, steam source terms, ice inventory, reduced igniter effectiveness, and equipment availability. These analyses were previously reviewed and it was concluded that the results were, in general, applicable to the Donald C. Cook Nuclear Plant. It has also been concluded that the range of values used to describe hydrogen deflagration phenomena (i.e., burn completeness, flame speed, etc.) were supported by numerous references in the literature on turbulent combustion in lean hydrogen mixtures and by the results of the AEPSC/Duke/EPRI/TVA combustion experiments.

Of the six (6) Donald C. Cook Nuclear Plant CLASIX analyses reported via Reference (5), it is noted that the highest peak pressure resulting from the base case scenario was only 10.9 psig, which is below the Donald C. Cook Nuclear Plant design pressure of 12 psig. The highest peak pressure resulting from the reported Donald C. Cook Nuclear Plant sensitivity studies was 19.8 psig. Additionally, it is noted that of the numerous Sequoyah sensitivity studies reported in Attachment 1 to Reference (16), the highest peak pressure resulted from TVA's case "1N", which assumed that all ice was melted when hydrogen was first released into the containment. For this case, TVA predicted a peak pressure of about 27.5 psig.

Structural analyses have been performed to determine the static pressure capability of the Donald C. Cook Nuclear Plant containment buildings, in order to assess the potential for containment failure due to hydrogen deflagration induced pressure loadings. As reported in Attachment 1 to Reference (18), Structural Mechanics Associates (SMA) of Cleveland, Ohio, determined that the maximum containment pressure capacity varies for different segments of the containment building. Based on a purely elastic analysis and considering the lowest as-built material properties, the ultimate capacity of the containment was determined to be 49.6 psig for the concrete mat, 61.2 psig for the concrete shell, and 42.6 psig for both the equipment and personnel hatches. These values were expected to increase if the "mean value" properties of the as-built materials were used, and decrease if specified minimum properties were used (in such a case, the limiting pressure would be reduced to 32.3 psig for the equipment and personnel hatches). Additionally, Reference (18) noted that, based on observed results from model tests, significant leakage (i.e., >1.0% of containment volume) from the containment might not occur until pressures exceeded the limiting pressures calculated in the study by at least 20%.

The limiting failure modes which were considered in Reference (18) for the equipment hatch and the personnel hatch were in the bending mode. It has been noted that since the plastic section modulus for rectangular shapes associated with the hatch plates is 1.5 times the elastic section modulus, and since plate and shell bending elements behave essentially elastic (i.e., small deformations) until the plastic section modulus is reached, then there should be significant safety margin in the hatch analysis reported above. Indeed, to quantify the effect of the plastic section modulus of the equipment hatch, a non-linear elastic-plastic analysis of the hatch cover plate was performed with the ANSYS

computer program, assuming the minimum as-built material property (i.e., F_y = 50.3 ksi). Evaluation at 70 psi internal pressure, or 1.64 times the elastic capacity of the cover plate, indicated that the maximum deflection of the plate was still linear and that the maximum plastic strain was 1.8 times the elastic strain at yield. Therefore, SMA concluded that the true pressure retaining capacity of the hatches, when the 1.5 factor discussed above was applied, was approximately the same as that of the concrete limiting portion of the containment evaluated at the "mean value" material property, or about 54.5 psig.

Additionally, Attachment 3 to Reference (19) presents the results of SMA's probabilistic description of the ultimate internal pressure capacity of the containment structures at the Donald C. Cook Nuclear Plant. This work was commissioned in order to assess the anticipated degree of dispersion which might be anticipated to occur in the calculated results, taking into account the inelastic safety margin present beyond the initial yield of the materials, as estimated on the basis of available data on inelastic behavior supplemented with engineering judgment. The failure modes considered in the latter SMA study were the same as those identified in the earlier study (i.e., shear failure in the base mat, membrane hoop tension failure of the concrete cylinder, and bending failure of the equipment and personnel hatches).

The latter SMA study concluded that the best estimate median limiting pressure capacity of the containment was approximately 57.8 psig. The pressure capacity that was exceeded with 95% frequency, considering only the inherent randomness around the median, was 46.0 psig. The pressure capacity that was exceeded with 95% frequency at a 95% confidence level, considering both the inherent randomness around the median and the uncertainty in the median itself, was 36.0 psig. Therefore, based on the two SMA studies and the CLASIX analyses described above, it is believed that the containment structure could maintain its integrity during postulated hydrogen deflagration events resulting from a degraded core accident.

B. Equipment

Attachment 2 to Reference (20) states that the TVA Equipment Survivability Report (ESR), which was submitted as Attachment 4 to Reference (16), is conservative for application to the Donald C. Cook Nuclear Plant. The TVA ESR discusses equipment response to CLASIX calculated containment temperature transients, where the equipment temperature was evaluated with the HEATING5 computer code. The TVA ESR also discusses confirmatory testing at TVA's Singleton Materials Engineering Laboratory on the survivability of exposed incore thermocouple cable and hot and cold leg Resistance Temperature Detector (RTD) cables in the lower compartment. Additional topics which are covered in the ESR include the applicability of Wyle Laboratories environmental qualification tests of electrical cable splice assemblies, and the Acurex Corporation equipment survivability tests described in Reference (8).

The issue of equipment survivability is presently under review, however, to ensure the applicability of previous TVA and Duke Power Company work to the Donald C. Cook Nuclear Plant hydrogen combustion and control program. We have retained Westinghouse/Offshore Power Systems to help answer certain NRC staff questions on this issue.

Additionally, it is noted that AEPSC staff met with NRC staff in Bethesda, Maryland, on September 13, 1983, in order to discuss the status of the Donald C. Cook Nuclear Plant hydrogen combustion and control program. At that meeting, we reiterated a statement made in Attachment 1 to Reference (19) regarding the survivability of the Donald C. Cook Nuclear Plant air return/hydrogen skimmer system fans. At the present time, Westinghouse/Offshore Power Systems is conducting a review of this issue in order to determine if the fans or any components of the fans will require redesign and, if so, to estimate the extent of the work required. Part of this project will include defining the parameters to which the fan should be designed for degraded core accident considerations.

Once the Westinghouse/Offshore Power Systems reviews are performed and AEPSC staff have had an opportunity to evaluate the review findings, we will then make our recommendations regarding suggested remedial action, if any, that is required. The recommendations will not only address equipment design changes, but also perhaps explore the possibility of rerouting of the reactor vessel head and pressurizer high point vent system to achieve a design configuration more consistent with the Sequoyah and McGuire Nuclear Plants.

V. Conclusions

AEPSC has designed a Distributed Ignition System for the Donald C. Cook Nuclear Plant. The DIS is expected to mitigate the consequences of a degraded core accident involving the generation of large amounts of hydrogen; this is accomplished via controlled ignition of the hydrogen near the lower flammability limit. The controlled ignition devices are thermal igniters utilizing GMAC-7G glow plugs. The DIS has been designed to be redundant, is expected to remain operational in a post-accident environment, can be actuated from the main Control Room, and is distributed throughout containment in order to handle all regions of concern. Additionally, the DIS components have been mounted to seismic standards for an added level of safety.

The containment structure has been analyzed to determine the ultimate limiting pressure capability. Studies performed with the CLASIX computer program indicate that hydrogen deflagration loadings will not result in containment integrity failure. Furthermore, detonations are considered unrealistic for an ice condenser containment due to the lack of an initiation energy source, the lack of geometrical confinement, and the lack of a rich hydrogen mixture.

Equipment survivability during hydrogen deflagrations has previously been evaluated by TVA and the Duke Power Company during the licensing processes for the Sequoyah and McGuire Nuclear Plants, respectively. In general, it is believed that these evaluations can be extended to the Donald C. Cook Nuclear Plant; however, we have retained Westinghouse/Offshore Power Systems to assist us in determining whether additional work needs to be performed. We are also investigating the possibility of rerouting the Reactor Coolant System high point vent system to discharge to the lower volume to provide a system more consistent with designs by TVA and Duke Power Company.

Upon resolution of certain issues relating to equipment and fan survivability, it is expected that the DIS will constitute the final hydrogen combustion and control system for the Donald C. Cook Nuclear Plant. The DIS can then be expected to perform its intended design function (i.e., to reliably ignite lean hydrogen mixtures near the lower flammability limit) with adequate safety margins.

Table I

IGNITER ASSEMBLY LOCATIONS*

Assembly Number	Elevation	Compartment/Area
A-1	708'	Ice Condenser Upper Plenum
A-2	709'	Ice Condenser Upper Plenum
A-3	709'	Ice Condenser Upper Plenum
A-4	709'	Ice Condenser Upper Plenum
A-5	709'	Ice Condenser Upper Plenum
A-6	710'	Ice Condenser Upper Plenum
A-7	709'	Ice Condenser Upper Plenum
A-8	686'	Inside #1 Steam Generator Enclosure
A-9	686'	Inside #2 Steam Generator Enclosure
A-10	686'	Inside #3 Steam Generator Enclosure
A-11	686'	Inside #4 Steam Generator Enclosure
A-12	686'	Inside Pressurizer Enclosure
A-13	659'	Outside #1 Steam Generator Enclosure
A-14	662'	Outside #2 Steam Generator Enclosure
A-15	662'	Outside #3 Steam Generator Enclosure
A-16	662'	Outside #4 Steam Generator Enclosure
A-17	662'	Outside Pressurizer Enclosure
A-18	647'	Primary Shield Wall
A-19	648'	Primary Shield Wall
A-20	648'	Primary Shield Wall
A-21	648'	Primary Shield Wall
A-22	641'	Primary Shield Wall
A-23	648'	Primary Shield Wall
A-24	631'	East Fan/Accumulator Room
A-25	629'	East Fan/Accumulator Room
A-26	629'	West Fan/Accumulator Room
A-27	634'	West Fan/Accumulator Room
A-28	618'	Pressurizer Relief Tank Vicinity
A-29	760'	Upper Volume Dome Area
A-30	760'	Upper Volume Dome Area
A-31	760'	Upper Volume Dome Area
A-32	748'	Upper Volume Dome Area
A-33	748'	Upper Volume Dome Area
A-34	748'	Upper Volume Dome Area
A-35	620'	Instrument Room
B-1	709'	Ice Condenser Upper Plenum
B-2	709'	Ice Condenser Upper Plenum
B-3	709'	Ice Condenser Upper Plenum
B-4	709'	Ice Condenser Upper Plenum

[illegible]

Table I (continued)

IGNITER ASSEMBLY LOCATIONS*

Assembly Number	Elevation	Compartment/Area
B-5	709'	Ice Condenser Upper Plenum
B-6	709'	Ice Condenser Upper Plenum
B-7	709'	Ice Condenser Upper Plenum
B-8	686'	Inside #1 Steam Generator Enclosure
B-9	686'	Inside #2 Steam Generator Enclosure
B-10	686'	Inside #3 Steam Generator Enclosure
B-11	685'	Inside #4 Steam Generator Enclosure
B-12	682'	Inside Pressurizer Enclosure
B-13	662'	Outside #1 Steam Generator Enclosure
B-14	659'	Outside #2 Steam Generator Enclosure
B-15	659'	Outside #3 Steam Generator Enclosure
B-16	659'	Outside #4 Steam Generator Enclosure
B-17	659'	Outside Pressurizer Enclosure
B-18	642'	Primary Shield Wall
B-19	637'	Primary Shield Wall
B-20	636'	Primary Shield Wall
B-21	636'	Primary Shield Wall
B-22	637'	Primary Shield Wall
B-23	645'	Primary Shield Wall
B-24	630'	East Fan/Accumulator Room
B-25	629'	East Fan/Accumulator Room
B-26	623'	West Fan/Accumulator Room
B-27	634'	West Fan/Accumulator Room
B-28	618'	Pressurizer Relief Tank Vicinity
B-29	760'	Upper Volume Dome Area
B-30	760'	Upper Volume Dome Area
B-31	760'	Upper Volume Dome Area
B-32	748'	Upper Volume Dome Area
B-33	748'	Upper Volume Dome Area
B-34	748'	Upper Volume Dome Area
B-35	620'	Instrument Room

*Note: Locations given are for Donald C. Cook Nuclear Plant Unit No. 2 and are typical for Donald C. Cook Nuclear Plant Unit No. 1. Igniter assembly numbers utilizing the prefix "A-" are Train "A" igniters; igniter assembly numbers utilizing the prefix "B-" are Train "B" igniters.

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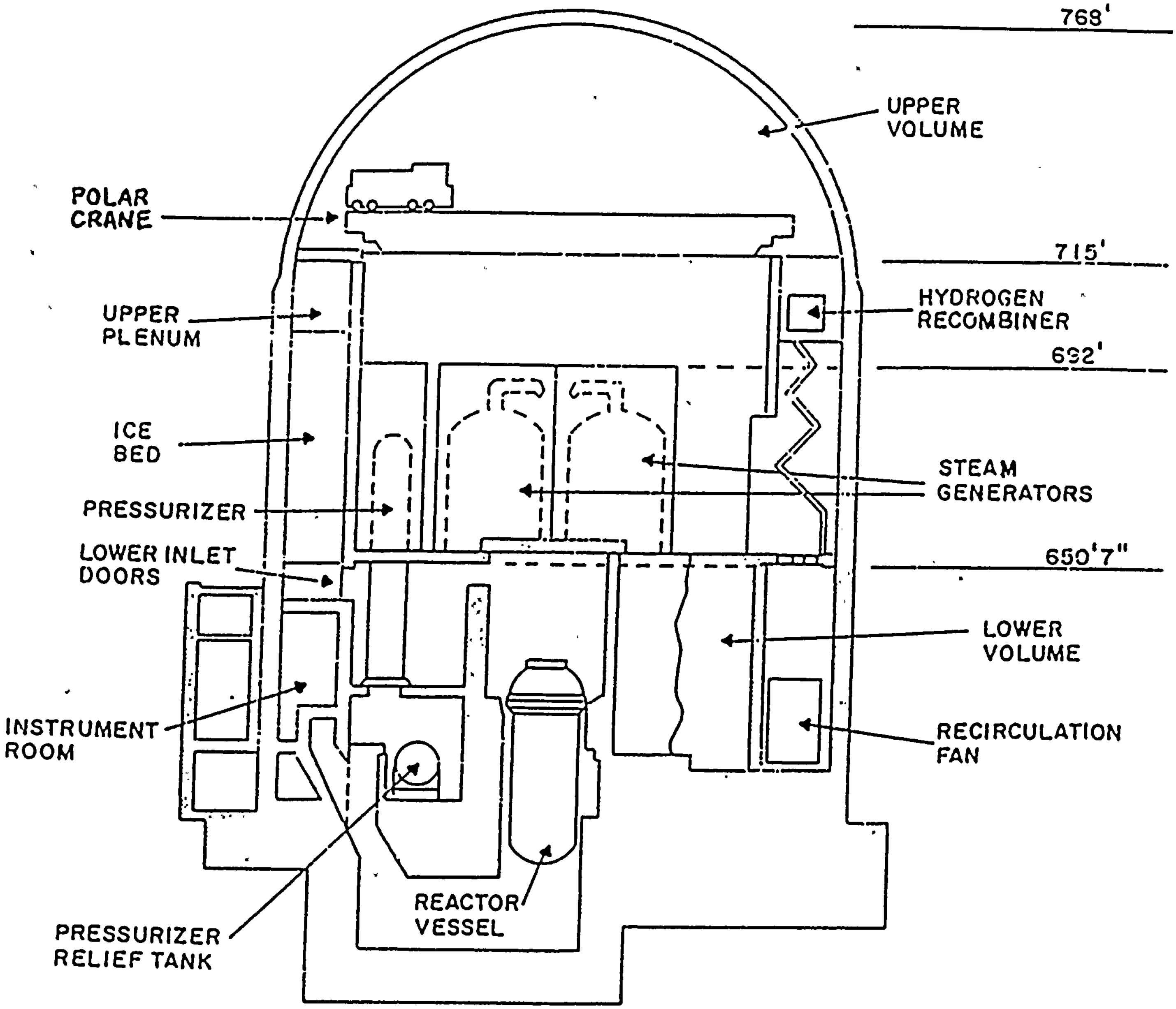


768'
UPPER VOLUME
POLAR CRANE
715'
HYDROGEN RECOMBINER
UPPER PLENUM
692'
ICE BED
STEAM GENERATORS
PRESSURIZER
LOWER INLET DOORS
650'7"
LOWER VOLUME
INSTRUMENT ROOM
RECIRCULATION FAN
REACTOR VESSEL
PRESSURIZER RELIEF TANK

Figure 1.

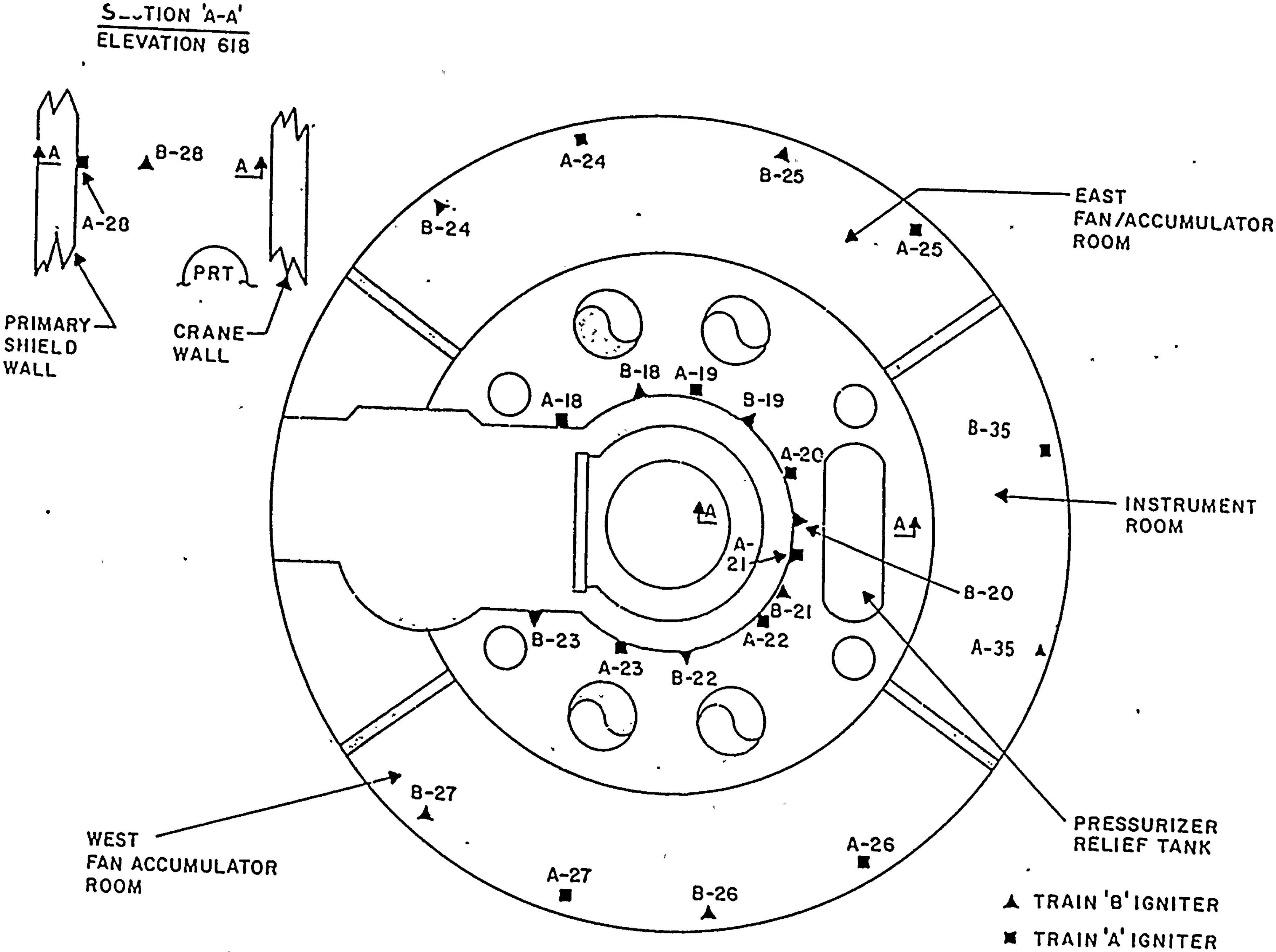
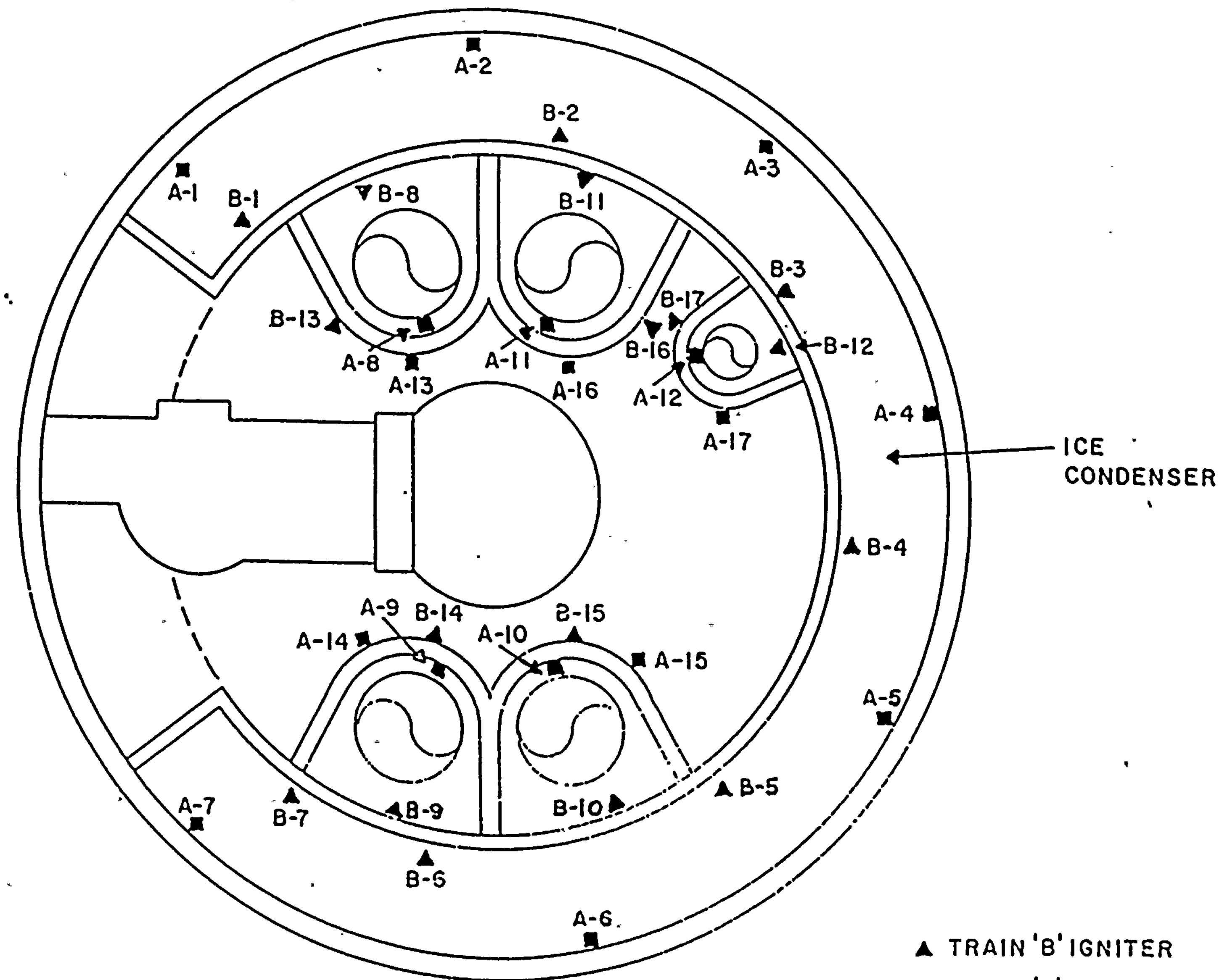


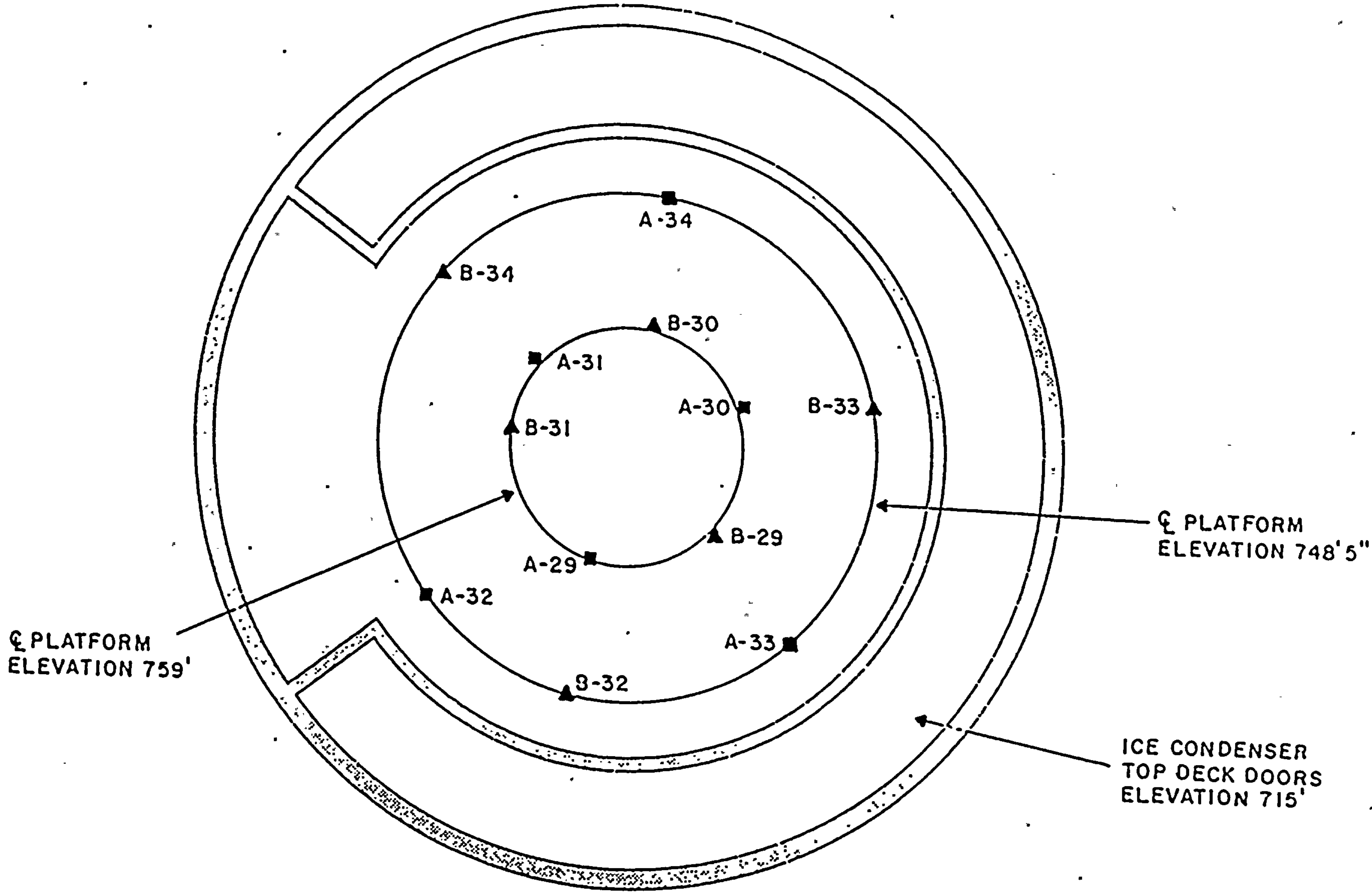
Figure 2.

D.C. COOK UNIT NO. 2
CONTAINMENT PLAN BELOW
ELEVATION 652'7"



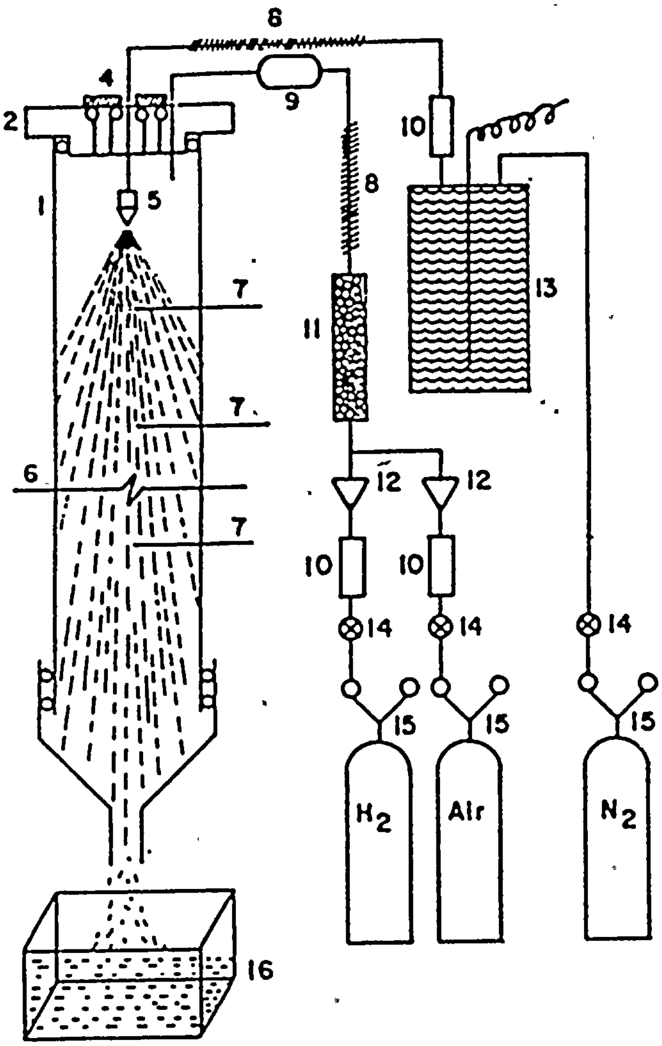
D.C. COOK UNIT NO. 2
CONTAINMENT PLAN ABOVE
ELEVATION 652'7"

Figure 3.



D.C. COOK UNIT NO. 2
CONTAINMENT PLAN ABOVE
ELEVATION 715'

Figure 4.



1. Inerting Tube (Plexiglas)
2. Vent & Plumbing Support Cap
3. Funnel
4. Vent Disks (A total of four)
5. Spray Nozzle
6. Electrodes
7. Thermocouple Probes
8. Heating Tape
9. Flash Arrester
10. Rotometers.
11. Hydrogen-Air Mixer
12. Check Valves
13. Hot Water Tank
14. Solenoid Valves
15. Pressure Regulators
16. Water Collector

Figure 5.
Hydrogen-Water Fog Inerting Experimental Setup

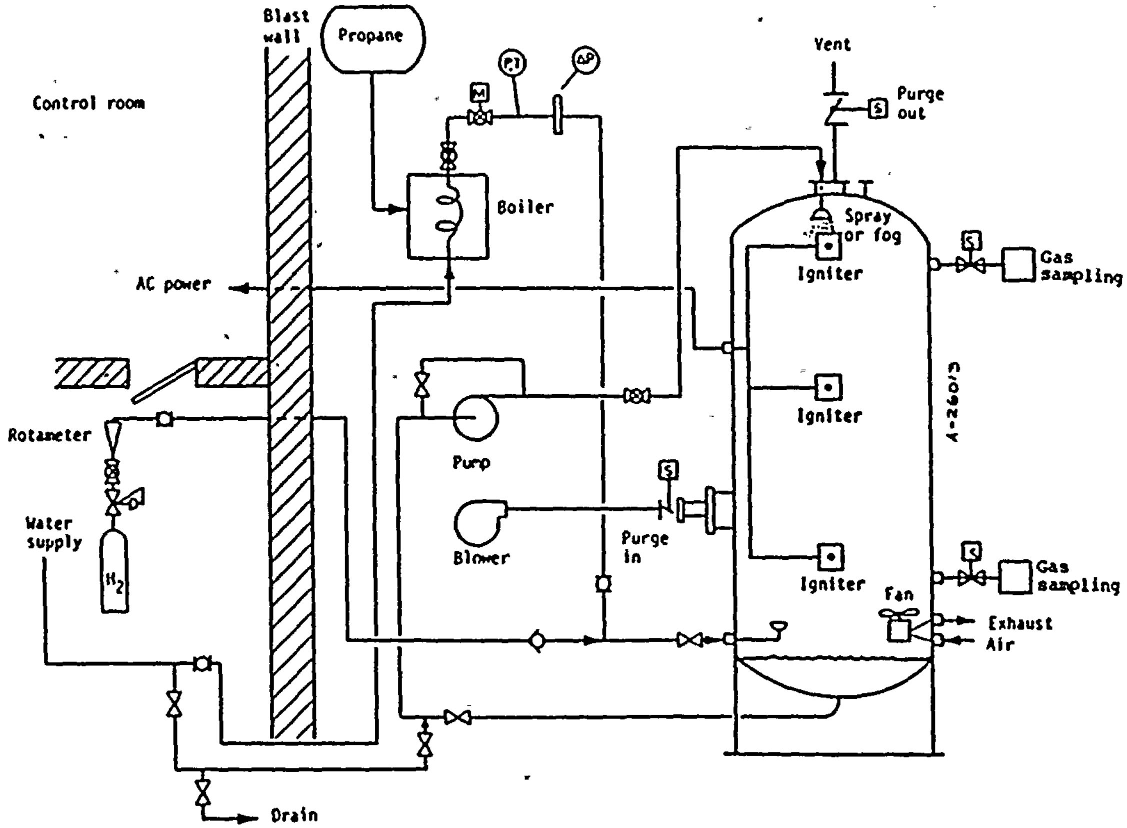


Figure 6. Hydrogen Control Facility Mechanical Schematic

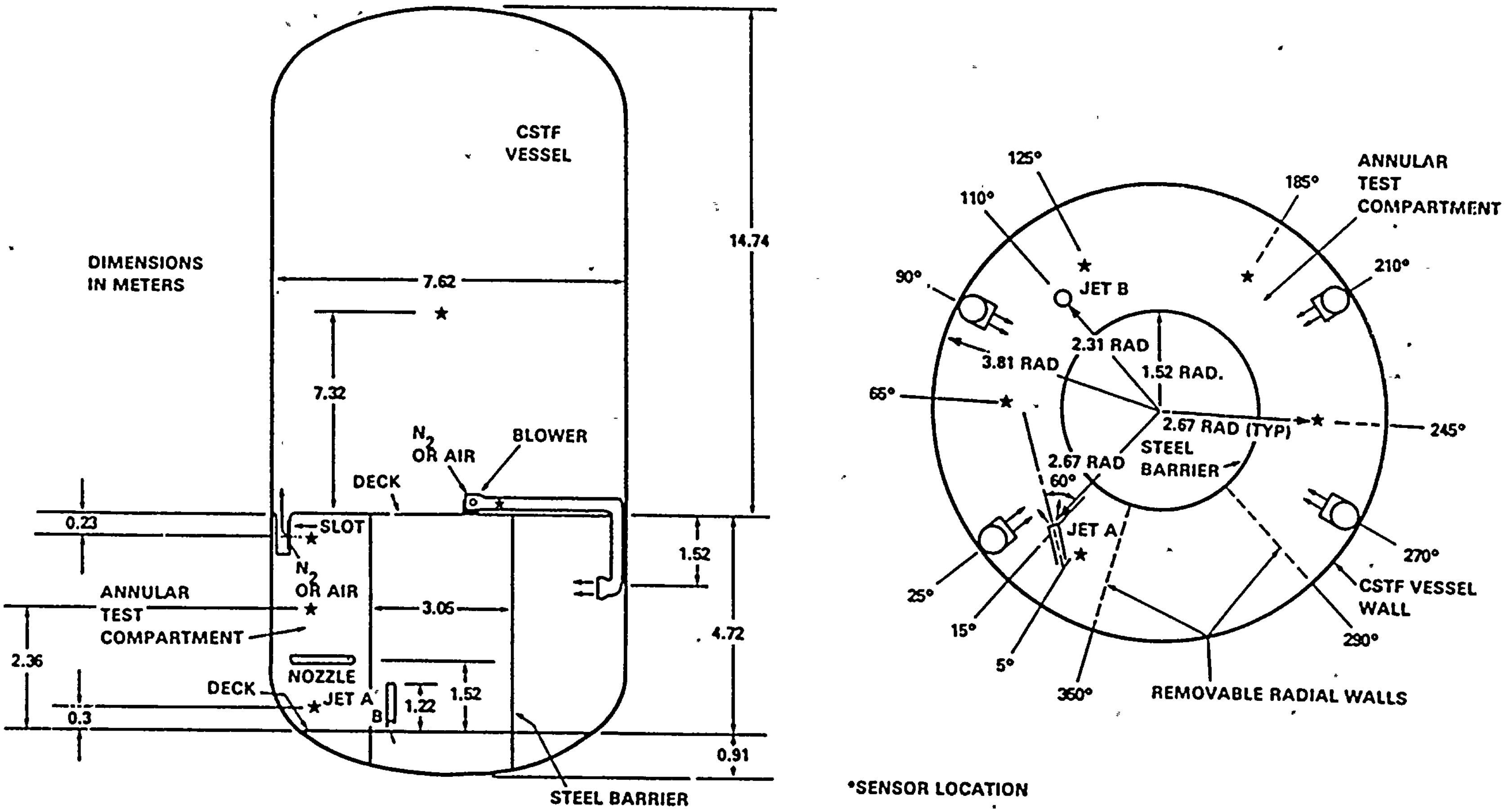


Figure 7.
Test Compartment Geometry

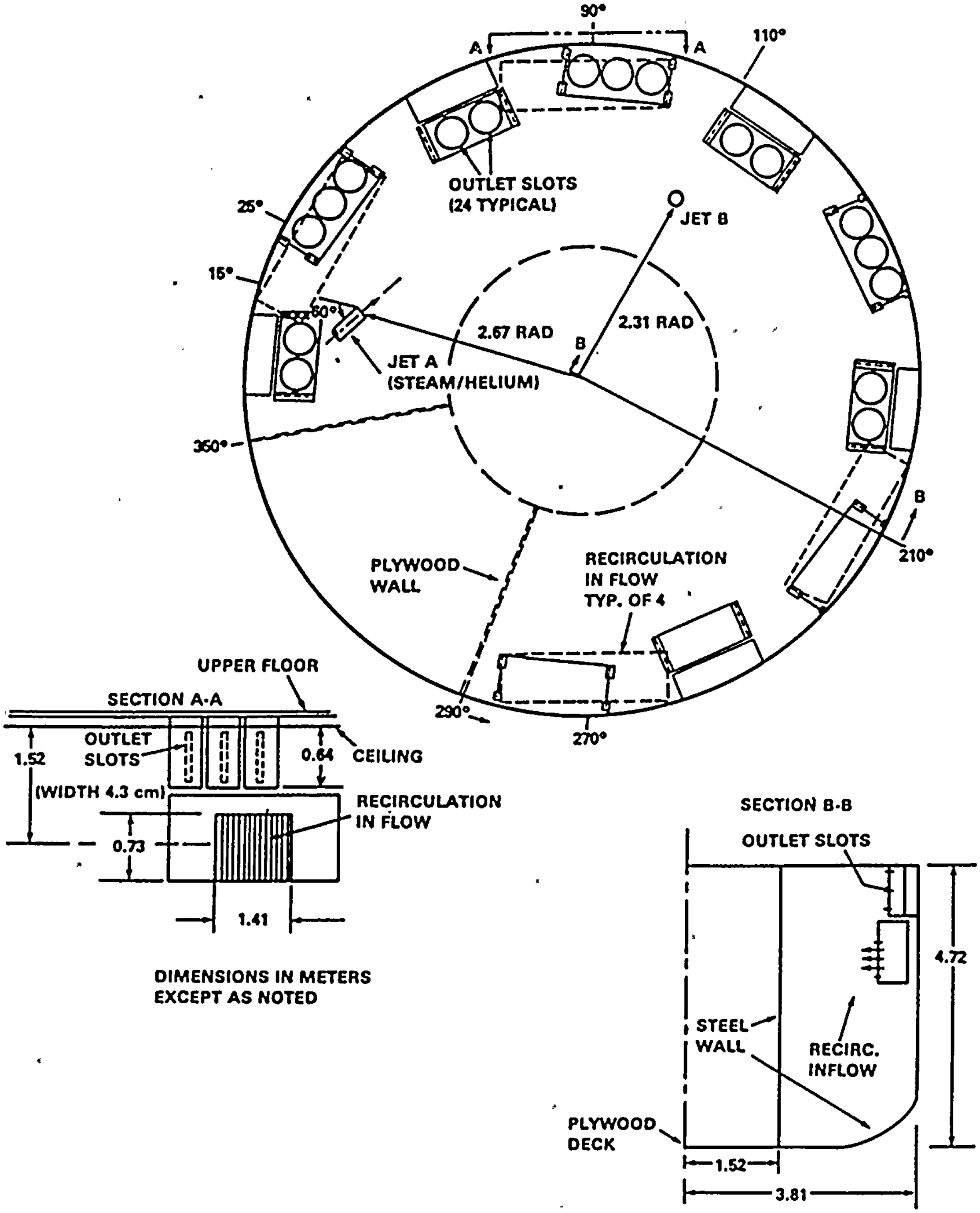


Figure 8.

Test Compartment Air
Recirculation Details