RESOLUTION OF EQUIPMENT SURVIVABILITY ISSUES FOR THE SEQUOYAH NUCLEAR PLANT

TENNESSEE VALLEY AUTHORITY

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NOTE: All items surrounded by asterisks (*) in section 2.3 and figure 2.3-6 are proprietary to Westinghouse and must be treated as such.

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1.0 Introduction

In January 1981 the Operating License for Sequoyah unit 1 was amended with the following additions:

(a) TVA shall amend its research program on hydrogen control measures to include, but not limited to, the following items:

   (i) Improved calculational methods for containment temperature and ice condenser response to hydrogen combustion and local detonation.

   (ii) Confirmatory tests on selected equipment exposed to hydrogen burns.

   (iii) New calculations to predict differences between expected equipment temperature environments and containment temperatures.

   (iv) Evaluate and resolve any anomalous results from the ongoing test program.

(b) The results of these investigations will be provided to the staff for review in May 1981. A schedule for confirmatory tests beyond this date will be provided consistent with the requirement to meet the January 31, 1982, deadline, Section (22)D(2) of the license.

In addition, the NRC issued Supplement No. 4 to the Sequoyah Nuclear Plant Safety Evaluation Report in January 1981. It is the purpose of the present submittal to address the May 1981 Operating License conditions and unresolved items in the Safety Evaluation Report through identification of key equipment, evaluation of that equipment by analysis and experiment, and demonstration of its survivability for hydrogen burn environments.

2.0 Resolution of Operating License Conditions

2.1 Containment Temperature Calculations

Containment pressure and temperature responses for a base case set of assumptions and for several additional sensitivity cases were analyzed using the original CLASIX code and submitted beginning with Volume II of the Sequoyah Core Degradation Program Study, September 2, 1980. Containment pressures following hydrogen combustion calculated by CLASIX were demonstrated to be within the ultimate capacity of the containment. Containment atmospheric temperatures as calculated by CLASIX were believed to be overly conservative for use in assessing the survivability of key equipment due to the absence of passive heat sinks in the code. Alternate calculational techniques were then employed to more realistically account for atmospheric energy removal to walls and other structures. These results were submitted during December 1980 and January 1981.

A condition was placed on the Sequoyah unit 1 Operating License in January 1981 to require "improved calculational methods for containment temperature and ice condenser response to hydrogen combustion . . ." The CLASIX code has since been modified to satisfy this condition, and additional containment pressure and temperature analyses have been performed. The modifications include the addition of passive heat sinks, heat transfer correlations, and radiant heat transfer to more realistically model the containment energy transport. In addition, a separate volume node was added to represent the ice condenser upper plenum. A head-flow correlation was also included for the air return fan model. All of these changes contribute to a more accurate representation of ice condenser containment processes.

Further changes were made in the implementation of the code and in some of the original input parameters. Originally, the initial blowdown phase of the transient was analyzed with the LOTIC code. The output from this code was then used as initial condition inputs for the CLASIX code analysis beginning at the degraded core phase. Now the modified CLASIX code is used to analyze the entire transient. The original blowdown associated with the small break LOCA with no ECCS injection (S_2D) was used for the modified analyses. The reduced ice mass currently allowed by the Technical Specifications was input in the runs with the modified code. In addition, more conservative burn times and propagation delay times were used for several compartments.

Three cases have been analyzed for Sequoyah using the modified CLASIX code. In the first case, it was assumed that hydrogen ignition would occur at 10 volume percent and result in complete combustion. The second case assumed ignition at 8 volume percent and 85% burn completeness, and the third case assumed ignition at 6 volume percent and 60% completeness. Pressure and temperature profiles for each of the three cases are shown in order in figures 2.1-1 through 2.1-30. Results are summarized in table 2.1-1. Note that the peak calculated pressures for each case are below the containment design pressure and that the calculated temperatures are markedly lower than results for similar cases obtained before with the original CLASIX code.

In the analyses performed in 1980 with the original version of CLASIX, the assumption of hydrogen ignition at 10 volume percent with 100% burn completeness was selected as the base case that conservatively modeled the probable behavior for Sequoyah. Since that time, continuing research efforts, literature searches, and discussions with experimenters and recognized combustion experts have led to the assumptions of 8 volume percent and 85% burn completeness as the new base case. A major basis for these selections is the experimental data for ignition concentrations and associated burn completeness for turbulent hydrogen-air mixtures presented by Hertzberg (see "Flammability Limits and Pressure Development in H_2-Air Mixtures," PRC Report No. 4305, January 1981). In addition, test data from the Fenwal combustion experiments show significant burning at even lower hydrogen concentrations. Therefore, TVA believes that the new base case of 8 volume percent ignition with 85% burn completeness conservatively represents the physical processes that would occur in the Sequoyah containment for the assumed accident scenario.

Using these assumptions, the modified CLASIX code may be used to calculate both pressure responses for use in evaluating containment structural capability and temperature responses for use in evaluating key equipment survivability. Therefore, the modified CLASIX code represents an "improved calculational method for containment temperature and ice condenser response to hydrogen combustion."

2.2 Containment Local Detonations

In our initial consideration of controlled combustion as a method of hydrogen mitigation, TVA evaluated the potential for causing local detonations. An investigation of the containment postaccident flow patterns and physical structures revealed no apparent locations where a reasonable mechanism for local detonation existed. Details supporting this conclusion were documented in our submittal of Volume II of the Sequoyah Core Degradation Program Study dated September 2, 1980, and supplemented in our revision of December 15, 1980, to that document in response to NRC questions on the issue.

However, also in response to a specific NRC question, TVA developed and submitted on December 1, 1980, a representative pressure profile that could result from a hypothetical local detonation. A more detailed basis for our choice of pulse shape and magnitude for this postulated local detonation was submitted on December :7, 1980.

A condition was placed on the Sequoyah unit 1 Operating License in January 1981 to require "improved calculational methods for containment . . . response to hydrogen combustion and local detonation." Since that time, TVA has evaluated the effects on structures and equipment of the postulated pressure profile presented in our December 1, 1980, submittal. Attachment A provides the detailed structural evaluation of the containment shell response and concludes that there is a factor of safety of three against yield. Considering the rapid attenuation of the effects of local detonation with distance and the physical separation of equipment to avoid local hazards, there is reasonable assurance that at least one redundant component would remain functional

Since the operating license condition was mandated, TVA has continued to actively pursue investigations into the potential for local detonation under circumstances when controlled ignition would be used to mitigate a TMI-type event. Review of the pertinent literature, consultation with recognized experts, and scrutiny of the various hypotheses that have been postulated in the interim period have led us to conclude that no location in the containment has been identified with a reasonable mechanism to experience a local detonation. There are a number of ingredients of which at least some must be present simultaneously for a detonation to occur. These factors will be addressed in the following discussion as they apply to each particular area of the containment.

Concentration

A primary requirement for initiation of a local detonation is a detonable concentration of hydrogen. The lower detonable limit of hydrogen in air is generally given as 18 volume percent and numerous researchers have resorted to using even higher stoichiometric fuel mixtures to enhance the potential for detonation in their experiments. It is well known and was demonstrated by TVA's experiments at Fenwal that thermal igniters are capable of burning much lower concentrations of hydrogen (aproximately 6 volume percent). Therefore, the igniters should certainly be able to maintain the overall containment hydrogen concentration at around 8 volume percent, well below even the lower detonable limit. Even if the overall concentration would be maintained at 8 volume percent, any potential local concentration significantly above this level should be identified. Each of the general containment areas has been examined for higher hydrogen concentrations due to a source term or concentrating mechanism as discussed below.

All of the potential hydrogen sources for the containment are located in the lower compartment. An initial area of attention must be the hydrogen-steam jet itself as it issues from the reactor coolant system. The jet, whether from a pipe break or the pressurizer relief tank rupture disk, will rapidly entrain air. TVA addressed this phenomenon in its December 1, 1980, response to NRC question 16. In addition, Duke Power, in Volume 4, Section 7.9, of its docketed "Analysis of Hydrogen Control Measures at McGuire Nuclear Station," provided an analysis by Lewis and Karlovitz. Based on this scenario, they concluded that the formation of a detonable mixture was improbable. Away from the immediate vicinity of the release, the hydrogen would then be thoroughly mixed throughout the lower compartment by the action of the air return fans and would be ignited by the

IDIS once a flammable concentration was reached. In addition, the volumetric mixing that would occur in the lower compartment would effectively moderate any sudden large releases of hydrogen from immediately entering the ice condenser. Mixing in the steam generator and pressurizer enclosures of the lower compartment was also addressed in our response of December 1, 1980, to NRC question 16. There we concluded that these enclosures would gradually increase in hydrogen concentration up to the overall level in the lower compartment but that there was not a significant concentrating mechanism present. The dead-ended regions of the lower compartment, following the initial blowdown phase, would be constantly swept by the action of the fans returning air to the lower compartment and preventing any buildup of hydrogen. Neither is a source of hydrogen present in the dead-ended regions.

In the upper compartment, the diffuse effluent from the ice condenser would be further mixed in the turbulent atmosphere induced by the containment sprays. There are no sources or concentrating mechanisms characteristic of the upper compartment.

Special attention has been focused by TVA and others on the concentrating mechanism that would occur in the ice condenser due to the condensation and removal of any steam accompanying the inflow from the lower compartment. We have addressed this issue on several occasions, including our response of

December 1, 1980, to NRC question 4 and again in our response of April 14, 1981. We have stated that by the time significant concentrations of hydrogen could be entering the ice condenser, the lower compartment steam fraction would have dropped enough to permit ignition to occur and reduce the hydrogen concentration in the lower compartment. Similarly, the effect of stripping this steam would be reduced and combustion of the flammable mixture could occur in the upper plenum. The presence of these two factors prevent detonable (greater than 18 volume percent) mixtures from occurring in the upper plenum of the ice condenser. However, even if the lower compartment were postulated to be nonflammable or inerted with steam, Lewis and Karlovitz have testified that since hydrogen would enter the upper plenum region so that it would become flammable in a gradual and not stepwise manner, the mixture would ignite before it became detonable and the flame front would then propagate back to that location where the rising mixture would just sustain combustion. No detonable concentration could exist upstream of this point due to the nonflammability or steam inerting of the mixture and no detonable concentration would exist downstream because of the combustion that had taken place in the flame front.

Therefore, after examining each of the containment areas for hydrogen sources and concentrating mechanisms, we believe that based on the postaccident circulation patterns and the expected performance of the igniters, no detonable local concentrations of hydrogen would exist.

Geometry

Another requirement also necessary for local detonation to occur which will be discussed next is an appropriate physical geometry. Experimental setups designed to produce transition to detonation are usually long cylindrical shock tubes which may have sizeable obstacles along the axis. Each of the containment regions is examined in the following for potentially detonable geometries.

Both the lower and upper compartments are large open volumes unsuited for the local confinement required. Similarly, the compartments in the dead-ended regions of the lower compartment are each relatively open.

However, the ice basket geometry in the ice condenser has been suggested as a likely location for the transition to detonation phenomenon. Superficially, this may appear to be so, but closer examination of the construction reveals this not to be the case. The channel surrounded by each set of four ice baskets is actually open on all four sides between the baskets. In fact, the ice basket design effectively allows cross flow between channels to prevent flow imbalances and maldistribution in ice melting rates. The melting of ice as the accident progressed would only open up the ice basket flow paths even more. Therefore, the sideways confinement in the ice bed is limited and is unlike an experimental shock tube which is completely confined radially.

In addition, the upper plenum has also been proposed as having a geometry lending itself to the transition to detonation phenomenon because of confinement and obstacles. TVA has addressed this region in some detail in our response of April 14, 1981. In the circumferential direction, the upper plenum is bounded on the sides by the containment and the crane wall. However, also in this direction the plenum is bounded above and below by door panels which open to allow flow in from the ice condenser and out to the upper compartment. Upon initiation of a burn in the upper plenum, the top deck blanket doors above would immediately begin to open at a very low pressure, thus precluding the necessary geometric confinement. The upper plenum does have air handling units mounted on the side walls which represent obstacles in the circumferential direction. However, the units are staggered and never occupy more than 10 percent of the available cross sectional area. Therefore, the upper plenum has neither the radial confinement or significant wake-producing obstacles necessary to the transition to detonation phenomenon.

Velocity

A further component that has been suggested as causing a transition to detonation in the ice condenser or upper plenum is a relatively high velocity jet that can promote turbulence when suitable obstacles are encountered. The flows up through the ice bed are relatively slow (on the order of one ft/sec) and are not capable of creating the amount of turbulence required to initiate a detonation. In addition, once the flows reach the upper plenum, they slow further and would not provide an initial impetus around the plenum since they are moving up toward the top deck blanket.

Ignition Strength

One final point in relation to the potential to promote a local detonation is that thermal igniters, while capable ignition sources for flammable mixtures, are known to be weak detonation sources when compared to sparks or other initiators. This opinion is held by Strehlow who maintained to the NRC Office of Policy Evaluation in a report dated January 9, 1981, that ". . . properly located and functioning glow plug igniters would reduce the probability of a burn leading to a transition to detonation to virtually zero."

An ongoing part of our investigations into the potential for local detonation at Sequoyah is the research program TVA has established in cooperation with Duke Power and American Electric Power through the Electric Power Research Institute. At the Hanford Engineering Development Laboratory, tests will be conducted to study the mixing processes and potential for pocketing during a hydrogen-steam blowdown in a simplified large scale model of an ice condenser containment. At the Whiteshell Nuclear Research Establishment, tests will be conducted on detonable mixtures of hydrogen in various pipe and sphere geometries with both induced turbulence and obstacles. The Whiteshell tests should be completed by October 1, 1981, and the Hanford studies by November 1, 1981. Further details on these tests were submitted by TVA on May 15, 1981, and are updated in our quarterly report series.

In summary, TVA has not been able to identify any locations in the Sequoyah containment where use of igniters would promote local detonation. However, in response to NRC questions, we postulated a representative pressure profile and have shown by analysis that the effects on the containment are acceptable. In addition, we are continuing to pursue research into the potential for local concentrations of hydrogen and the effects that might result.

2.3 Equipment Temperature Analyses

An evaluation of the effects of hydrogen burns on key equipment inside containment is required to show that deliberate ignition of hydrogen is an acceptable method of protecting against events that result in significant hydrogen generation. In previous submittals, TVA has supplied data on the expected thermal response of equipment for (a) short durations by using adiabatic flame temperatures in conjunction with radiation and natural convection heat transfer coefficients and (b) the long-term heatup based on an energy balance between the various heat removal features in the containment and the energy released. These approaches were taken at that time due to the lack of methods to reasonably predict the containment atmospheric temperature response to a hydrogen burn. While these methods are valid, the more straightforward approach of using an atmospheric temperature profile to evaluate equipment survivability is now available as a result of the modifications to the CLASIX code discussed in section 2.1.

In the analyses discussed below, these modified CLASIX atmospheric temperature profiles were used. The analyses were run from just before the first burn until well after all burns were completed to allow for the incremental heatup that results from each burn and to establish the cooldown rate at the end of the transient. Each piece of equipment analyzed was initially assumed to be uniform in temperature at the highest value predicted by CLASIX prior to the first burn.

Figure 2.3-1 provides the lower compartment atmospheric temperature profile calculated with the original version of CLASIX and our estimate of gross heat sink temperatures originally submitted in December 1980. The modified version of CLASIX for the S_2D base case described in section 2.1 being analyzed shows five burns in the lower compartment and 39 burns in the upper plenum. Figures 2.3-2 and 2.3-3 provide the temperature profile for each region. Burns were not predicted to occur in the dead-ended or upper compartments. The peak temperature in the lower compartment is 984° F, and 1192° F is the peak in the upper plenum. The temperature peaks in the upper plenum are very brief due to the small quantity of hydrogen consumed in each burn (15-20 pounds), the large vent area available out of the upper plenum, and the relatively cold air (less than 100°F) exiting the ice bed. Figure 2.3-4 is a segment of figures 2.3-2 and 2.3-3 that shows with more definition the duration of the high temperature peaks and the time between burns in both the upper plenum and lower compartment. The figure is for the period of time in which lower compartment burning occurs, but is representative of behavior throughout the entire transient.

The pieces of equipment chosen to be analyzed using the CLASIX temperature profile were a transmitter case, an igniter assembly, and a cable in conduit. This equipment, along with exposed thermocouple and RTD cable, represents equipment that due to location, construction, and size, would be most sensitive to the effects of hydrogen burns. The components chosen for analysis have an outside surface of steel or cast iron and are therefore amenable to analysis since surface degradation is not a concern. The exposed thermocouple and RTD cables were tested to provide assurance that effects such as surface degradation were properly accounted for (see section 2.4 for a discussion of the confirmatory tests). Even though the transmitter is located in one of the dead-ended compartments where no burns are predicted to occur, it was analyzed using the lower compartment temperature profile. The igniter box was analyzed using the upper plenum temperature profile. The cable in conduit was analyzed using both profiles. Heat transfer coefficients used for the lower compartment equipment were 10 percent greater than the values used in CLASIX during a burn for the steel heat sinks. As mentioned earlier, one of the modifications to CLASIX was the incorporation of radiative heat transfer, so radiation to the equipment was considered. In the upper plenum, two cases were run. The first used heat transfer coefficients calculated as in our December 1980 submittal on the short-term temperature response of equipment. This heat transfer coefficient was a composite of radiation and material convection. The radiation portion was based on the flame and gas having an emissivity of 1.0. The actual value for the emissivity of air is approximately 0.1, where there is little steam in the air as would be the case in the ice condenser upper plenum. The second upper plenum case used the maximum heat transfer coefficient of 8.5 BTU/hr-ft^2-^{o}F presented in our original short-term thermal response submittal. This value is conservatively based on a peak temperature of 2350^{o}F instead of 1192^{o}F which is the maximum calculated upper plenum temperature. Since the second upper plenum case produced higher equipment temperatures, results from this case have been used in the evaluation of the equipment as discussed below.

Transmitter

Results of the analysis of the transmitter case are shown in Figure 2.3-5. The maximum temperature in the case is 246^{o}F. This is well below the MSLB-LOCA qualification test temperatures. Figure 2.3-6 shows the test profile originally used to functionally qualify the transmitters for design basis accidents. The test profile shows temperatures of * * or greater for * * with the temperature being ramped down to * * over the next * *. Westinghouse report "Qualification Report of Barton Pressure and Differential Pressure Transmitters" shows internal transmitter component temperatures in excess of * * were obtained to show adequate qualification. Based on the Westinghouse qualification report and the temperatures calculated in our analysis, we conclude the transmitters will survive a series of hydrogen burns.

Cable in Conduit

Figure 2.3-7 provides the thermal response of a cable in conduit to the lower compartment temperature profile. Figure 2.3-8 shows the results when the upper plenum profile is used. The cable has a stranded copper conductor center surrounded by insulation. There is an outer layer of PVC which provides protection for the insulation during storage, shipping, and pulling. Testing at Singleton Laboratory (see section 2.4) showed that degradation of the PVC does not occur until the cable temperature exceeds 300°F. In addition, the tested electrical insulation showed no damage for temperatures between 400 and 500°F. In the analysis, standard half-inch conduit was used and the cable was assumed to be in contact with the inside of the metal conduit. The analysis showed the maximum surface temperature of the cable was 280°F, and the centerline temperature was 265°F. Based on the calculated temperatures compared to the test data, the cable in conduit can be expected to survive hydrogen burns associated with a degraded core event.

Igniter Assembly

Figure 2.3-9 shows the results of the analysis of the igniter box to the upper plenum temperature profile. The igniter box model consisted of the box, transformer, cable, and air spaces. The heat losses from the transformer were modeled as a heat source inside the box. The analysis showed the box interior air temperature was 240°F, the cable temperature was 208°F, and the transformer core temperature was 206°F. The transformer is designed to operate at a maximum winding temperature of 428°F. Based on the temperature calculated in the analysis, it is concluded the igniter box will survive repeated hydrogen burns.

Air Return Fan Survivability

TVA addressed air return fan survivability in our submittal of December 17, 1980. In that submittal, we stated that the fan motors are designed to withstand up to 300°F for four hours in emergency conditions. Hydrogen combustion temperature effects on the fan motors were evaluated based on atmospheric temperature profiles calculated by the original version of CLASIX (without structural heat sinks) for three sensitivity cases where one or more upper compartment burns occurred. The upper compartment temperature only exceeded 300°F in one of these cases and then only for a few seconds. That particular case involved the rapid combustion of 430 pounds of hydrogen in the upper compartment. Based on this assessment, we concluded that the air return fan motors would survive the temperature effects associated with hydrogen combustion. The NRC Sequoyah Nuclear Plant Safety Evaluation Report Supplement No. 4 of January 1981 agreed with TVA's conclusion.

Since our earlier submittal, new analyses have been performed with the modified CLASIX code (including both passive heat sinks and a separate volume representation of the ice condenser upper plenum as described in section 2.1). These analyses have shown that 39 small burns would occur in the upper plenum and that no burns would occur in the upper compartment. The concern has recently been expressed about air return fan survivability during this scenario. The temperature effects on the fan motors during numerous burns in the upper plenum would be less severe than during the upper compartment burn evaluated in our earlier submittal. In this new scenario, the upper compartment temperature does not exceed 160°F since no burns occur there. The upper plenum burns consist of individual burns of about 20 pounds of hydrogen occurring about a minute apart. Not only is this a slower energy addition rate than considered previously, but it would be occurring locally in the upper plenum about 70 feet above the air return fans. The effluent from the upper plenum would be thoroughly mixed in the cooler upper compartment air and would be cooled by the action of the containment sprays before eventually reaching the air return fans. There is no reasonable mechanism for this relatively hot effluent to reach the air return fan inlet plenum without undergoing significant cooling. Therefore, we conclude once again that the air return fan motors would survive the temperature effects associated with hydrogen combustion.

2.4 Confirmatory Equipment Testing

Singleton Laboratory

To address concerns raised about the survivability of the exposed incore thermocouple cables and the hot and cold leg RTD cables located in the lower compartment and the cables which supply power to the igniters located in the upper plenum of the ice condenser, tests have been performed on these cables at TVA's Singleton Laboratory. These tests were designed to confirm that the cables could survive the temperatures to which they would be subjected during a hydrogen burn.

The thermocouple and RTD cables were repeatedly exposed to a high temperature (approximately 1400°F) environment intended to represent the temperature peaks produced in the lower compartment. The temperature profile (figure 2.4-1) used for these tests bounds the results of the modified CLASIX code analysis that assumed ignition occurred at eight volume percent. As can be seen from figure 2.4-1, we believe that the severity of the temperatures used in the test more than compensates for the minor difference in the frequency of the test profile and the actual eight percent burn profile. (The test profile was selected prior to receipt of the base case CLASIX results.)

The power cables for the igniters are not exposed to the containment atmosphere, but are completely enclosed in conduit. Therefore, the cables would not be directly subjected to the temperature peaks produced as a result of the hydrogen burned in the upper plenum of the ice condenser (see figure 2.3-3) or elsewhere in containment. The average temperature of the igniter cable would, of course, increase due to burns in the upper plenum but the conduit would attenuate this increase. A constant temperature test profile was chosen to represent the transient cable environment during the total 40-minute duration of the repeated upper plenum burns predicted by CLASIX. This was done of necessity to avoid simulating each of the temperature peaks. These constant temperature tests were performed for several temperatures up to 700°F for 45 minutes in order to conservatively bound the integrated heat flux that would result during an actual transient test. The 700°F test profile bounds the peak calculated cable temperature of 280°F (see section 2.3 and figure 2.3-8).

Before and after the temperature tests, the cables were each tested to establish the functionality of the cable insulation. These tests consisted of applying 1500V dc for one minute from conductor to conductor and from conductor to shield before and after the cables were subjected to the temperature profile. The value of 1500V dc was chosen because this was the voltage used to test the thermocouple cable before original acceptance from the manufacturer. In addition, each of the test specimens were visually examined for degradation following the temperature tests. Testing details for each cable type are summarized below. No anomalous results were reported.

Thermocouple Cable

The incore thermocouple cables are located in the lower compartment and would be subjected to the five burns shown in figure 2.4-1. To confirm that the thermocouple cable would survive the temperatures produced during the burns, the cable was exposed to the temperature test profile also shown in figure 2.4-1. The test conditions conservatively bound the calculated containment atmospheric conditions, even when scaling effects are considered. This became apparent following the thermocouple cable test because even the measurement thermocouple readings (described below) taken inside the outer jacket of the cable were higher than the peak calculated atmospheric temperature.

The test was conducted in a Lindberg Tube Furnace with a low temperature zone maintained at a constant 300 $\pm$ 10°F and a high temperature zone maintained at a constant 1400 $\pm$ 25°F. The temperatures of the zones were monitored with 20 gage chromel-alumel thermocouples. At the beginning of the temperature test, the cables were placed in a 300°F environment for 60 minutes. At the end of this 60 minute period, the cable was transferred to a 1400°F environment for 30 seconds and then back into the 300°F environment for 170 seconds. The 1400°F for 30 seconds followed by the 300°F for 170 seconds cycle was repeated until five cycles were completed. After the fifth cycle, the cable was maintained in a 300°F environment for an additional 60 minutes. The cable was then allowed to cool to ambient temperature.

During the temperature test, a thermocouple junction was formed at one end of the thermocouple cable under test. The frayed edges of the test cable above the thermocouple junction were coated with ceramic paste to seal the end of the cable. Cable temperatures as measured by the thermocouple itself increased continuously upon transfer to the 1400°F zone and decreased continuously upon return to the 300°F zone. The highest temperature recorded from this junction was 1368°F which occurred during the fifth cycle in the 1400°F environment.

In addition, a measurement thermocouple (20-gage, chromel-alumel) was placed beneath the outer silicone-impregnated fiberglass jacket of the thermocouple cable under test. The temperatures recorded by the measurement thermocouple were, on the average, 242°F below those recorded by the thermocouple junction at the end of the test cable during the time the cable was in the 1400°F environment. The temperatures recorded by the measurement thermocouple were, on the average, 28°F higher than those recorded by the test cable during the time the cable was in the 300°F environment after the first cycle in the 1400°F environment. The difference in these two temperature measurements demonstrates the ability of even the outermost fiberglass jacket to aid in the thermal insulation of the conductors. The cable is designed with three layers of Kapton film, a copper shield with a minimum of 85 percent coverage, and a second silicone impregnated fiberglass braid in addition to the overall fiberglass jacket. A visual inspection of the cable after the test revealed that the outer jacket had changed color from yellow to gray and the Kapton film had changed from yellow to black. However, the cable successfully passed the 1500V dc test for one minute from conductor to conductor and from conductor to shield described above. Due to the severity of the temperature test and the successful completion of the voltage test, we believe that the incore thermocouple cables will survive the temperatures produced by hydrogen burns in the lower compartment.

RTD Cable

The hot and cold leg RTD cables are located in the lower compartment and would be subjected to the same environmental conditions as the incore thermocouple cables. The test procedure, temperature profile, and tube furnace used in the thermocouple cable test were utilized in the testing of the RTD cable. The RTD cable is a four conductor cable designed with two tightly woven stainless steel shields separated by a layer of fiberglass in addition to the insulation on the individual conductors. A measurement thermocouple (20-gage, chromel-alumel) was placed beneath the outer stainless steel shield. The highest temperature recorded by this thermocouple was 1013°F. The lowest temperature recorded by the measurement thermocouple while in the 300°F environment after being exposed to the 1400°F environment for one cycle was 342°F. The measurement thermocouple alternated between an average temperature of 340 °F and 993 °F as the cable was cycled between the 300°F and the 1400°F environments. The RTD cable was not energized during the temperature test. A visual inspection of the cable revealed a change in color from yellow to dark gray of the fiberglass braid between the stainless steel shields and a darkening of the insulation on the individual conductors. After the test, the RTD cable successfully passed the 1500V dc voltage test. Due to the severity of the temperature test and the successful completion of the voltage test, we believe that the hot and cold leg RTD cables will also survive the temperatures produced by hydrogen burns in the lower compartment.

Igniter Power Cables

Although the igniters are located throughout the containment, the survivability of those located in the upper plenum of the ice condenser is of particular concern due to the number of burns that occur in that area. The power cables for the igniters are single conductor, No. 10 AWG, insulated with a crosslinked polyethylene with a polyvinyl chloride (PVC) jacket. The temperature profile for this test was a constant temperature which was maintained for 45 minutes. This constant profile was selected because the igniter cables are enclosed in conduit and are not exposed directly to the peak temperatures from each hydrogen burn and because of the difficulty involved in simulating the 39 upper plenum burns.

The test consisted of placing a section of the igniter cable in a length of conduit and sealing the ends of the conduit. A 20-gage chromel-alumel thermocouple was also placed in the conduit to monitor the interior temperature. The conduit was then placed in a Blue M oven, after which the temperature of the oven was raised to 700 $\pm$ 10°F and maintained at that temperature for 45 minutes. During the test, an iron-constantan thermocouple was used to monitor the temperature of the oven. Approximately 15 minutes after the oven temperature reached 700 F, the thermocouple monitoring the interior temperature of the conduit also reached 700°F and remained at that temperature for the remainder of the test (approximately 30 minutes).

After allowing the oven to cool to ambient temperature, the cable was removed and a functional test and a visual inspection of the insulation was performed. The functional test consists of applying 1500V dc between the single conductor and a ground plate to which the cable had been strapped. The cable successfully passed this voltage test. A visual inspection revealed that the PVC jacket which is used for mechanical protection of the insulation had decomposed. However, the insulation itself appeared to remain fully functional.

In April 1978, Wyle Laboratories performed environmental qualification tests on electrical cable splice assemblies to be used at Browns Ferry Nuclear Plant (Wyle Laboratories Test Report No. 43854-3). The cable used in several of the splice assemblies was the same type cable (a single conductor No. 10 AWG) as that used to supply power to the igniters.

Briefly, the Wyle qualification test consisted of irradiating the splice assemblies for a total integrated dose of 6.9×10^7 rads, temperature aging for 168 hours in air at 250°F, and then exposing them to a LOCA environment while energized. The LOCA environment included a temperature profile with a maximum temperature of 325°F for five minutes followed by a decrease in temperature to 304°F over a 24 minute period. During the next 45 minute interval, the temperature was reduced to 282°F. At 75 minutes, the temperature was reduced very rapidly to 230°F. Then, over a period of 23 hours and 45 minutes, the temperature was further decreased to 150°F. Referring to section 2.3, these test temperatures bound the temperatures calculated for the cable in conduit during the series of upper ple[illegible] [illegible]drogen burns.

A postaccident functional test was performed which included measuring the insulation resistance and leakage currents of the cable splice assemblies with the items immersed in water. Values of resistance were determined from conductor to conductor and from conductor to ground. Each circuit was then powered to produce an operating current of one ampere. All test items complied with the postaccident functional test requirement that the items shall carry its required load at no more than a ten percent reduction in operating voltage. The only visual indication of cable deterioration was a swelling of the PVC jacket.

Although the test was specifically for the qualification of an electrical splice, it represents an indication of the cables' ability to survive elevated temperatures that bound temperatures calculated during the series of upper plenum burns. Therefore, based on the voltage tests and visual inspections after the Singleton temperature test and the Wyle qualification test, TVA believes the igniter cable would survive in a hydrogen burn environment.

Electric Power Research Institute's Electric Equipment Survivability Tests (Acurex)

The Electric Power Research Institute (EPRI) has contracted with Acurex Corporation to perform tests to:

1. Observe the generic effects of hydrogen burning on representative samples of safety-related electrical equipment used in nuclear reactor containments; and
2. To demonstrate survivability by performing equipment functional tests after hydrogen burn exposure.

TVA is not directly funding this testing program. We were, however, requested to review the EPRI-proposed statement of work and provided comments based on the experience gained during the Fenwal tests and our discussions with the NRC staff. TVA is a member of EPRI and will be provided with the results of these and any future tests which EPRI performs.

We understand that the following list of test articles are those to be used in this testing program.

1. Asco
   Solenoid Valve
   P/N NP831654E

2. Conax
   Electrical Conductor
   Seal Assembly (ECSA)
   P/N N-11001-32

3. Dekoran
   Instrument Wire
   Multipair-Shielded
   P/N Dekorad Inst. Wire
   Type 974, Samuel Moore
   Aurora, OH 0174778-2
   4 pair, 18Ga

4. Dekoran
   Instrument Wire-Shielded
   P/N Dekorad Inst. Wire
   Type 1952 Samuel Moore
   Aurora, OH 88975-15
   single pair, 16Ga

5. Foxboro
   Pressure Transmitter
   P/N NE11AM or NE13DM

6. Limitorque
   Valve Operator
   P/N SMB-000-2

7. Namco Controls
   Limit Switch
   P/N 180-11302 or
   P/N 740-20100

8. Rockbestos
   Power Cable
   P/N 600V Firewall III
   XHHW BEC Type TC (UL):
   2 each 14 AWG2/C & 5/C
   1 each 4 AWG 3/C

9. Rockbestos
   Coaxial Cable
   RSS-6-104-1980

10. WEED Instruments
    RTD Sensor and
    Thermowell
    P/N 1B5D/611

11. CONAX
    Thermocouple Assembly
    Type E Dual

These tests are currently scheduled to be performed at Acurex immediately following the hydrogen combustion test series which TVA, AEP, and Duke Power are co-funding with EPRI.

3.0 Resolution of Safety Evaluation Report Items

In Appendix B of our first quarterly report, submitted on December 15, 1980, TVA provided a list of key components inside containment that could be required to function after a hydrogen burn. After discussion with the NRC staff and further analysis, we are adding four items to this key equipment list and indicating our evaluation of their survivability.

(1) Containment Sprays

The containment spray system was not included in the original list because its only components located inside containment were piping, nozzles, and check valves which would clearly survive in a hydrogen burn environment.

(2) Hydrogen Recombiners

TVA has evaluated the survivability of the recombiners, and we believe that they will survive and be functional to mitigate long-term hydrogen production. We submitted a more detailed evaluation on May 15, 1981.

(3) Reactor Coolant System Pressure Indication

This instrumentation was originally not thought to be needed because its primary function is as a logic interlock for the RHR suction valves. The transmitters inside containment are qualified to LOCA-MSLB conditions so we believe they will survive in a hydrogen burn environment (see section 2.3).

(4) PORV Block Valves

TVA still maintains that the PORV block valves are not one of the key components required to function to mitigate a small-break LOCA degraded core event. However, we believe the block valves are capable of withstanding a hydrogen burn environment due to their qualification. The block valves are inherently less sensitive to high temperature than the transmitters evaluated in section 2.3

With the addition of these components to the key equipment list and our evaluation that they would survive a hydrogen burn environment, TVA believes that, in conjunction with issues addressed previously in section 2.0, all of the items relating to equipment survivability noted in Supplement No. 4 of the Safety Evaluation Report have been resolved.

TABLE 2.1-1
SEQUOYAH CLASIX RESULTS SUMMARY

		(10 v/o)	(8 v/o)	(6 v/o)
Number of Burns	LC	0	5	17
	UP	41	39	41
Magnitude of Burns (1bm)	LC	-	80-85	38-48
	UP	20-25	14-18	9-17
Total H_2 burned (1bm)		933	1067	1189
H_2 Remaining (1bm)		604	468	348
Peak Temperature (F)	LC	218*	984	693
	LP	196*	452	311
	UP	1797	1191	669
	UC	157	155	143
	DE	191*	220	194
Peak Pressure (lbs/in^{2}g)	LC	8.2	11.6	8.9
	LP	8.5	11.5	8.9
	UP	9.4	11.3	8.8
	UC	8.9	11.3	8.7
	DE	8.2	11.6	8.9
Ice Remaining (1bm)		7.65×10^5	7.65×10^5	7.72×10^5
Figure Numbers		2.3-1-2.3-10	2.3-11-2.3-20	2.3-21-2.3-30

*Occurs before burn period

LC - lower compartment
LP - lower plenum
UP - upper plenum
UC - upper compartment
DE - dead-ended regions

4.0 Conclusions

This submittal has addressed each of the May 1981 conditions on the Sequoyah Nuclear Plant unit 1 Operating License and each of the items from Supplement No. 4 of the NRC Safety Evaluation Report related to equipment survivability. For the following reasons, TVA believes that the key equipment inside containment would survive repeated hydrogen burns.

Modifications made to the CLASIX code have significantly improved its ability to reasonably predict containment atmospheric temperatures as well as pressures. These modified temperature profiles were used as the basis for thermal response analyses of appropriate key equipment chosen because of construction or location. Upon comparison, calculated equipment temperatures were found to be below the temperatures used for qualification to MSLB or LOCA conditions for equipment so qualified or below manufacturer's recommended service limits for other equipment. Components which did not readily lend themselves to conservative thermal analyses such as exposed thermocouple and RTD cable, were physically tested in temperature profiles which exceeded the peak temperatures and durations predicted by the CLASIX code. All of the components tested passed orginal equipment type voltage tests performed to detect insulation breakdown.

Even though TVA has not identified reasonable mechanisms for controlled ignition to promote local detonations at Sequoyah, we have analyzed the structural effects of a pressure profile from a postulated local detonation on the containment shell and found the results to be acceptable. In addition, we have summarized our evaluation of the potential for promoting local detonation.

The list of key equipment that may be required to mitigate a small break degraded core event has been updated to resolve items noted in the Safety Evaluation Report. The survivability of each piece of key equipment on the list has been evaluated to be acceptable.

In conclusion, TVA believes that the key components for degraded core accidents have been identified, evaluated through an appropriate combination of analysis, experiment, and comparison to existing qualification data, and demonstrated to be able to survive in a hydrogen burn environment without corrective action.

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