TEST PLANS TO DEMONSTRATE HYDROGEN COMBUSTION INITIATED BY
A TAYCO IGNITER IN A SPRAY ENVIRONMENT

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ABSTRACT

This report describes project plans for a series of small-scale tests to demonstrate that the Tayco hydrogen igniter will effectively initiate combustion in the presence of a water spray representative of the spray in the upper compartment of the Sequoyah containment. The test facility is essentially a larger version of the facility previously used by FMRC to determine the effects of water fog on hydrogen flammability. The facility will contain redundant, independent instrumentation to measure and control test parameters and to verify successful ignitions.

The following nine parameters have been considered in preparing preliminary test matrices: 1) water flux, 2) hydrogen concentration, 3) drop size, 4) igniter voltage, 5) water temperature, 6) gas temperature, 7) gas velocity, 8) water vapor concentration, and 9) drop velocity. The last four parameters will not be varied in the test matrices because 1) they do not significantly affect igniter temperature and gas mixture ignitability, or 2) they are dependent on one of the other test parameters. Water flux and hydrogen concentration will be varied in the ignitability test matrix, but drop size, water temperature, and igniter voltage will be varied only if preliminary screening tests indicate that they have a significant effect on igniter surface temperature. A preliminary decision tree has been constructed to show how ignitability test parameter values will be selected, assuming that only water flux, hydrogen concentration and igniter voltage need to be varied.

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I
TEST OBJECTIVE AND APPROACH

The objective of the test plans described in this report is to demonstrate that the Tayco igniter will initiate hydrogen combustion in a water spray environment similar to that in the upper compartment of the containment building in the Sequoyah Nuclear Plant. These tests are intended to satisfy the Nuclear Regulatory Commission (NRC) condition[1] for the Tennessee Valley Authority (TVA) operating license for Sequoyah.

The TVA approach to demonstrate igniter effectiveness is to conduct a series of lean hydrogen-air mixture combustion tests with an unshielded Tayco igniter directly exposed to water fluxes similar to those expected in Sequoyah. This is a highly conservative test arrangement, since the igniters in the Sequoyah plant are outfitted with spray shields to divert most of the water spray around the igniters. The spray flux impinging on the unshielded igniter will be the primary parameter to be varied in these tests. Spray fluxes in the tests will be compared to the Sequoyah upper compartment average flux of 0.915 gpm/ft^2 corresponding to 9500 gpm (from both trains of the containment spray system) in the 10,400 ft^2 upper compartment cross section. If ignition occurs with water fluxes of this magnitude,or only slightly less, the igniter effectiveness will be demonstrated.

TVA confidence in this approach is based on separate effects testing previously reported[1,2] to the NRC. These tests indicated that a 0.92 gpm/ft^2 spray flux would cool the igniter so as to reduce its surface temperature from about 1715°F dry to about 1275°F at full spray exposure. The 1275°F surface temperature obtained with the water spray is higher than the 1160°F-1200°F igniter surface temperatures reported[2] to ignite relatively dry hydrogen-air mixtures (water vapor concentrations less than about 15 vol% for turbulent gas mixtures). Thus, relatively dry hydrogen-air mixtures, such as might be released from the ice condenser into the Sequoyah upper compartment during postulated accidents, should be ignitable even when the Tayco igniter is exposed to these large water fluxes.

The test facility and instrumentation planned for these igniter demonstration tests are described in Section II. Test parameter values and a tentative test matrix (for screening tests) and a decision tree (for combustion tests) are presented in Section III.

II
FACILITY DESIGN

2.1 EXPERIMENTAL ARRANGEMENT

Conceptually, the test facility is a larger version of the vertical flammability tube previously used(3) by FMRC to determine the effects of water fog on the ignitability of hydrogen-air mixtures. A schematic drawing of the test enclosure and auxiliary equipment is shown in Figure 2-1. The size of the test enclosure is based on the constraints that: 1) the spray envelope at the igniter elevation roughly fill the enclosure without significant wall interference; 2) ambient air intrusion into the enclosure be negligible during testing; 3) enclosure walls be transparent; and 4) fabrication time and costs be minimized. These constraints and the spray nozzle described below have led FMRC to design a steel framed Lexan enclosure 3 ft x 3 ft in cross section and 5 ft long.

A SPRACO 1116-1317 full-cone spray nozzle has been selected for most of these tests because it produces a volume mean drop size (350 micro meters at 20 psig) close to that (370 μm) of the SPRACO 1713A hollow cone nozzle used in Sequoyah. The SPRACO 1116 generates a relatively uniform narrow cone spray (64° cone angle) as opposed to the bimodal spray from the 1713A hollow cone nozzle. The 8-gpm nozzle flow rate at 15 psig corresponds to an enclosure cross section average flux of 0.89 gpm/ft^2, which is close to the average spray flux at Sequoyah. Possible drop-size effects due to agglomeration in Sequoyah will be investigated by conducting some tests with SPRACO full-cone nozzle No. 4824-1213, which produces an 850 micrometer volume mean drop size at the same 8-gpm flow rate. Water spray instrumentation described in Section 2.2 will be used to determine drop size and water flux distributions in the test enclosure.

The water supply for the nozzles will be pumped at a controlled rate from an 82-gal electric water heater. Water collected at the bottom of the test enclosure will be automatically recycled to the heater in order to allow for a relatively long test period.

Hydrogen-air mixtures, heated to the spray temperature, will enter the top of the test enclosure through a four-arm gas distribution manifold. Hydrogen concentrations will be in the range 4-8 vol% and mixture flow rates will be

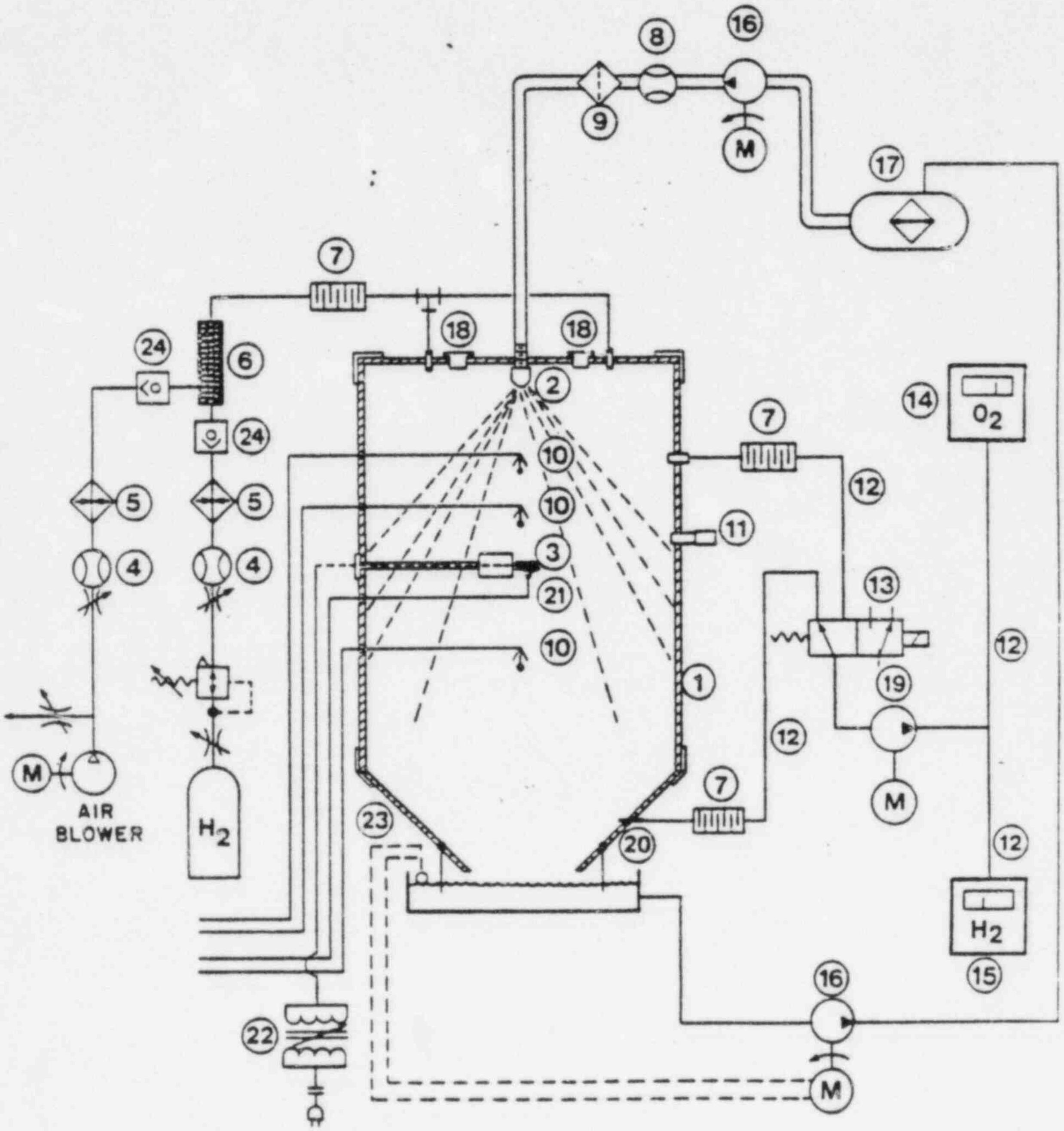

Figure 2-1 Hydrogen Igniter Test - Preliminary Schematic

FIGURE 2-1 (LIST OF COMPONENTS)

Item No.	Description
1	3'x3'x5' Lexan Test Enclosure
2	SPRACO 1116-1317 Full Cone Nozzle
3	Tayco Igniter (120-130 VAC)
4	Rotameter
5	Heat Tracing Sections
6	Hydrogen-Air Mixer
7	Flash Arrestors
8	Water Flow Meter
9	Filter
10	Thermocouple with spray shield
11	Pressure Transducer (0-15 psig Data Instruments)
12	Gas Sampling Line
13	3-Way Solenoid Valve
14	Oxygen Analyzer (Servomex Type A250)
15	Hydrogen Analyzer (Beckman Model 7C)
16	Water Pump
17	Water Heating Tank (82 gal)
18	Vent Disks
19	Gas Sampling Pump
20	Rubber Flaps
21	Igniter Surface Thermocouples (2)
22	0-290 VAC Variable Transformer
23	Float Switch for Water Return Control
24	Check Valve

Items Not Shown

- PMS Drop Size Probe
- Water Flux Collection Array
- Data Recorders
- Temp Controller (Omega Model 6102)
- Power Supplies
- Signal Conditioning Amplifiers

15-60 cfm, corresponding to average velocities in the test enclosure of 0.03-0.11 ft/s. The gas mixture will flow over the Tayco igniter and out the funnel-shaped bottom section of the enclosure along with the water spray.

Detailed drawings of the enclosure and the gas and water supply systems and instrumentation are available from FMRC.

2.2 INSTRUMENTATION

The tests will be sufficiently instrumented to eliminate any doubt as to gas mixture, igniter, and spray conditions and a successful ignition. For the gas mixture, temperatures, flow rates, and compositions will be measured. Gas temperatures will be measured with chromel-alumel thermocouples in the test enclosure and the temperature controllers installed in the gas feed lines. Flow rates will be measured with rotameters in the air and hydrogen lines. Hydrogen concentrations will be estimated by the ratio of flow rates and will be checked by a hydrogen analyzer sampling from the top of the enclosure.

Igniter surface temperature will be measured with a type K (chromel-alumel) thermocouple spot welded to the underside of the igniter coil. This is the same technique used by AECL[4] for their igniter temperature measurements. Two thermocouples will be used in parameter screening tests (Section 3.1), while only one thermocouple will be needed for the gas ignition tests.

Water spray measurements will include drop size, drop velocity, and water flux distributions. Drop size and velocity distributions will be obtained with the Particle Measuring Systems (PMS) optical array imaging probe. The PMS probe available at FMRC is designed to sample, count, size, and statistically analyze water drops in the size range 100-1,000 μm. According to SPRACO, 90% of the drops from the 1713A spray nozzle are in that size range.

Although approximate estimates of water fluxes can be inferred from the PMS probe data, a more reliable and direct measurement is planned for these tests. FMRC will fabricate an array of water collection troughs each approximately the same size as the igniter. This array will be inserted into the test enclosure prior to running surface temperature and ignitions tests. Water flowing for a specified period of time will be collected in graduated cylinders connected to the trough array.

Combustion tests will include three independent measurements to determine whether the gas mixture is ignited:

1) The response of three spray-shielded 0.010 in. thermocouples (two above the igniter and one below it) will be monitored to detect either upward or downward flame propagation. This was the primary technique used in the FMRC water fog tests[3].

2) A pressure transducer (Data Instruments, 0-15 psig, 0-5 volt output) mounted on the side wall of the test enclosure will be used to measure any transient overpressure associated with flame propagation in the enclosure. Threshold values for thermocouple and pressure transducer response to designate ignition will be determined based on checkout tests with dry hydrogen-air mixtures. Slight pressure increases should also cause deployment of the vent disks at the top of the enclosure.

3) Gas will be sampled from the lower section of the enclosure and input to hydrogen and oxygen analyzers. The former is a Beckman thermal conductivity analyzer with 0-10% H_2 range, and the latter is a Servomex paramagnetic Type OA-250 with a 0-25% O_2 range. A decrease in <u>both</u> hydrogen concentration and oxygen concentration is an indication of ignition and the extent of combustion. A decrease in hydrogen concentration accompanied by an increase, or negligible change, in oxygen concentration does not necessarily imply ignition, because it might be due to air entry through the bottom of the test enclosure. Air leakage should not be an insurmountable problem with the large gas and water flow rates and the flexible plastic flaps installed on the bottom of the enclosure.

Data from the thermocouples, the pressure transducer, and the gas analyzers will be digitized and recorded on a computer-based data acquisition system incorporating a DEC LSI-11 computer. Gas concentration comparisons for ignitability determinations will be performed on the computer. Auxiliary data, such as gas and water flow rates,will also be stored in the computer data bank.

2.3 TEST PROCEDURES

Water spray characterization tests will entail removing the igniter assembly from the test enclosure and then inserting first the PMS drop-size probe, and then the water flux collection array. PMS probe data will provide drop-size and velocity distribution data, while the water collection array will provide

water flux data at the igniter location (at the center of the test enclosure) and at several other locations in the enclosure.

Igniter surface temperature tests will be conducted by first establishing the specified gas and water flow rates and temperatures and then actuating the igniter and allowing the temperature to reach equilibrium. Two thermocouples will be used in order to reduce potential problems with bead detaching and/or water impingement onto the bead.

Ignitability tests will also be initiated by first obtaining the desired water flow rate and temperature and then actuating the igniter. Once the igniter temperature is stabilized, the gas mixture will be established by first flowing air and then gradually increasing the hydrogen flow rate. The gas flow will be maintained until ignition is confirmed or until the test enclosure has been completely purged with the gas mixture and the hydrogen concentration is stabilized.

2.4 DATA REPORTING

Water spray drop-size distributions will be reported in the form of distribution plots along with the standard statistical parameters such as volume mean diameter and standard deviation. Water flux data will be reported in terms of flux at the igniter, cross-section average flux, and the standard deviation among the flux measurements throughout the cross section.

Ignitability test data from the three ignitability determination measurements (Section 2.2) will be compared. If the three methods all agree, the test results will be obvious. If the three methods produce ambiguous data, the test result may or may not be classified as ignitable depending on instrument response during the dry check-out tests.

III
TEST MATRICES

3.1 RELEVANT PARAMETERS

Nine different test parameters have been considered in developing test matrices. These parameters are: 1) water flux, 2) hydrogen concentration, 3) drop size, 4) igniter voltage, 5) water temperature, 6) gas temperature, 7) gas flow rate, 8) water vapor concentration, and 9) drop velocity. Our approach has been to reduce this list to a more manageable number by eliminating variables which can be shown either 1) to have only an insignificant effect on hydrogen mixture ignitability and igniter surface temperature, or 2) to be dependent on one of the other test parameters.

Some of the parameters can be eliminated from considerations of their expected effects during hypothesized burns in the Sequoyah upper compartment. Gas flow rate; i.e., gas velocity in the test enclosure, is one such parameter. Gas velocities anticipated from the outlet of the upper plenum of the ice condenser in Sequoyah are expected to be about 1 ft/s (D. Renfro, TVA personal communication June 1983). In the absence of water spray, smaller gas velocities would be expected at igniter locations on the upper compartment walls. Since spray droplet velocities are much larger (terminal velocities on the order of 10 ft/s for the SPRACO 1713A nozzle droplets), water spray flow rate and drop size will actually determine entrained air flow rates which in turn will dictate the effective turbulent gas velocity in the vicinity of the igniter. Therefore, the nominal gas velocity through the test enclosure (on the order of 0.1 ft/s) will be irrelevant and need not be included in the test matrix.

Gas temperature is also expected to have only a minor effect on ignitability and igniter surface temperature. Temperature effect data for dry mixture downward propagation limits are shown in Figure 3-1. The expected temperature range (between burns) for Sequoyah upper compartment hypothesized accident conditions, as simulated by CLASIX calculations, is 120-130°F (41°-55°C); i.e., on the order of the estimated water spray temperatures. Over this narrow range, Figure 3-1 indicates a negligible change in the lower hydrogen flammability limit. In fact, gas temperatures would have to vary by about 60°C (108°F) to produce a 1 vol% change in the hydrogen lower limit

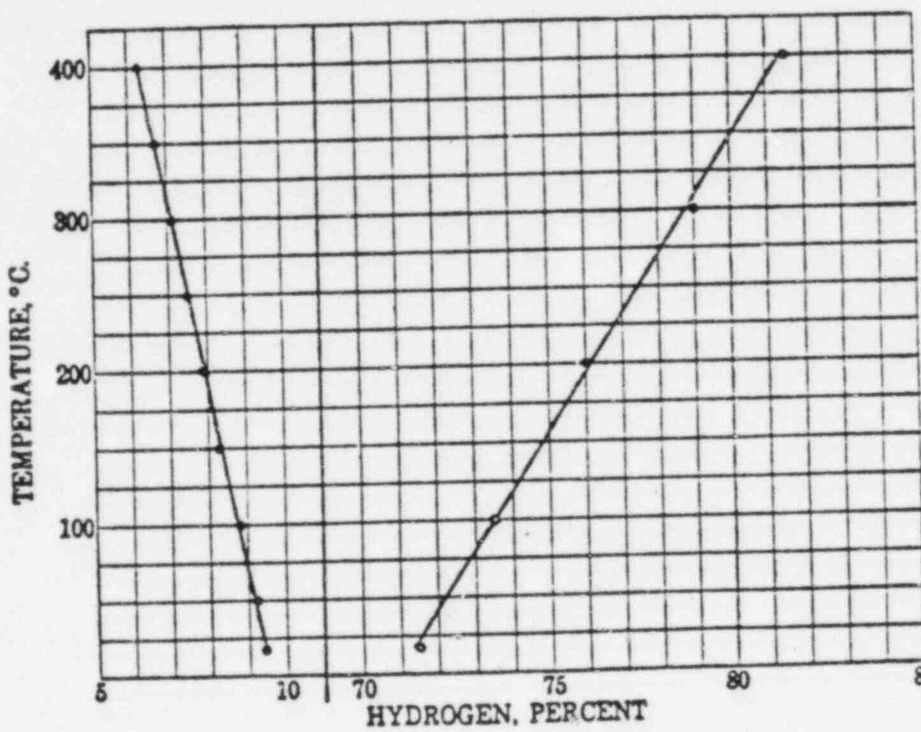

Figure 3-1 Influence of Temperature on Downward Propagation Limits of Flammability of Hydrogen in Air (from ref 5)

concentration. Since expected gas temperature variations are 1) much smaller than 60°C, and 2) determined by water spray temperatures, there is no need to include gas temperature variations in the test matrix.

Water vapor concentration is another parameter that can be bounded from accident scenario considerations. If the maximum spray/gas temperature is 130°F, the corresponding maximum water vapor saturation concentration (for a one atmosphere total pressure) is about 15%. The effect of steam concentration on hydrogen ignitability limits can assessed from the AECL data shown in Figure 3-2. In particular, water vapor concentrations less than about 15% do not appreciably affect the hydrogen ignitability limit for turbulent gas mixtures. By the same token, igniter surface temperature should also be insensitive to these water vapor concentrations because the thermal conductivity of water vapor at 130°F is very close to that of air. Therefore, water vapor concentration variability can also be eliminated as a test parameter; its effective value in the tests will be close to the saturation concentration at the test temperature.

Drop velocity effects are also believed to be relatively insignificant compared to the other experimental parameters. The drop velocity anticipated to impinge on the igniter in the test enclosure should be only slightly higher than the terminal velocity*. Thus, it should be a reasonable, or slightly conservative, simulation of the droplet impingement velocity for the Sequoyah igniter. Drop velocities in the test enclosure will be measured with the PMS drop size probe, but drop velocities cannot be varied independently of water flux and drop size.

Of the remaining five parameters, only one (hydrogen concentration), refers to the inherent ignitability of the gas mixture itself. The other four parameters (water flux, drop size, water temperature, and igniter voltage) are only important insofar as they may significantly affect igniter surface temperature. Therefore, their importance can be ascertained from noncombustion tests in which only the igniter temperature is measured. A tentative test matrix for these screening tests is described in Section 3.2.

3.2 IGNITER SURFACE TEMPERATURE TESTS

These tests are designed to determine the influence of the following parameter ranges on the unshielded igniter surface temperature.

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*The initial drop velocity for the SPRACO 1116 nozzle operated at 8 gal/min is estimated to be only a few feet per second higher than the terminal velocity.

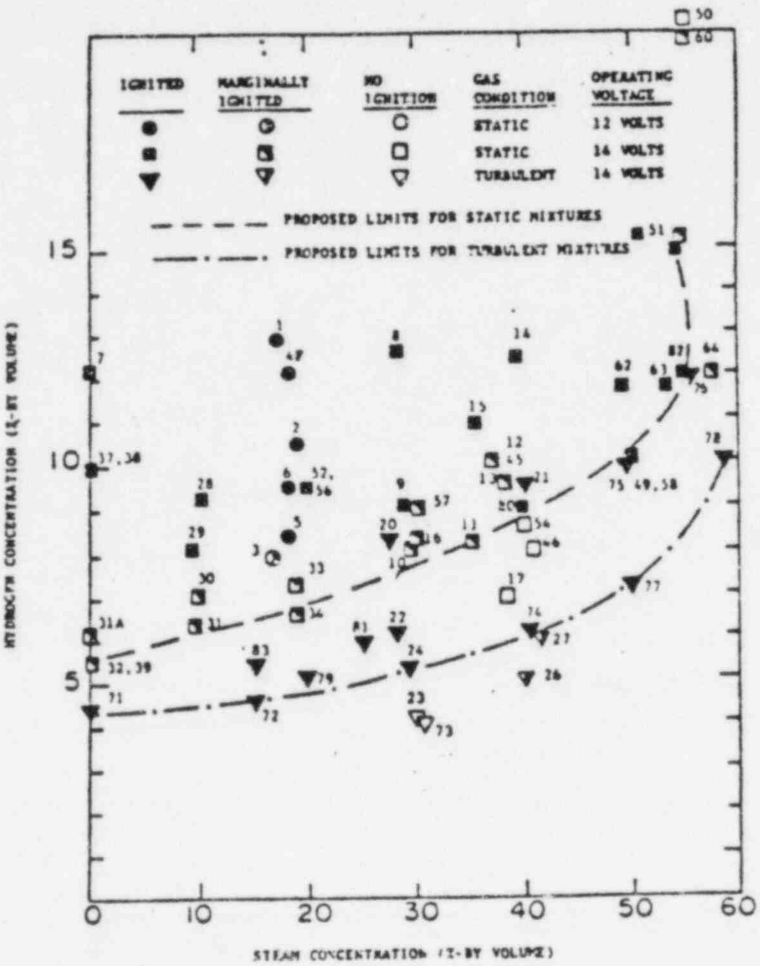


Figure 3-2 The ignition Limits of Hydrogen/Air/Steam Mixtures Using a GM AC Model No. 7 Thermal Glow Plug Located at the Center of a 17-Liter Quasi-Spherical Vessel (from ref. 4)

Water Flux	0 - 1.8 gpm/ft^2
Igniter Voltage	120 - 130 volts
Drop Size	380 - 850 μm
Water Temperature	Ambient (70-75) - 130°F

TVA data reported in References 1 and 2 are already available for the effects of water flux and igniter voltage. Water flux has been shown to be a critical factor. For example, a water flux of 0.92 gpm/ft^2 reduced the igniter surface temperature from about 1700°F in dry air to about 1275°F with one specific spray nozzle. Igniter voltage variations produced a less dramatic change: from about 1760°F at 120v to about 1880°F at 130v. The test matrix shown in Table 3-1 for the planned tests includes only a few confirmatory tests (Tests 2 and 3) with water flux and igniter voltage variations.

Drop-size effects will be investigated in the screening tests by replacing SPRACO nozzle 1116, which is to be used in the first four tests, with SPRACO nozzle 4824. Operation of SPRACO nozzle 4824 at 30 psig (Test 5 in Table 3-1) should produce the same water flux as nozzle 1116 at 15 psig, (Test 2), but the volume average drop size should increase from 385 micrometers to about 850 micrometers. The FMRC PMS probe will be used to measure drop sizes during these two tests, and the corresponding pair of tests (Tests 6 and 7, these with a water flux of 1.8 gpm/ft^2). If igniter temperatures in either pair of tests differ by more than 50°F, both nozzles will be included in the ignitability test matrix.

Water temperature effects will be determined by comparing the results of Tests 2 and 4, which have water temperatures of 75°F and 130°F, respectively. As with drop size, if these two tests result in igniter temperatures that differ by more than 50°F, water temperature effects will be included in the ignitability test matrix.

3.3 IGNITABILITY TESTS

Since ignitability demonstration test conditions depend in part upon the results of the igniter surface temperature tests, a firm test matrix cannot be presented for the ignitability tests. TVA instructions for ignitability test conditions are to choose a conservative set of initial parameter values, and then to make changes as dictated by the results of the preceding tests. The

TABLE 3-1

IGNITER SURFACE TEMPERATURE PRELIMINARY TEST MATRIX

Test	SPRACO Nozzle	Water Flux (gpm/ft^2)	Water Temp (°F)	Igniter Voltage
1	1116	0	-	120
2	1116	0.9	75*	120
3	1116	0.9	75	130
4	1116	0.9	130	120
5	4824	0.9	75	120
6	4824	1.8	75	120
7	1116	1.8	75	120

*Initial tests will be run with water at near ambient temperatures, expected to be 65-75°F.

rationale is to merely demonstrate ignitability under realistic-to-conservative test conditions without obtaining a complete set of ignitability data over the entire range of experimental parameters.

In keeping with this test plan rationale, FMRC and TVA have prepared the preliminary decision tree shown in Figure 3-3 to specify test condition contingencies. Three parameters: water flux, hydrogen concentration, and igniter voltage, have been specified for each test. We assume, for purposes of this report, that the other two parameters: drop size and water temperature, have been shown to have negligible effects in the igniter temperature tests. Nominal values for these two parameters are 120°F and the drop size generated by the SPRACO 1116 nozzle to obtain the specified water fluxes. If the igniter temperature tests show that these parameters are indeed important, a new decision tree will be constructed.

The first test will be conducted with 6 vol% hydrogen, water flux of 0.9 gpm/ft^2, and an igniter voltage of 120V. Figure 3-3 shows that, if an ignitability test results in ignition, the following test will be conducted with a larger water flux. If the test results in no ignition, either the water flux is decreased, the hydrogen concentration is increased to 8 vol%, or the igniter voltage is increased from 120v to 130v. After the indicated tests have been conducted, FMRC and TVA representatives will discuss possible additional test conditions. The intent is to terminate testing when ignition has been verified (perhaps by repeating a successful ignition test) at a water flux comparable to, or preferably greater than, that expected to impinge on the spray-shielded igniters in Sequoyah.

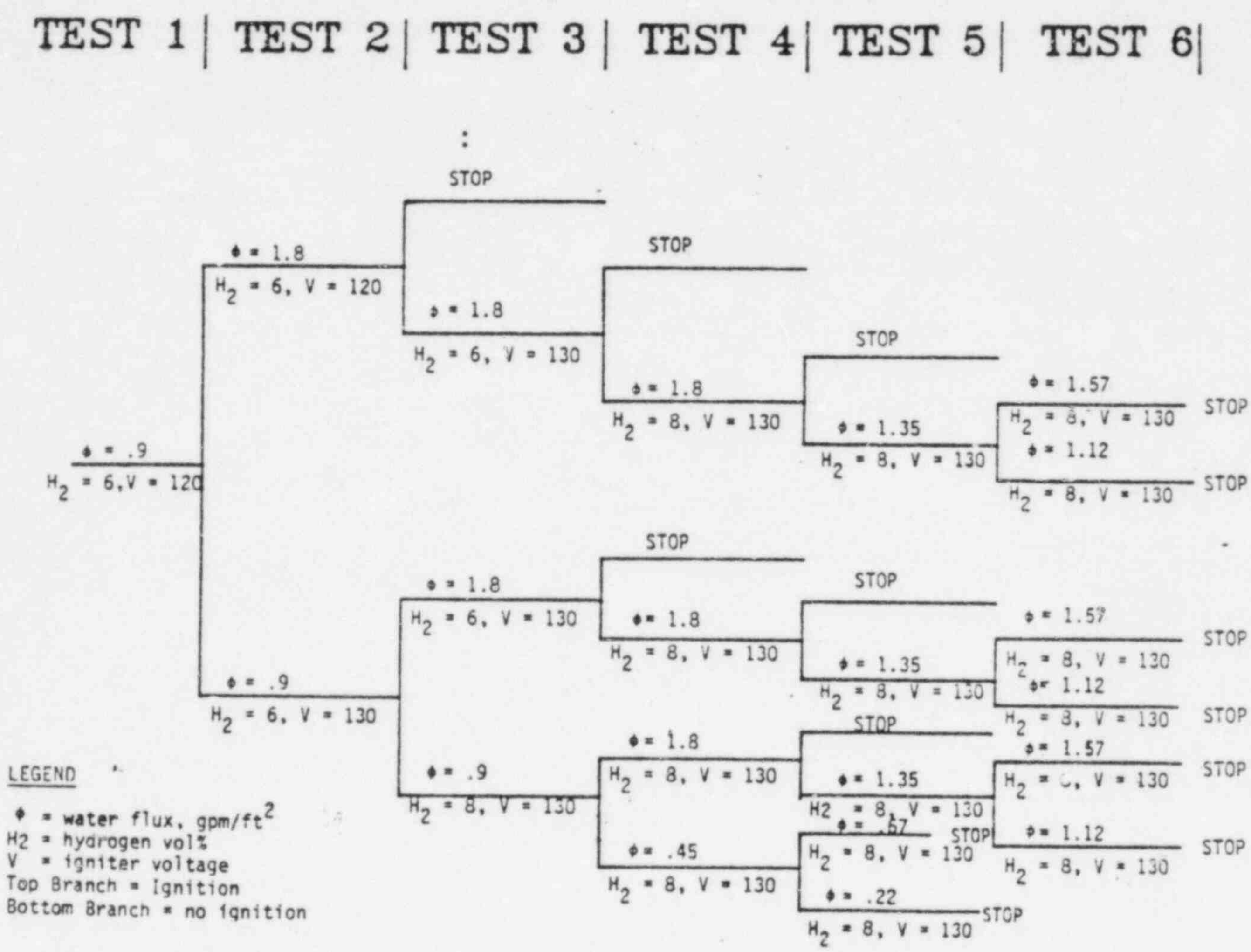


Figure 3-3 Preliminary Decision Tree for Ignitability Tests

IV

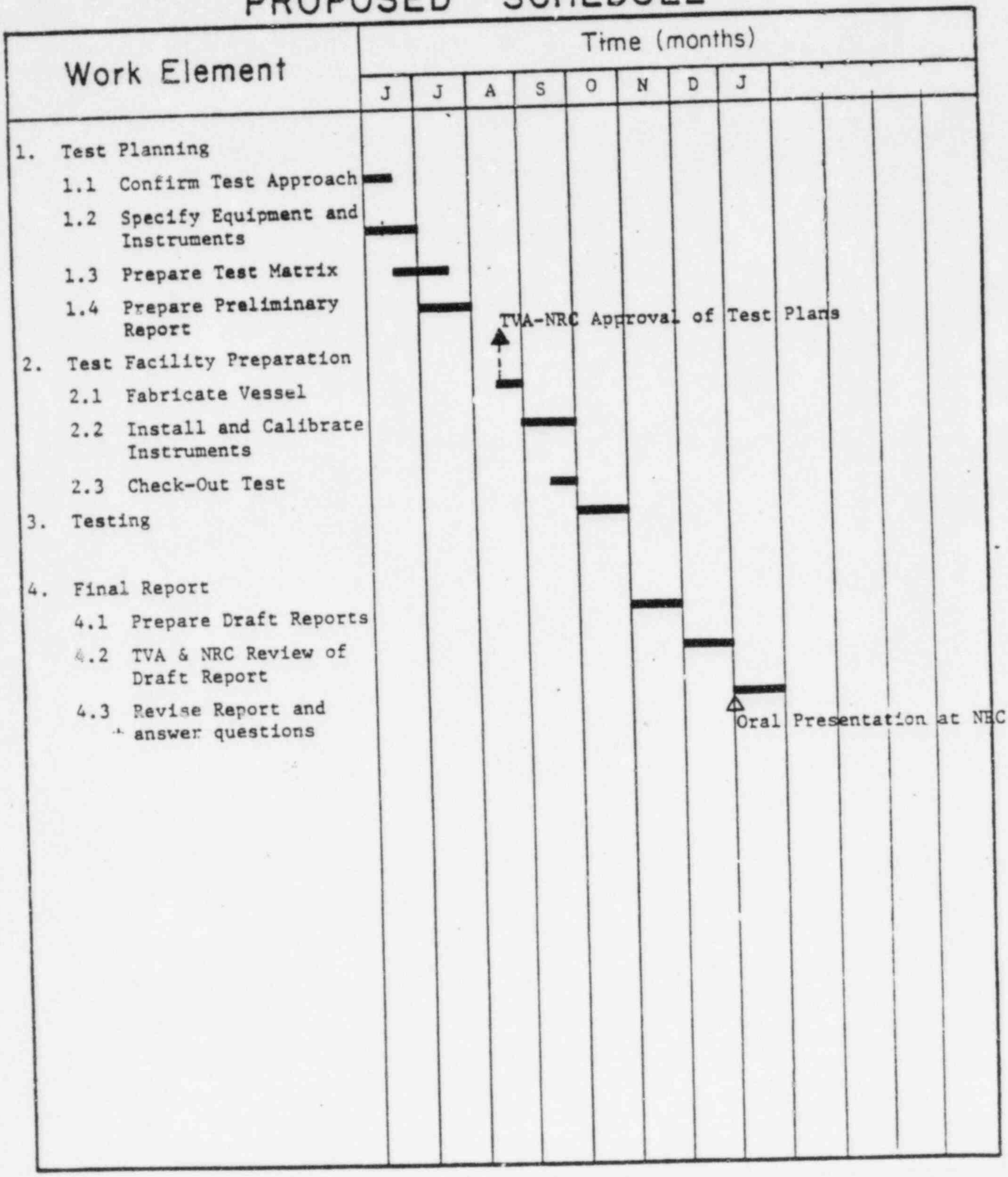
PROGRAM SCHEDULE

Test preparations have proceeded to the point that engineering drawings/schematics have been completed and all equipment and/or components are available at FMRC for test facility fabrication.

As indicated in Figure 4-1, it is anticipated that test facility preparation and checkout can be completed within two months, and that testing can be completed one month later. This schedule would allow a project final report to be written, revised to incorporate TVA comments, and submitted to the NRC by the end of 1983.

FIGURE 4-1

PROPOSED SCHEDULE



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