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MASTER

REON SACRAMENTO PLANT

REPORT NO. RP-TM-0007

TO

SPACE NUCLEAR PROPULSION OFFICE - CLEVELAND EXTENSION

PHOEBUS-2

HYDROGEN DISPOSAL BURN POND

OCTOBER 1966 CONTRACT SNPC-35

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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DISCLAIMER

AEROJET
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GENERAL

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PHOEBUS-2
HYDROGEN DISPOSAL BURN POND

ROCKET ENGINE OPERATIONS – NUCLEAR

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A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

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ABSTRACT

The Phoebus-2 Hydrogen Disposal Pond (Burn Pond) Report includes a survey of available hydrogen disposal methods, a discussion of problem areas in using a hydrogen disposal pond system, the hydrogen disposal method to be used by Aerojet-General, and the testing which leads to the final hydrogen disposal pond design.

C. S. Boncore

C. S. Boncore, Manager
REON Test Facility Design

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I. INTRODUCTION

Because of the impracticality of using an actual reactor-engine, rocket nozzles developed for nuclear testing at the Nevada Test Site, under the NERVA and PHOEBUS programs, are performance-evaluated in chemical simulation firings using liquid oxygen and liquid hydrogen as propellants. Normally, in liquid rocket systems, the hydrogen is first used to regeneratively cool the nozzle and is then mixed with the propellant for combustion. In the case of the nuclear nozzles under development, however, the total coolant flow exceeds that required for combustion simulation during firing and, thus, an appreciable quantity of the available hydrogen coolant must be dumped overboard. For chemical testing of the PHOEBUS nozzle, the hydrogen coolant and propellant lines have been decoupled from one another to permit independent variations in engine performance without affecting cooling characteristics. This results in a need to dispose of the total nozzle coolant hydrogen (up to 250 lb/sec) in a safe and controlled manner. Combustion with atmospheric oxygen is the only feasible method for disposing of gas at these high flow rates, over about a 17-second period.

Conventional flare stacks were considered as means of disposal. However, such factors as the wide range in anticipated hydrogen flow rates, very large purge-gas requirements, low combustion efficiency, and marginal satisfaction with existing single and multiple-stack installations prompted the selection of an alternate concept: the so-called "burn pond" disposal method. Essentially, this is a system in which the coolant hydrogen is ducted to an area sufficiently remote from the test stand to be safe, is dispersed through a pipe manifold submerged in water from which it evolves into the atmosphere above the pond, and is there ignited and burned. While the water serves primarily as a seal to prevent backmixing of air into the distribution manifold and pipeline, it also protects the manifold and the pond from thermal radiation damage. In effect, the burn pond is a high-discharge area stack of zero height, with a water seal.

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This basic concept has been used with success, both at Complex 37B at Cape Kennedy and at the Douglas Test Site in Sacramento. However, the Aerojet facility is required to operate under such stringent conditions as to pose a completely new set of problems. The Complex 37B pond, for example, is designed to dispose of about one lb/sec of hydrogen at minimum backpressure, whereas the Aerojet system must handle up to 250 lb/sec at disposal line inlet pressures up to 1220 psi. Other installations then could offer only the most general of guidelines in the planning and operation of the Aerojet pond. (See Reference 1).

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II. SURVEY OF AVAILABLE HYDROGEN DISPOSAL METHODS

A. DISCUSSION

Two general methods are available for disposing of flammable waste gases: venting to the atmosphere without ignition or combining with an oxidizer to form a non-hazardous, or readily disposable, product which may be ignited. Collecting and re-use was also a theoretical possibility; however, the cost and complexities of a system for catching and storing hydrogen at low temperatures and at flow rates up to 250 lb/sec were immediately evident.

This section discusses the various methods of hydrogen disposal investigated which culminated in the decision to adapt the burn pond concept to the PHOEBUS-2 hydrogen disposal requirements.

B. SINGLE AND MULTIPLE FLARE STACKS

Waste hydrogen gas can be conventionally disposed of by expelling through commercially available flare stacks. (See Reference 2). The discharge gas (mixing with the atmosphere) is ignited by an open pilot flame at the stack exit and is disposed of through combustion. This method is most effective and stable when operated within a specific range where velocity and other conditions are ideal. Decreases in gas flow rates, for example, can result in the gas velocity falling below the minimum limit, which will allow the flame to propagate back into the confined pipe. This results in a potential explosion hazard. Conversely, at stack velocities above the ideal velocity, and without an elevated ignition system, the gas can escape unburned. These accumulations of unburned gas, sometimes well above the ignition limit, possibly could be wind-blown into an ignition source, again creating a hazard to personnel and equipment. The wide combustible mixture range of hydrogen dictates the need for a method that will provide near-total burnoff of the effluent within a controlled area.

Stack velocity can be better controlled, and a wider range of flows can be handled, if a multiple stack installation is employed. However, the problem of low stack velocities during low flow conditions and start transients is further compounded by interaction effects between stacks.

C. BURN PONDS

Another method that merited further investigation was the burn pond disposal method currently in use at Cape Kennedy and at the Douglas Test Facility, Sacramento.

This system operation can be described basically as one in which hydrogen gas is dispersed through a pipe distribution system submerged in water from which it evolves into the atmosphere. The buoyant column of hydrogen is turbulently mixed with air, ignited and burned.

These hydrogen burn ponds were specifically designed to safely dispose of waste hydrogen gases venting at low pressures and at low flow rates (1 to 15 lb/sec) from storage vessels and vehicle tankage. The burn pond vent systems employ a manifold in an "X" configuration located just beneath the surface of the water. From the manifold, small, evenly-spaced risers protrude from the water. Each riser is covered by a larger diameter, adjustable height bubble cap whose outer skirt extends back into the water, thereby creating a low-pressure water seal.

The basic principle of providing a water seal against atmospheric air entry appeared of real value; however, the differences of flow rates and pressures scheduled for the PHOEBUS-2 nozzle coolant were of sufficient magnitude to pose a different set of problems. The PHOEBUS-2 nozzle coolant flow rate is approximately 50 times that of the design operating level for the existing ponds. For short-duration runs of approximately 17 seconds, high coolant discharge pressures up to

1220 psig will occur as compared to near-atmospheric exhaust for periods of 15 to 20 minutes, for the Cape Kennedy and Douglas ponds. Since the operating conditions for the Cape Kennedy-Douglas Facility burn ponds were so different from that of the PHOEBUS-2 burn pond, only the concept of the water seal would be useful in the new design.

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III. PROBLEM AREAS

The foreseeable problem areas of the burn pond concept were divided into two broad categories: the hydrogen-water interface phenomena, and ignition and combustion characteristics for hydrogen-in-air with the resultant effects of the flame on the surroundings.

A. HYDROGEN-WATER INTERFACE

The nozzle coolant gas is discharged into water which absorbs the momentum of each gas jet and from which the gas rises buoyantly into the atmosphere. This interface was considered the least amenable to analysis in designing the system. The interaction of such factors as the disintegration of the gas jets as they penetrate the water, the dynamics of gas evolution through the water, and water surface turbulence were considered so highly complex as to preclude an analytically based design. Other unanswered problems considered of prime importance were localized water freezing in and around the discharge nozzles, instantaneous water loss as the incoming gases expand and rise buoyantly creating a gas-lifting effect, and gradual water loss by entrainment and vaporization.

B. COMBUSTION

The hydrogen rising buoyantly from the surface of the pond is ignited and burns with atmospheric oxygen. Problem areas anticipated include:

1. Ignition of the hydrogen emitting from the surface of the water
2. Detonation resulting from hydrogen accumulation and delayed ignition.
3. Flame geometry.
4. Meteorological factors.
5. Thermal radiation as it may affect the surrounding test equipment.

To evaluate these and other unforeseen problem areas, it was decided to fabricate and test a scale model pond (approximately 1/25-scale in terms of flow rate).

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IV. THE AEROJET-GENERAL HYDROGEN DISPOSAL METHOD

A. SCALE MODEL HYDROGEN BURN POND

A site at the Cryogenics Laboratory was selected for installation of scale model test burn pond (Figure 1). A maximum flow rate capability of approximately 10 lb/sec dictated the 1/25-scale factor for the model pond. Since the greatest degree of uncertainty lay in the hydrogen-water interface problem area, a one-to-one scale relationship for distribution header size and spacing and discharge port design was established to evaluate gas jet breakup and evolution from the water together with possible freezing effects. The size and configuration of the scale pond was, in effect, a section lifted from the full-scale pond. Its design was based on providing the same gas evolution/water volume ratio as for the main pond.

The scale model pond is located in a large basin approximately 250 ft from the Cryogenics Laboratory, (Figures 2 and 3). With the exception of the 6-in. distribution manifold used in lieu of the 14-in. manifold, the piping is characteristic of the main pond. The pipe supports within the pond are adjustable to allow positioning of the piping at various elevations. The ignition system consists of two, premixed, propane-air pilot flames located on the edge of the pond. The system flow path, including instrumentation transducer locations, is shown schematically in Figure 4. A total of eleven developmental tests were conducted, as summarized in Table I. Color and/or black and white motion picture coverage data taken of each test are listed in Table II.

Figure 1
Cryogenics Laboratory

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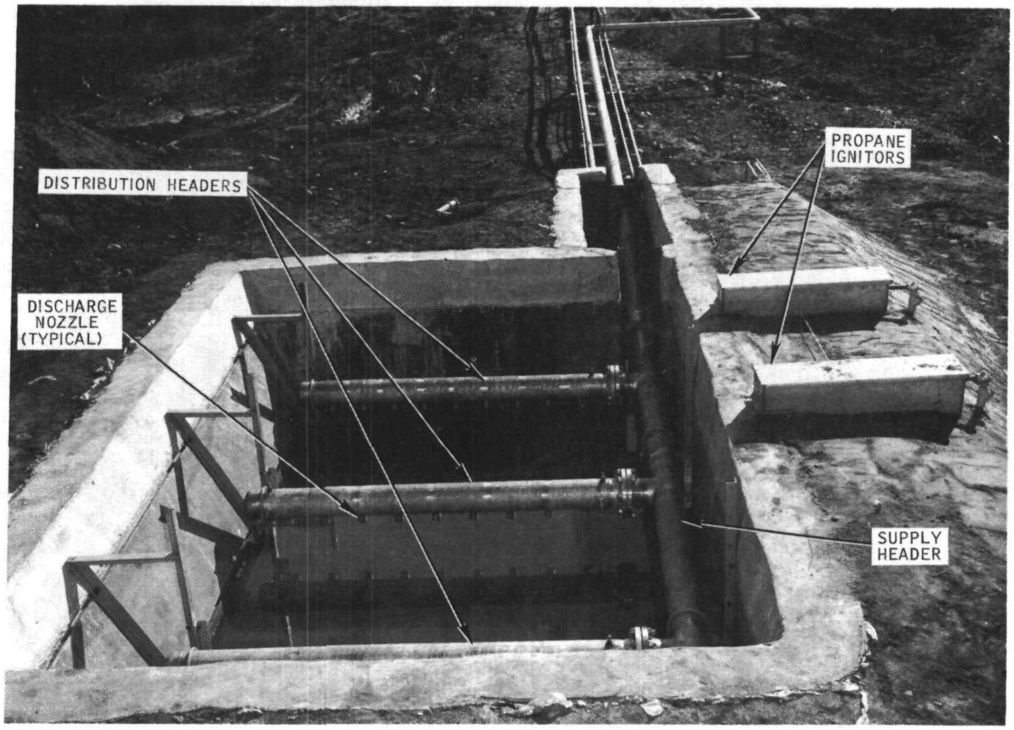

Figure 3

Scale Burn Pond

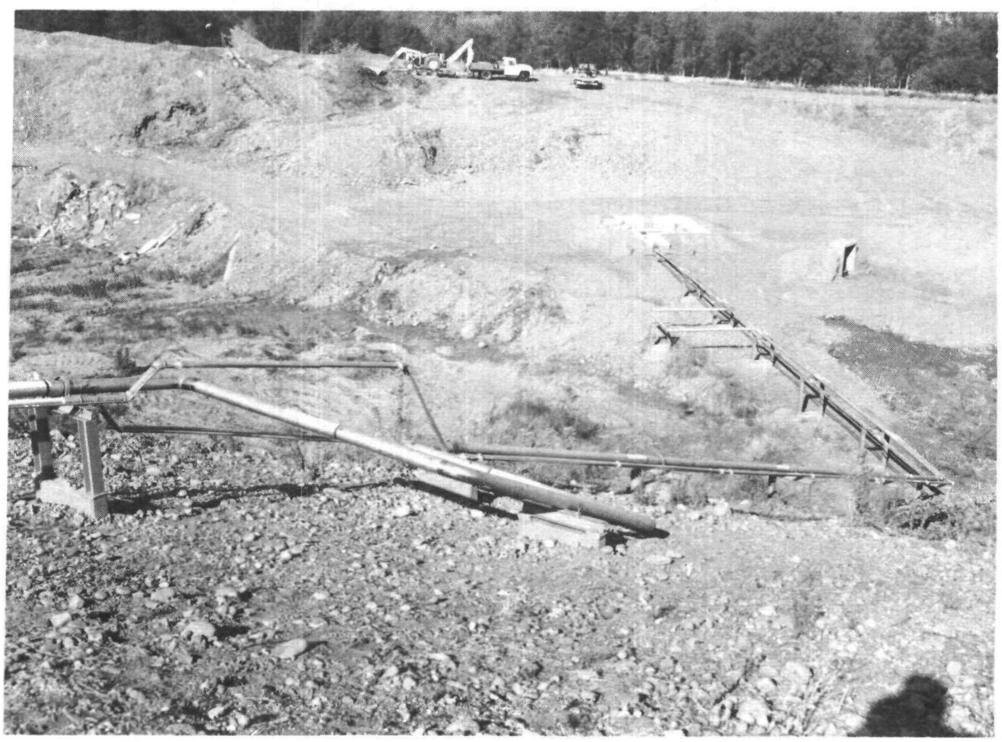

Figure 2

Scale Model Burn Pond, Piping and Pond

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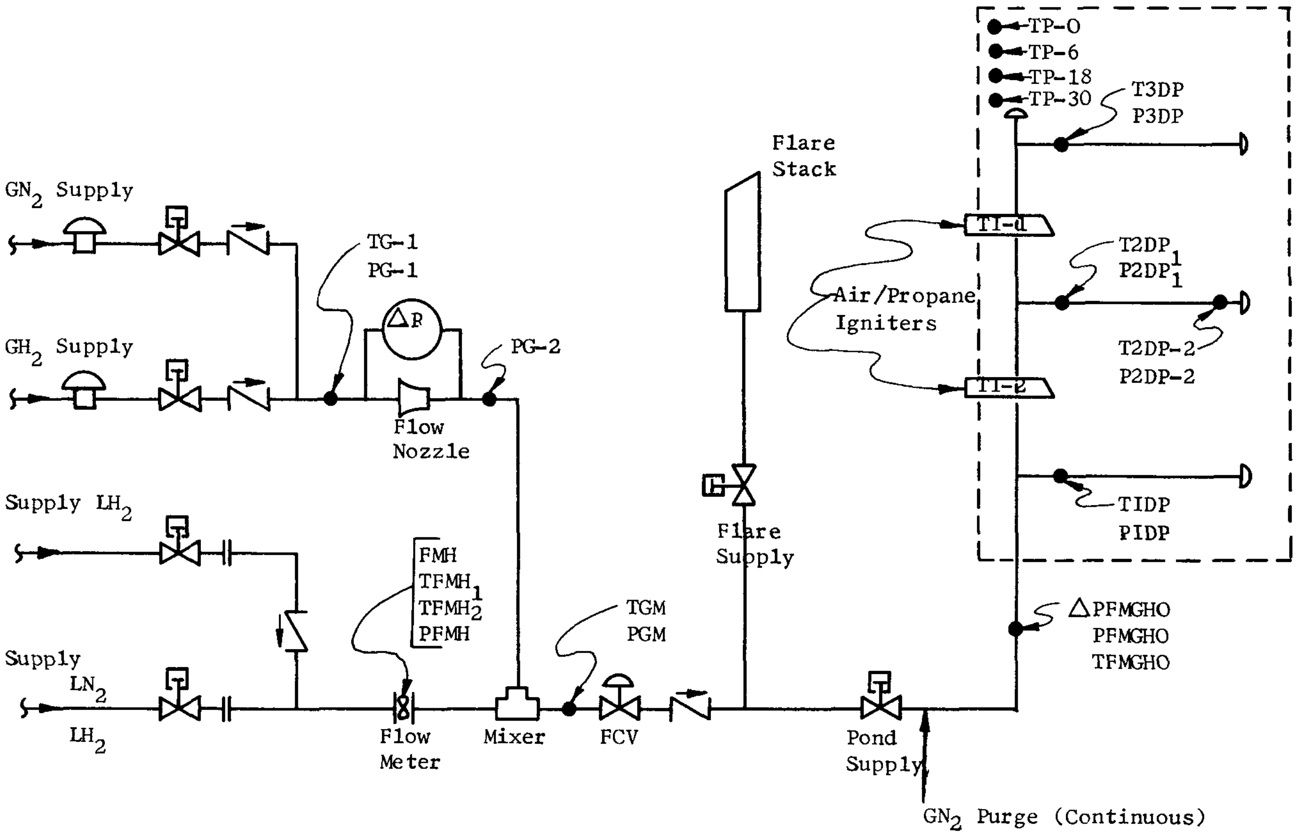

Figure 4

Scale Model Hydrogen Burn Pond, Flow Diagram and Transducer Location

TABLE I

PHOEBUS-2
SCALE MODEL HYDROGEN BURN POND
DEVELOPMENTAL TEST SUMMARY

RUN NUMBER	TEST FLUID	FLOW RATE (lbs/sec)	TEMP. CONDITION (°RANKINE)	TEST DURATION (SECONDS)	TEST SIMULATION	TEST OBJECTIVES	*Original Conditions TEST SYSTEM MODIFICATION
001	Liquid Nitrogen	44 (Max)	140° (Min)	50	Main pond nominal hydrogen flow momentum (Sub-sonic Flow)	System Shakedown and effects on water a) Movement b) Temperature c) Seal	* 27 ea 1-1/2" vertical discharge nozzles located 12" from bottom of pond with water depth of 3' -0"
002 & 003	Mixed Nitrogen	29	192	40	Main pond nominal hydrogen flow momentum (Sonic Flow)	Effects on water a) Buoyancy b) Turbulence c) Temperature d) Seal	27 ea 7/8" dia vertical discharge orifices replacing 1-1/2 Dia nozzles
004	Mixed Nitrogen	22	210	35	Main pond nominal hydrogen flow momentum (Sonic Flow)	Effects on water a) Buoyancy b) Turbulence c) Temperature d) Seal	Repositioned orifices 30" from bottom of pond to dissipate jet momentum
005	Ambient Hydrogen Gas	1 3 4.5	Amb.	15	Main pond nominal hydrogen flow momentum (Sub-sonic Flow)	Effects on water a) Buoyancy b) Turbulence c) Temperature d) Seal Ignition characteristics, flame configuration, area temp. gradients	Removed 7/8" Dia. orifices and lowered distribution headers to original position

TABLE 1 (Cont.)

RUN NUMBER	TEST FLUID	FLOW RATE (lbs/sec)	TEMP. CONDITION (°RANKINE)	TEST DURATION (SECONDS)	TEST SIMULATION	TEST OBJECTIVES	TEST SYSTEM MODIFICATION
006	Ambient Hydrogen Gas	1 3 4.5	Amb.	20	Main pond nominal hydrogen flow momentum (Subsonic Flow)	Effects on water a) Buoyancy b) Turbulence c) Temperature d) Seal Ignition characteristics, flame configuration, area temp. gradients	Rotated Outside headers 45° inward to aim 18 nozzles toward center of pond
007	Mixed Hydrogen	9.6	103°R	22	Main pond nominal hydrogen flow and temperature (Subsonic Flow)	Effects on water a) Buoyancy b) turbulence c) Temperature d) Seal Ignition characteristics, flame configuration, area temp. gradients	Rotated Outside headers 45° inward to aim 18 nozzles toward center of pond
008	Mixed Hydrogen	9.6	100°R	25	Main pond nominal hydrogen flow and temperature (Subsonic Flow)	Effects on water a) Buoyancy b) Turbulence c) Temperature d) Seal Ignition characteristics, flame configuration, area temp. gradients	Added pond splash extension - Relocated nozzles to original position and installed 19 ea. diffusers.

TABLE I (Cont.)

RUN NUMBER	TEST FLUID	FLOW RATE (lbs/sec)	TEMP. CONDITION (°RANKINE)	TEST DURATION (SECONDS)	TEST SIMULATION	TEST OBJECTIVES	TEST SYSTEM MODIFICATION
009	Mixed Hydrogen	9.6	123°R	23	Main pond nominal hydrogen flow and temperature (Subsonic Flow)	Effects on water a) Buoyancy b) Turbulence c) Temperature d) Seal Ignition characteristics, flame configuration, area temp. gradients	Removed 19 ea. diffusers and again rotated 2 ea. outside fingers 45° to aim nozzles inward to center of pond
010	Mixed Hydrogen	9.6	125°R	20	Main pond nominal hydrogen flow and temperature (Subsonic Flow)	Effects on water a) Buoyancy b) Turbulence c) Temperature d) Seal Ignition characteristics, flame configuration, area temp. gradients	Added 1/8 dia. x 1/2" oc wire screen above pond and increase water depth to 3' -6"
011	Liquid Hydrogen	9.6	37°R	20	Main pond nominal hydrogen flow at extreme temperature condition	Effects on water a) Buoyancy b) Temperature c) Temperature d) Seal Ignition characteristics, flame configuration, area temp. gradients	Removed screen from above pond and decreased water depth to original

TABLE II

SCALE MODEL HYDROGEN BURN POND
TEST PROGRAM 1.2-13-NNX

FILM LIST

RUN #	FILM #	TYPE FILM	FRAME RATE (FPS)	LENS USED	CAMERA POSITION	TEST DESCRIPTION			OBJECT VIEWED
						MEDIUM	FLOW RATE	TEMP	
001	007	Color	64	Telephoto	180°	LN_2	45 #/sec		Pond Surface
002	175	B & W	24	Telephoto	90°	Mixed Nitrogen	20 #/sec	190°R	Pond
	176	Color			180°				
003	177	Color	24	Telephoto	180°	Mixed Nitrogen	29 #/sec	190°R	Pond
	178	B & W			90°				
004	198	B & W	24	Telephoto	90°	Mixed Nitrogen	22 #/sec	200°R	Pond
	199	Color			180°				
005	229	B & W	24	Telephoto	90°	Ambient Hydrogen	1,3,&4.5 #/second	AMB	Pond
	230				180°				
	231	Color		Wide/Vert 10 MM	180°				Flame
006	255	B & W	24	Telephoto	90°	Ambient Hydrogen	1,3,&4.5 #/second	AMB	Pond
					180°				Pond

TABLE II (Cont.)

RUN #	FILM #	TYPE FILM	FRAME RATE (FPS)	LENS USED	CAMERA POSITION	TEST DESCRIPTION			OBJECT VIEWED
						MEDIUM	FLOW RATE	TEMP	
006	257	Color		Wide/Vert 10 MM	180°				Flame
	259		20	Hulcher	180°				Flame
007	283	Color	24	Wide/Vert	180°	Mixed Hydrogen	9.6 #/sec	120°R	Flame
008	364	B & W		Telephoto	90°	Mixed Hydrogen	9.6 #/sec	120°R	Pond
	365	Color		Telephoto	180°				Pond
	366	Infrared		Wide/Vert	180°				Flame
	367	Color		Telephoto	180°				Pond
	368	B & W	400	Telephoto	180°				Pond
009	369	B & W	24	Telephoto	90°	Mixed Hydrogen	9.6 #/sec	120°R	Pond
	370	B & W	24	Telephoto	180°				Pond
	372	Color	24	Telephoto	180				Pond
	373	B & W	400	Telephoto	180°				Pond
010	490	Color	24	Telephoto	180°	Mixed Hydrogen	9.6 #/sec	120°R	Pond
	489		400	Telephoto					Flame
	491		24	Wide/Vert 10 MM					Flame

TABLE II (Cont.)

RUN #	FILM #	TYPE FILM	FRAME RATE (FPS)	LENS USED	CAMERA POSITION	TEST DESCRIPTION MEDIUM	FLOW RATE	TEMP	OBJECT VIEWED
001	510	Color	24	Telephoto	180°	Liquid Hydrogen	9.6 #/sec	37°R	Pond
	511			Wide/Vert 10 MM					Flame

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B. FULL-SCALE HYDROGEN BURN POND

The full-scale burn pond is positioned in a depression approximately 400 ft from test stand H-4B (see Figure 5). It is 35-ft wide, 85-ft long and 3-ft 6-in. deep. A weir at one end allows a maximum water depth of 3 ft. The pond is constructed of gunite and has a heat-resistant refractory coping that extends 12 in. below the top edge.

The gas distribution system within the pond is in a "trellis" or ladder configuration, as shown in Figure 6. Hydrogen is distributed within the pond through a 14-in. manifold to thirty-two 6-in. lateral branches, spaced at 5-ft intervals. From the bottom of each distribution branch, twenty-two 1-1/2-in. pipe nipples, spaced 8-1/2 in. apart, discharge the gas toward the bottom of the pond. The gas is discharged from the nozzles, under approximately 2 ft of water, at a nominal flow of approximately 0.35 lb/sec-per-nozzle.

The pond ignition system is comprised of four pump-fed, Diesel flame thrower units, two at each end of the pond.

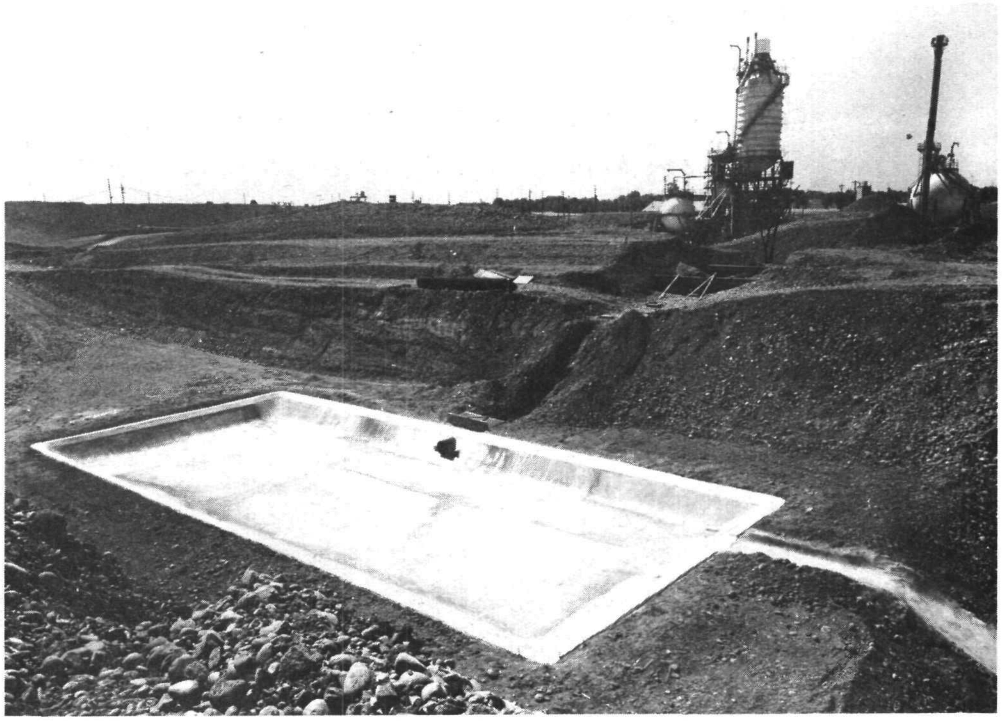


Figure 5

Full-Scale Hydrogen Burn Pond

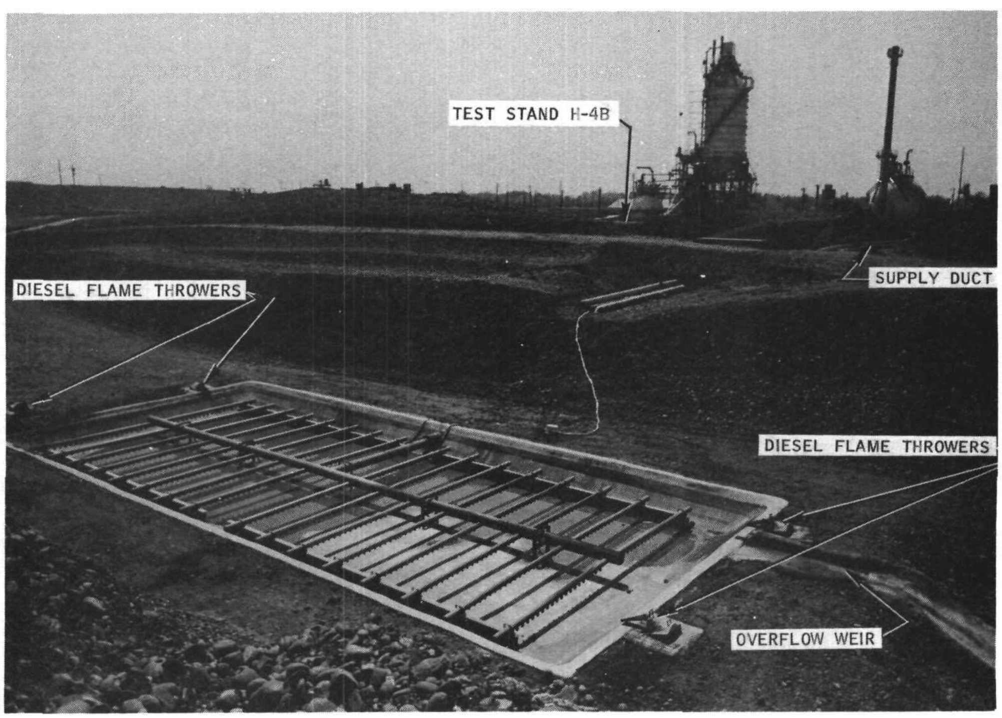


Figure 6

Full-Scale Hydrogen Burn Pond Piping

V. BURN POND TESTING

A. SCALE MODEL HYDROGEN BURN POND TESTING

1. Liquid Nitrogen Testing

a. Test Objectives

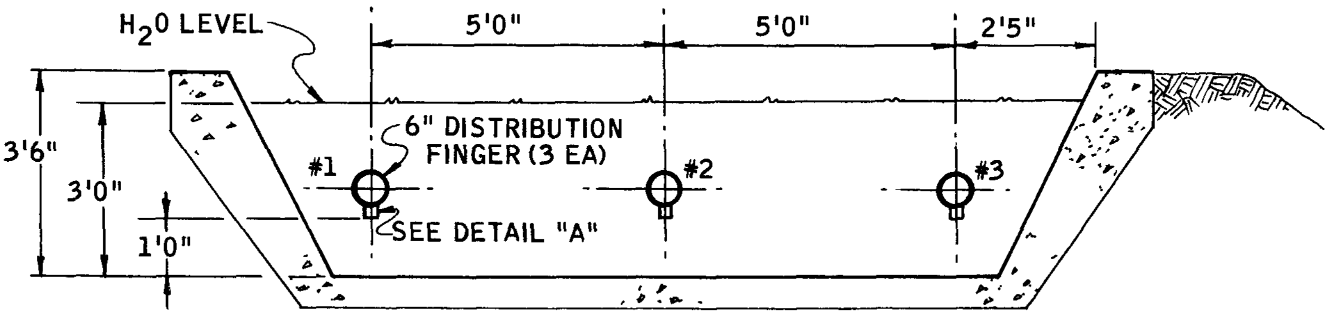
The primary purpose of this test was to activate the mechanical, instrumentation and controls systems installed by the contractor. As a secondary objective, the test was conducted to determine the following:

(1) Gas distribution at subsonic velocities
(2) Water surface turbulence
(3) Water freezing effects at the gas discharge nozzles
(4) Simulation of gas jet momentum equivalent to gaseous hydrogen flow planned for subsequent tests.

b. Summary of Test 001 (Figures 7 and 8)

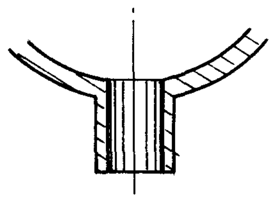
A maximum mass flow rate of 44 lb/sec of nitrogen was recorded during approximately 50 sec of test time. This produced a gas momentum from the discharge nozzles in excess of the equivalent nozzle momentum calculated for the main PHOEBUS burn pond, which was designed for a hydrogen flow of 250 lb/sec at 135°R.

Water surface turbulence created by the expelled gas was initially at an acceptable level; that is, water losses from splashing and gas lifting were low. Near the end of the test, cold vapors were observed, indicating that liquid nitrogen was being discharged through the nozzles into the pond. At this time the pond became totally obscured by the vapors and the test was terminated. Post-test examination of the pond showed that approximately one foot of water remained, with an ice layer at the surface varying from approximately 1/16- to 1/2-in. thick (Figure 9).



SYSTEM SHAKEDOWN

POND SECTION

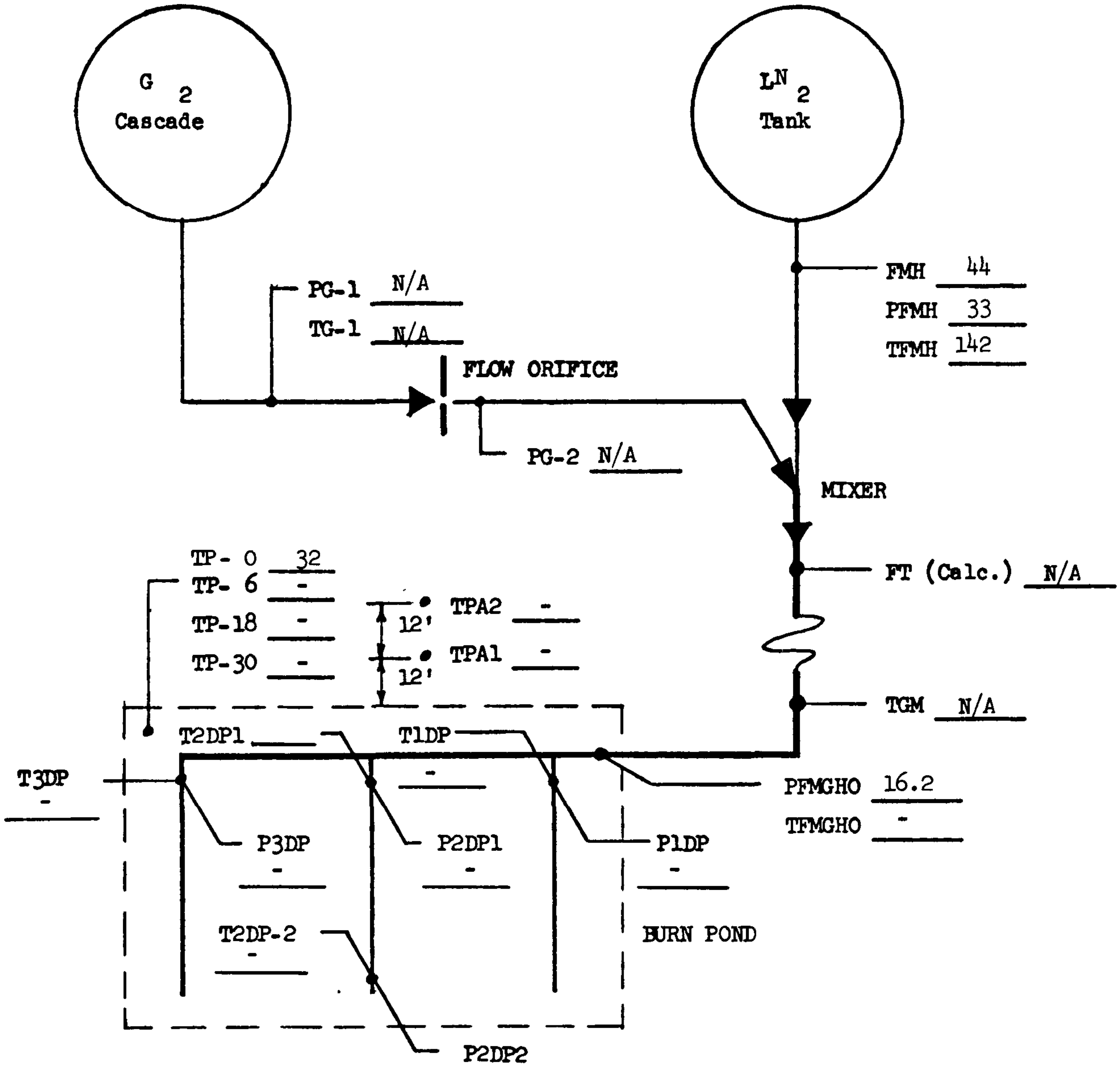


DETAIL "A"

1-1/2" SCH 80 NOZZLE (27 REQ'D)

Figure 7

Pond Section-LN_2, Test No. 001



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST 44 lb/sec LN_2

RUN # 001 DATE 11/11/65

DATA TIME - SECS.

TEST DURATION 50 SEC.

H_2O LOSS 23 IN. FLAME HEIGHT - FT.

WIND -

Figure 8

Instrumentation Schematic, Summary Test No. 001

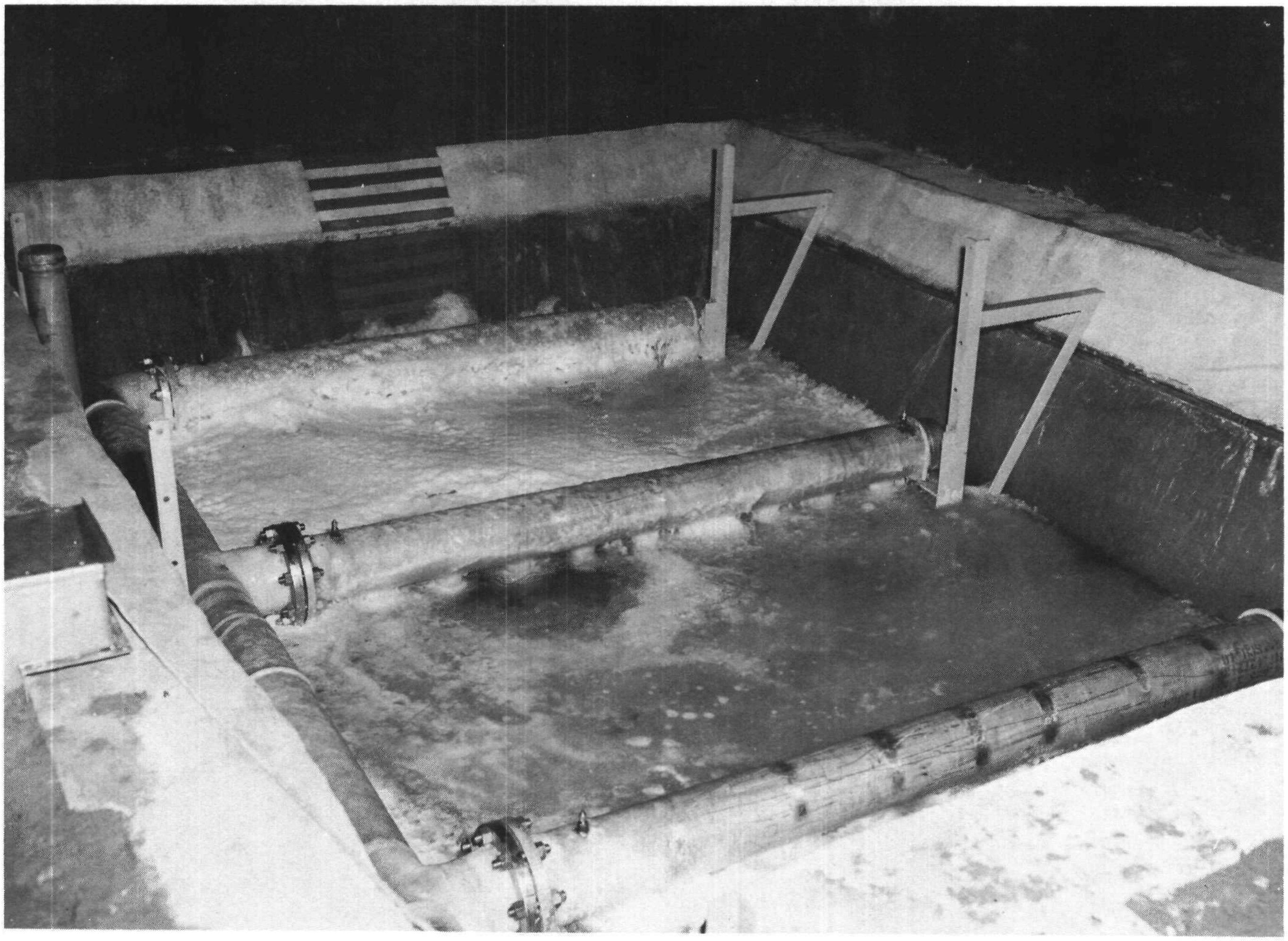


Figure 9
Pond Post Test Photo, Test No. 001

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There was no damage to either the concrete pond or piping systems as a result of the liquid nitrogen flow.

c. Conclusions

Freezing of the discharge ports does not appear to be a problem during flow conditions with liquid nitrogen. Unequal flow distribution to the three lateral branches was visually observed during the test. This condition appeared to be a result of pressure unbalance in the pond distribution system resulting from the subsonic discharge velocities of each of the twenty-seven 1-1/2-in. discharge ports.

2. <u>Mixed Nitrogen Testing</u>

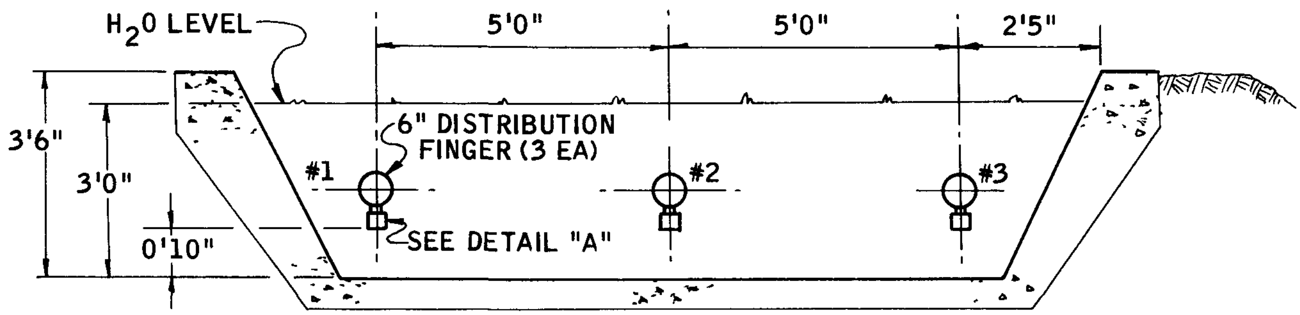
a. Test Objectives

The objective of this test series was to determine the effects of discharging cold gas into the water at a mass flow rate and velocity that would simulate the momentum of the gas jets predicted for the main pond. Primarily the buoyancy (lifting of the water), water temperature change, pond surface turbulence and maintenance of the water seal were to be determined. Each nozzle was orificed for critical flow to eliminate the system unbalance seen in the previous test.

b. Test Summaries

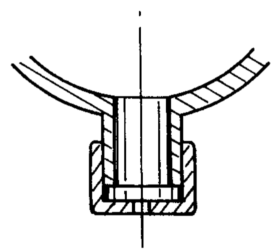
(1) Test 002 (Figures 10 and 11)

This test utilizes approximately 13 lb/sec of ambient nitrogen gas and 16 lb/sec of liquid nitrogen mixed together to produce an average gas temperature of 195° Rankine. Cold gas vapors observed at the start of the test indicated improper mixing of the liquid and gas which allowed slugs of liquid to enter into the pond. As witnessed in Test 001, there was a violent reaction of the water to the liquid. Jets of water were observed 10 to 15 ft above the pond. Approximately 14 in. of water remained at the end of the test but this was sufficient to maintain the seal. There was no indication of icing.



MOMENTUM SIMULATION - SONIC FLOW

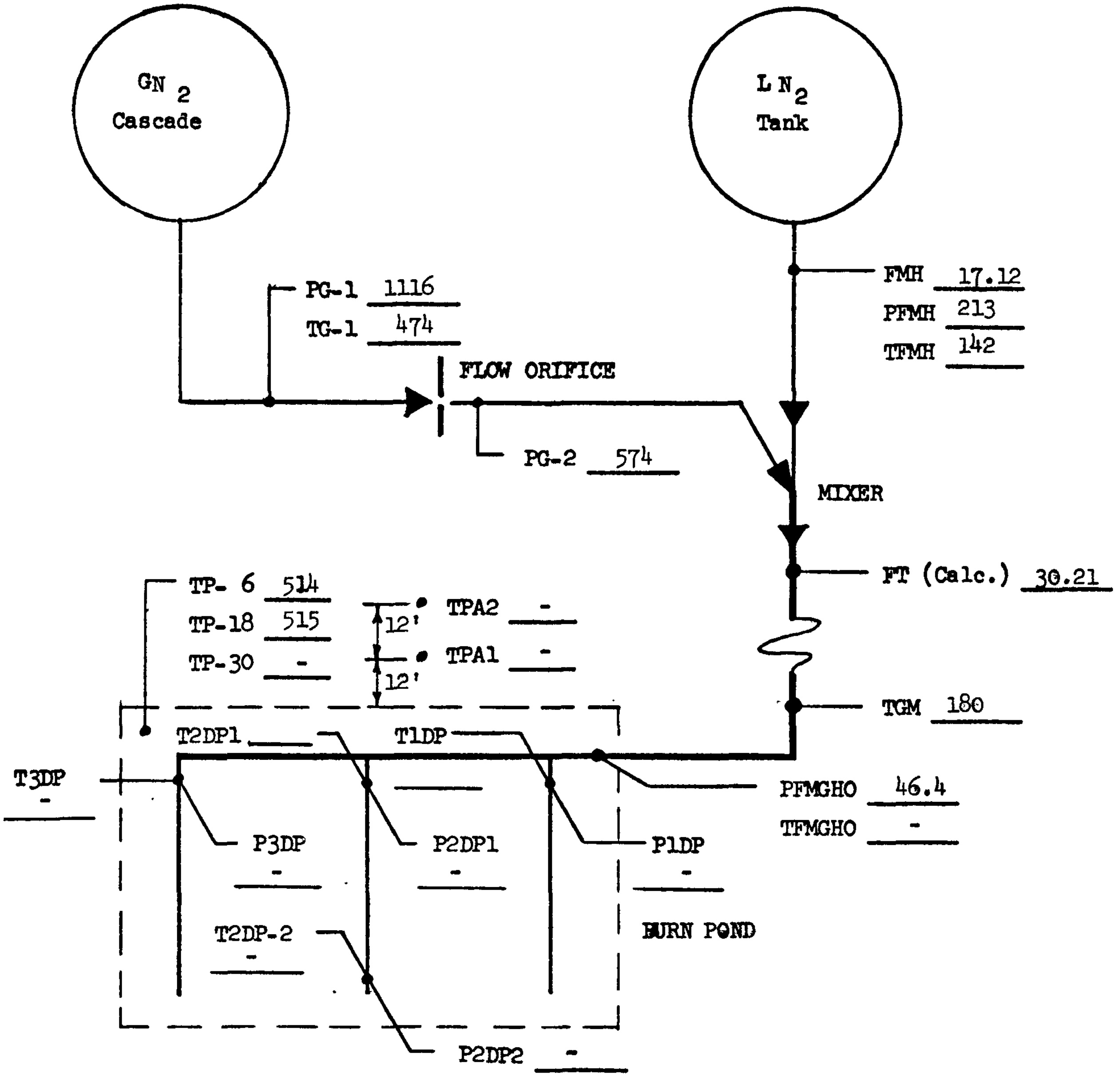
POND SECTION
H_2O LOSS 22 INCHES



DETAIL "A"
7/8" SONIC ORIFICE (27 REQ'D)

Figure 10

Pond Section, Mixed N_2 Test Nos. 002, 003



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST Mixed N_2, 29 lb/sec.

RUN # 002 DATE 11/24/65

DATA TIME 30 SECS.

TEST DURATION 31 SECS

H_2O LOSS 22 IN. FLAME HT. - FT.

WIND -

Figure 11

Instrumentation Schematic, Summary Test No. 002

(2) Test 003 (Figures 10 and 12, Table III)

The requirements of this test were the same as in the previous test; however, the procedure for producing a properly mixed gas was improved to eliminate the introduction of liquid into the pond. The nominal gas temperature was 195° Rankine. The results of this test were essentially the same as in Test 002.

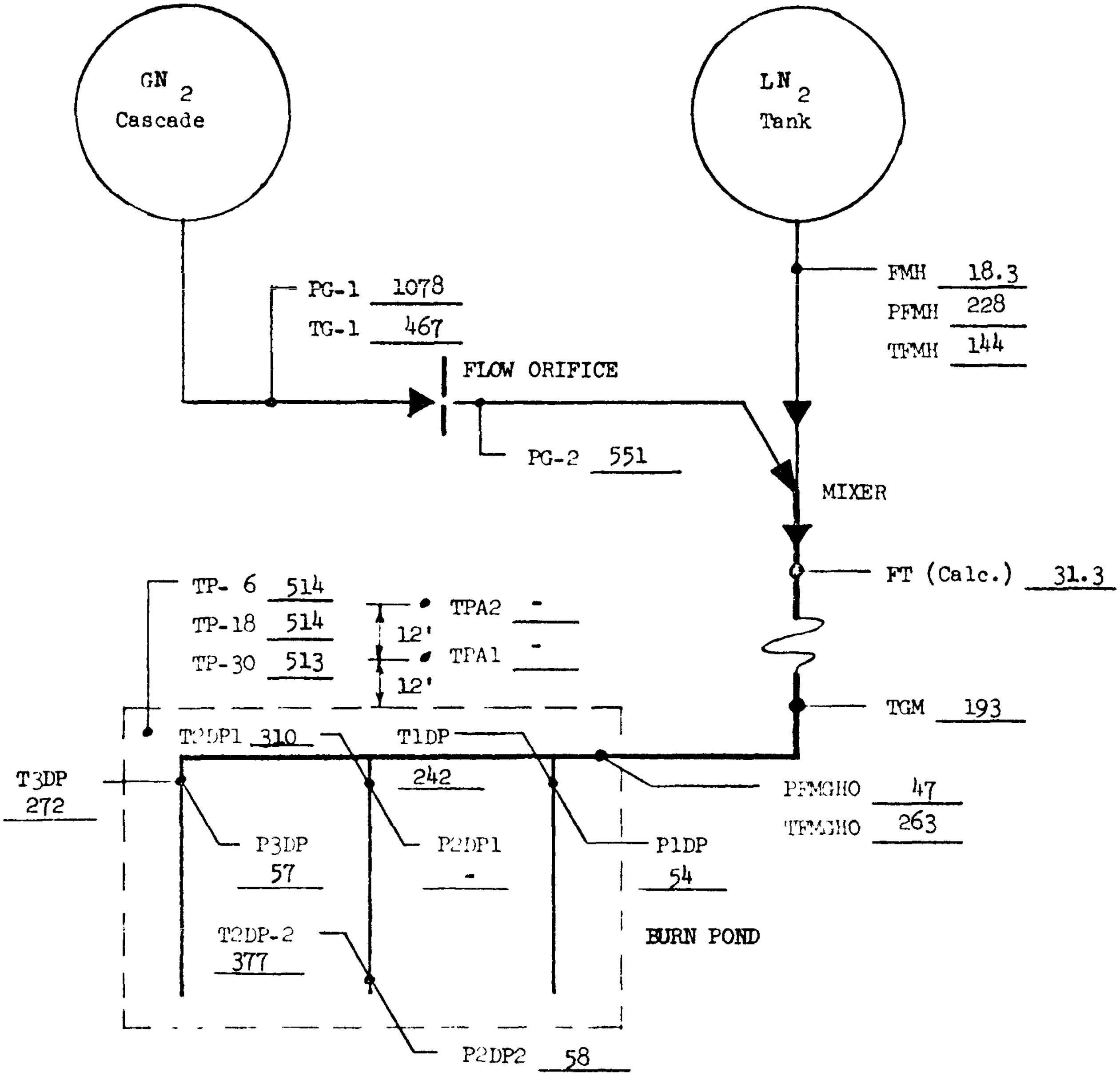
(3) Test 004 (Figures 13 and 14, Table IV)

For this test the distribution piping within the pond was raised approximately sixteen inches bringing the total distance from the nozzle exits to the bottom of the pond to 2-ft, 4-in. The piping was raised in an attempt to more completely dissipate the momentum of the gas jets within the pond.

The total flow rate of this test was approximately 22 lb/sec at an average temperature of 210° Rankine. The results of this test were about the same as Tests 002 and 003; however, the water seal was lost as a result of the raising of the piping.

c. Conclusions

The critical flow orifices at each of the discharge nozzles appeared to distribute the flow equally. However, the increased expansion ratio and volumetric change of the gas appeared to significantly contribute to high water loss by the increased jetting and lifting action of the water. It was further concluded, following these tests, that the proximity of the gas discharge nozzles to the sloped walls may be providing an undesirable condition whereby the impingement of the gas jet upon the wall is forcing water out of the pond. This condition was brought about by the scale pond design criteria of duplication of the main pond nozzle-to-water-volume and surface-area ratio.



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST Mixed Nitrogen, 29 lb/sec

RUN # 003 DATE 11/24/65

DATA TIME 40 SECS.

TEST DURATION 40 **SECS.**

H_2O **LOSS** 22 **IN. FLAME HT.** - **FT.**

WIND -

Figure 12
Instrumentation Schematic, Summary Test No. 003

TABLE III

SCALE MODEL HYDROGEN BURN POND
INSTRUMENTATION RECAP - RUN # 003 DATE 11/24/65

Type Test Mixed Nitrogen 29 lb/sec

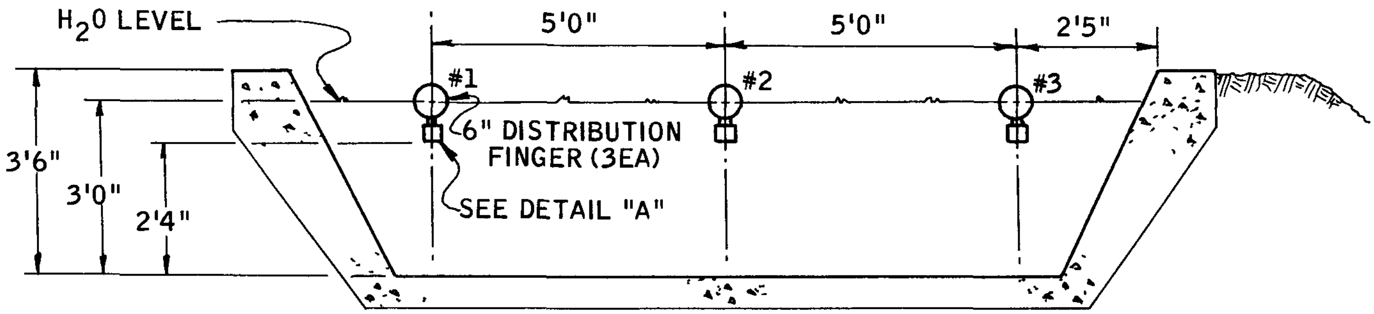
			LAPSE TIME READINGS - SECONDS												
PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
FMH	LN2 Flow Meter	Lb/sec	19	17	15	14.5	17	17	17	18	18				
PFMH	Pressure @ Flow Meter	Pisa	248	240	237	235	241	239	235	232	229				
TFMH-1	Temperature @ Flow Meter	°R	146	145	145	145	144	144	144	144	144				
TFMH-2	Temperature @ Flow Meter	°R	148	146	146	146	146	145	145	146	145	145	146		
TP-0	H_2O Temperature @ Bottom of Pond	°R	517	517	517	516	516	516	515	515	514	513	512	510	
TP-18	H_2O Temp, 18" from Bottom of Pond	°R	517	517	517	517	517	516	515	515	514	513	512	510	
TP-30	H_2O Temp, 30" from Bottom of Pond	°R	516	516	516	516	515	515	515	514	513				
ΔPFMGHO	ΔPressure @ Pond Inlet	Psig	11.8	11.7	13.3	16.4	14.6	13.7	11.4	14.4	11.2				
ΔPFMGHO	ΔPressure @ Pond Inlet	Psia	38	46	51	53	51	49	48	49	47				
TFMGHO	Temperature @ Pond Inlet	°R	484	483	483	484	483	437	384	323	263	211			
TIDP	Temperature @ #1 Dist. Pipe Inlet	°R	508	492	470	443	412	378	336	293	242	202	173		
T2DP-2	Temperature @ #2 Dist. Pipe Outlet	°R	519	513	502	490	477	455	431	405	377				
T3DP	Temperature @ #3 Dist. Pipe Inlet	°R	514	500	481	455	424	395	358	315	272				

TABLE III (Cont.)

Type Test Mixed Nitrogen 29 lb/sec

PARAMETER	FUNCTION	UNITS	LAPSE TIME READINGS - SECONDS 0	5	10	15	20	25	30	35	40	45	50	55	60
PIDP	Pressure @ #1 Dist. Pipe Inlet	Psia	47	56	62	63	60	58	57	56	54				
P2DP-2	Pressure @ #2 Dist. Pipe Outlet	Psia	50	60	67	68	65	62	61	60	58				
P3DP	Pressure @ #3 Dist. Pipe Inlet	Psia	50	59	66	67	65	61	61	59	57				
TG-1	Temperature @ Gas Flow Nozzle	°R	475	474	473	472	471	470	469	468	467				
PG-1	Pressure Upstream Gas Flow Nozzle	Psia	1075	1067	1071	1070	1070	1073	1076	1079	1078				
PG-2	Pressure Downstream Gas Flow Nozzle	Psia	549	546	548	548	548	549	550	551	551				
TGM	Temperature Mixed Gas	°R	192	196	198	197	196	195	195	194	193				

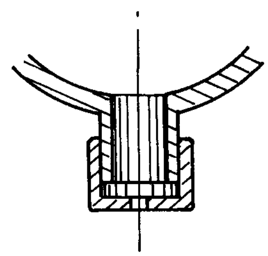
1.2-13-NNX-004 MIXED NITROGEN



MOMENTUM SIMULATION - SONIC FLOW

POND SECTION

H_2O LOSS 22 INCHES

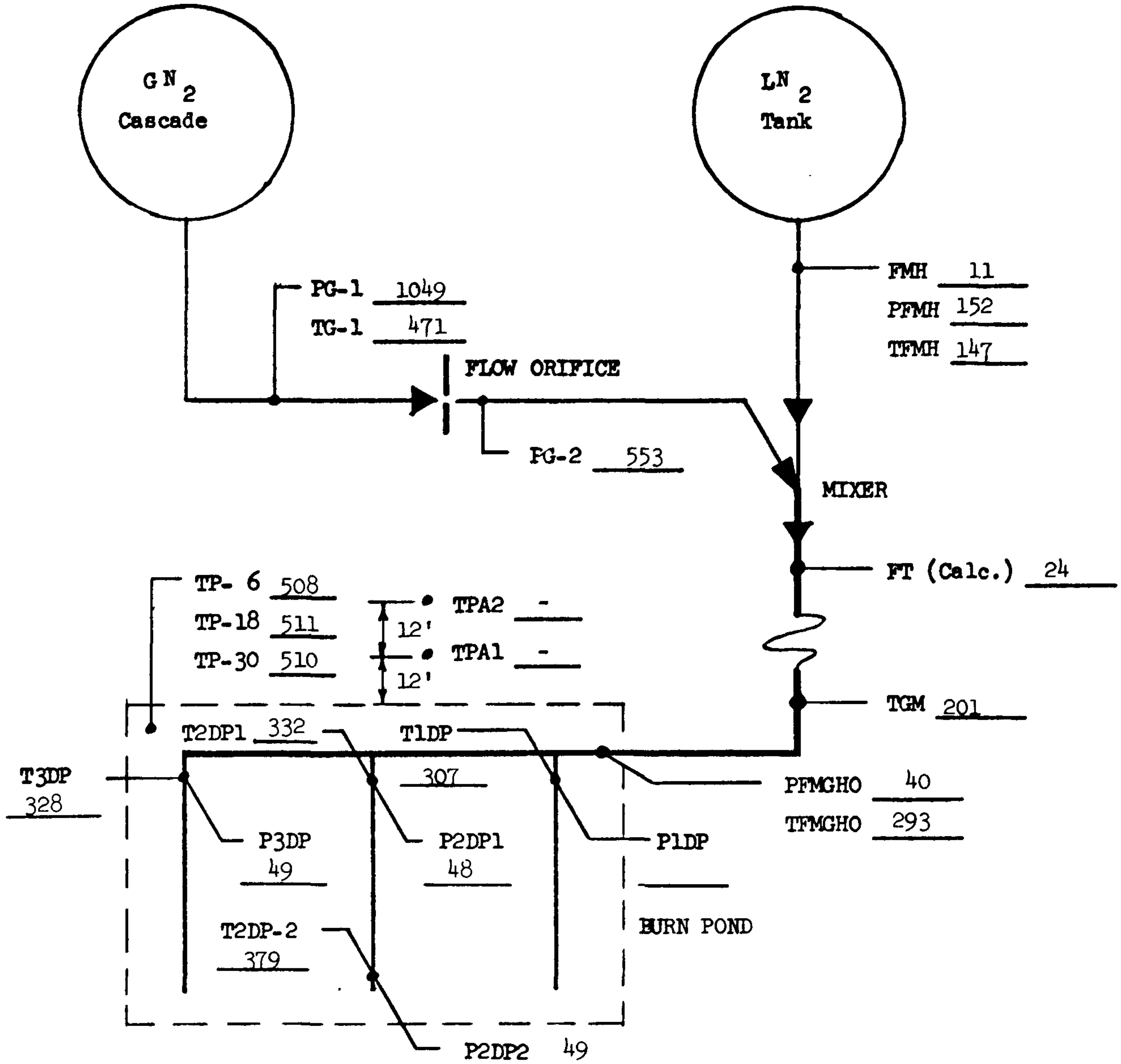


DETAIL "A"

7/8" DIA SONIC ORIFICE (27REQ'D)

Figure 13

Pond Section, Mixed N_2 Test No. 004



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST Mixed Nitrogen 22 lb/sec

RUN # 004 DATE 11/30/65

DATA TIME 35 SECS.

TEST DURATION 35 SECS.

H_2O LOSS 22 IN. FLAME HT. - FT.

WIND -

Figure 14

Instrumentation Schematic, Summary Test No. 004

TABLE IV

PHOEBUS-2 SCALE BURN POND
INSTRUMENTATION RECAP - RUN # 004 DATE 11/30/65

Type Test Mixed Nitrogen 22 lb/sec

			LAPSE TIME READINGS - SECONDS												
PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
FMH	LN_2 Flow Meter	Lb/sec	10	10	10	10	10	11	10	11					
TFMH-1	Temperature @ Flow Meter	°R	152	150	149	148	148	148	147	147					
TFMH-2	Temperature @ Flow Meter	°R	165	165	158	165	151	159	155	169					
TP-0	H_2O Temperature @ Bottom of Pond	°R	513	513	513	513	512	512	511	511					
TP-6	H_2O Temp, 6" from Bottom of Pond	°R	510	510	510	510	509	509	508	508					
TP-18	H_2O Temp, 18" from Bottom of Pond	°R	513	513	513	513	512	512	512	511					
TP-30	H_2O Temp, 30" from Bottom of Pond	°R	513	513	513	511	512	511	511	510					
ΔPFMGHO	ΔPressure @ Pond Inlet	Psig	6.11	6.54	5.57	6.34	6.09	6.02	6.80	7.00					
PFMGHO	Pressure @ Pond Inlet	Psia	41	41	41	41	41	40	41	40					
P2DP-1	Pressure @ #1 Dist. Pipe Outlet	Psia	51	51	50	50	50	49	48	48					
P2DP-2	Pressure @ #2 Dist. Pipe Outlet	Psia	53	53	52	51	51	50	50	49					
P3DP	Pressure @ #3 Dist. Pipe Inlet	Psia	52	53	52	51	51	50	50	49					
TFMGHO	Temperature @ Pend Inlet	°R	408	390	370	352	334	320	305	293					

TABLE IV (Cont.)

Type Test Mixed Nitrogen 22 lb/sec

PARAMETER	FUNCTION	UNITS	LAPSE TIME READINGS - SECONDS 0	5	10	15	20	25	30	35	40	45	50	55	60
T1DP	Temperature @ #1 Dist. Pipe Inlet	°R	421	404	385	367	350	334	318	307					
T2DP-1	Temperature @ #2 Dist. Pipe Inlet	°R	440	423	406	389	372	358	342	332					
T2DP-2	Temperature @ #2 Dist. Pipe Outlet	°R	468	452	440	428	412	401	398	379					
T3DP	Temperature @ #3 Dist. Pipe Inlet	°R	436	419	402	385	370	355	339	328					
TG-1	Temperature @ Gas Flow Nozzle	°R	477	476	475	474	473	472	472	471					
PG-2	Pressure Downstream Gas Flow Nozzle	Psia	549	548	549	549	554	550	551	553					
TGM	Temperature Mixed Gas	°R	222	219	214	210	205	207	202	201					

The elevation of the nozzles within the pond for Test 004 did not produce any significant changes in water losses from the previous tests. The water losses were enough to expose the elevated discharge nozzles, thereby effecting a loss of the water seal designed to prevent the entry of atmospheric air into the system.

3. Ambient Gaseous Hydrogen Testing

a. Test Objectives

This test series consisted of flowing ambient gaseous hydrogen into the pond at a mass flow rate of 4.5 lb/sec required to simulate the gas momentum of the main pond. Each test was started at a flow rate of approximately 1-lb/sec until pond ignition was obtained. In addition to determining the effects on the water as in the previous test series, the ignition characteristics, flame configuration and temperature gradients of the surrounding area were determined.

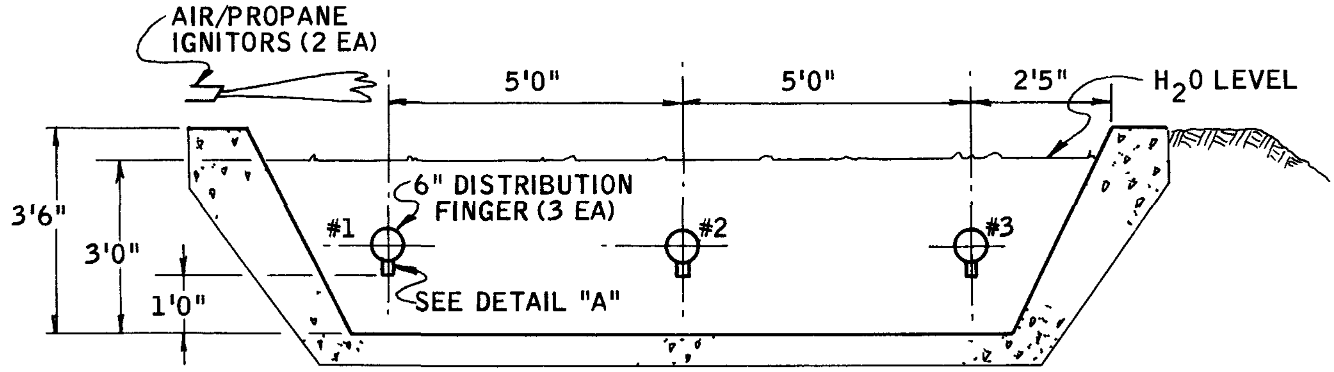
b. Test Summaries

(1) Test 005 (Figures 15 through 18, and Table V)

This test utilized ambient gaseous hydrogen at mass flow rates of 1, 3- and 4.5-lb/sec for a minimum of 15 sec at each flow condition. The ignition of the effluent gas, achieved at a flow rate of less than 1-lb/sec, was smooth and barely audible. At a flow rate of 4.5 lb/sec, the flame was columnar in nature and estimated to be from 150 to 175 ft in height.

The movement of the water appeared to be less violent than in the previous test series. A review of the motion pictures taken from a position parallel to the lateral branches showed a definite unbalance of the gas

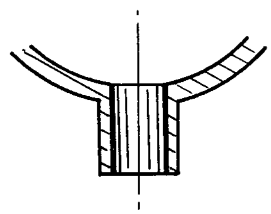
1.2-13-NNX-005 AMBIENT HYDROGEN GAS - 1, 3 & 4.5 #/SEC



MOMENTUM SIMULATION

POND SECTION

H_2O LOSS 18 INCHES

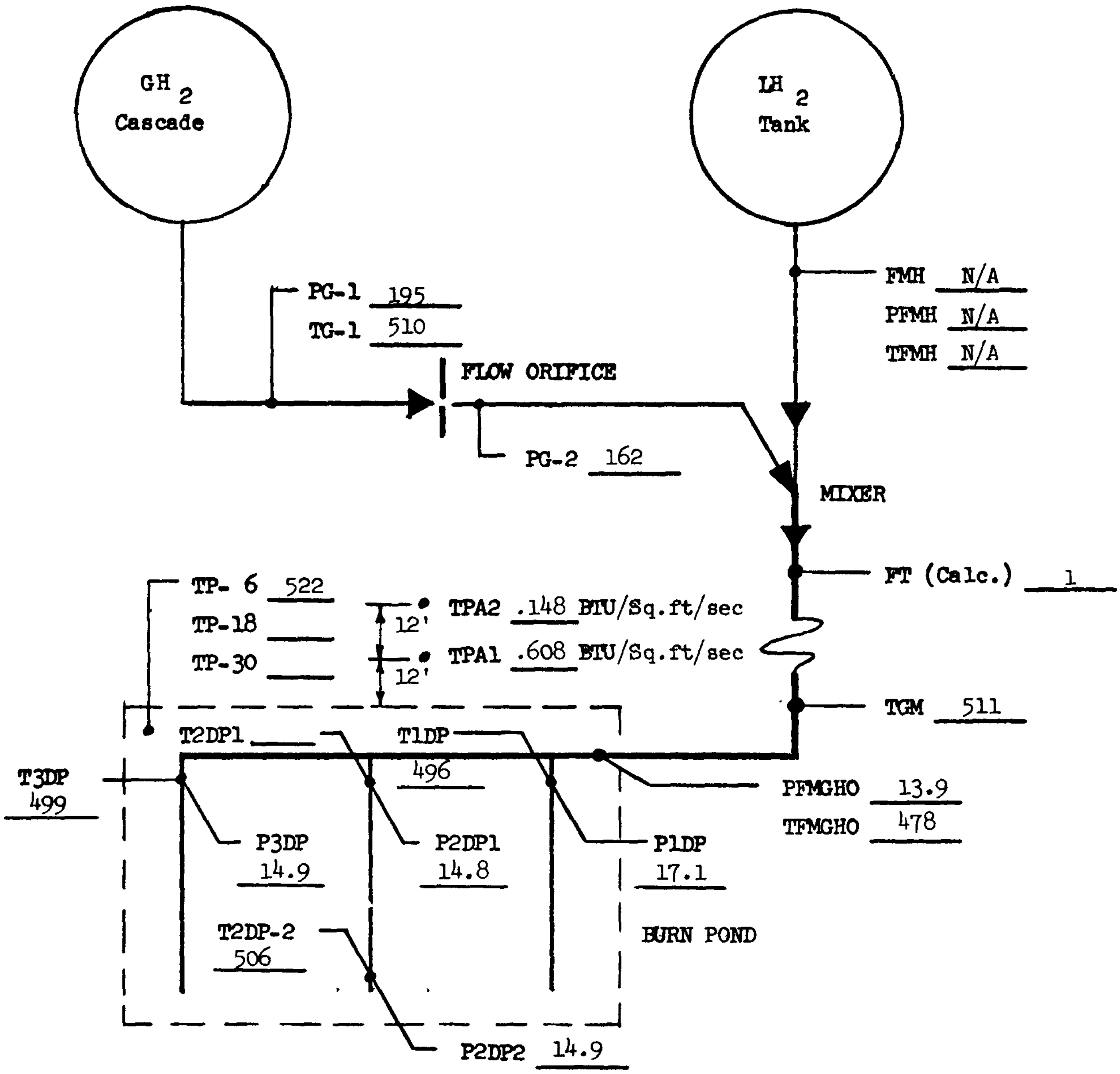


DETAIL "A"

1-1/2" SCH 80 NOZZLE (27 REQ'D)

Figure 15

Pond Section, Ambient H_2 Test No. 005



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

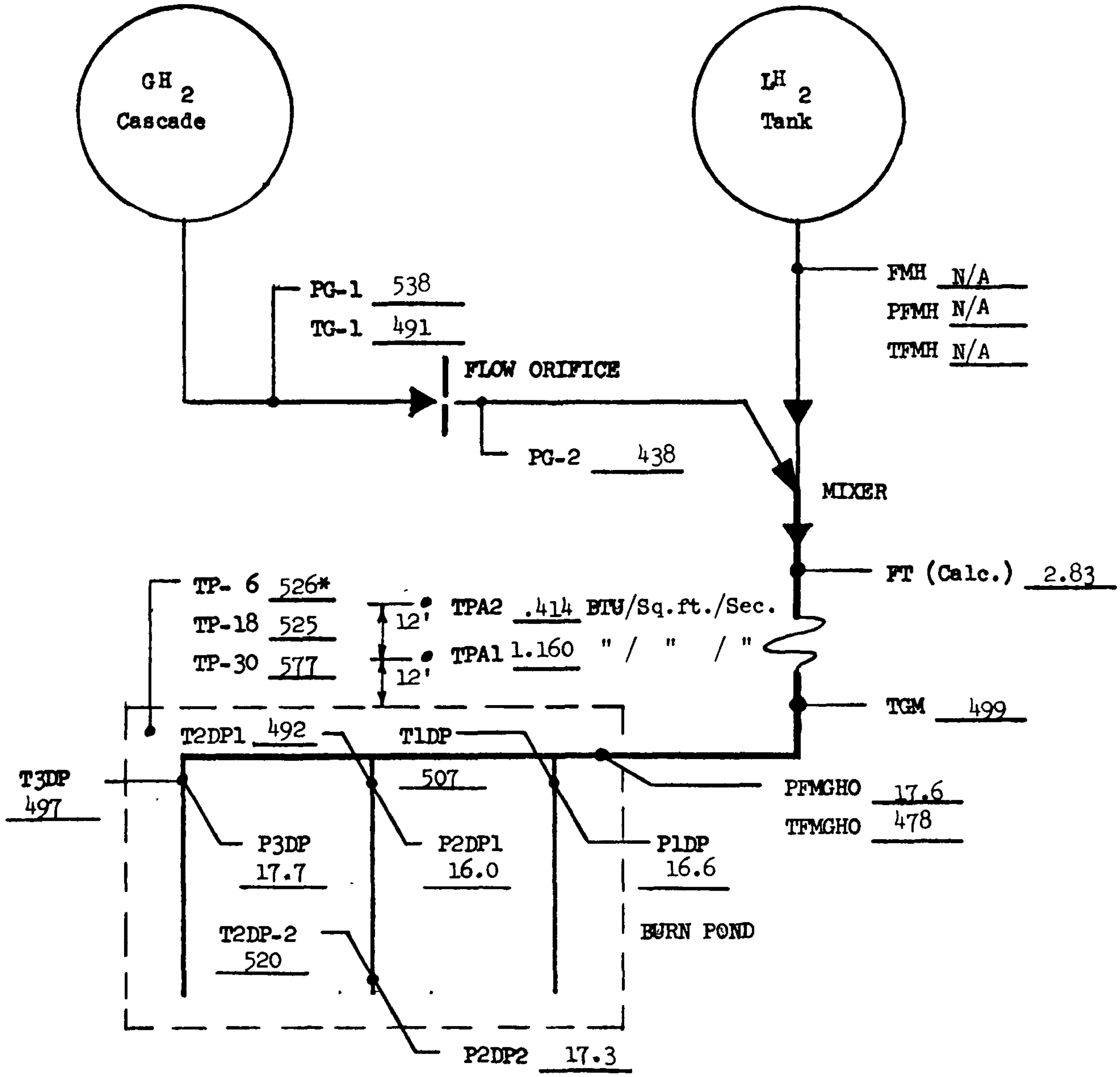
TEST GH$_2$ Ambient 1#

RUN # .005 DATE 12 /3 /65

DATA TIME 15 SECS.

Figure 16

Instrumentations Schematic, Summary Test No. 005, @ 15 Seconds



LEGEND, 1st LETTER

- P PRESSURE, PSIA
- T TEMPERATURE, °R
- F FLOW LB/SEC
- * NOMINAL VALUE

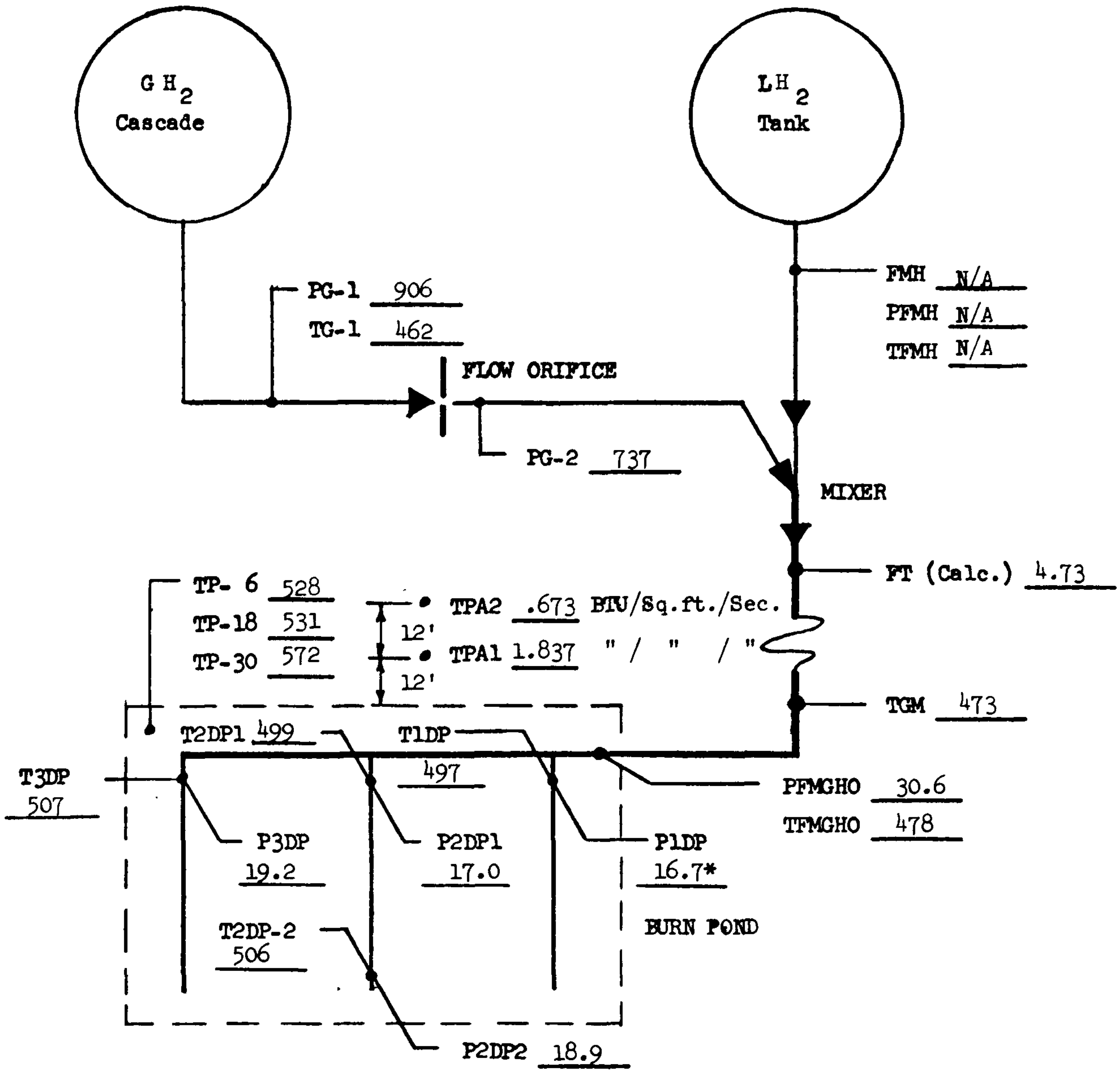
TEST GH_2 Ambient 3#

RUN # 005 DATE 12 / 3/65

DATA TIME 45 SECS.

Figure 17

Instrumentation Schematic, Summary Test No. 005, @ 45 Seconds



LEGEND, 1st LETTER

P PRESSURE, PSIA
T TEMPERATURE, °R
F FLOW LB/SEC
* NOMINAL VALUE

TEST GH_2 Ambient 4.5#
RUN # 005 DATE 12 /3 /65
DATA TIME 60 SECS.
TEST DURATION 60 SECS.
H20 LOSS 18 IN. FLAME HT. 175 FT.
WIND Calm

Figure 18

Instrumentation Schematic, Summary Test No. 005, @ 60 Seconds

TABLE V

PHOEBUS-2 SCALE BURN POND
INSTRUMENTATION RECAP - RUN # 005 DATE 12/03/65

Type Test GH_2 (Amb) @ 1, 3, & 4.5 lb/sec

			LAPSE TIME READINGS - SECONDS FS1/FS2 35.6 sec												
PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
TP-6	H_2O Temp @ 6" Up From Bottom of Pond	°R	518	519	521	522	522	522	522	523	525	526	527	527	528
TP-18	H_2O Temp @ 18" Up From Bottom of Pond	°R	521	521	521	522	522	522	524	523	525	525	527	527	531
TP-30	H_2O Temp @ 30" Up From Bottom of Pond	°R	513	519	521	522	521	521	540	532	550	577	542	578	572
T1DP	Temp @ #1 Dist. Pipe Inlet	°R	511	499	498	496	496	492	514	514	497	509	509	491	497
T2DP-1	Temp @ #2 Dist. Pipe Inlet	°R	492	497	497	494	494	493	491	490	492	492	492	496	499
T2DP-2	Temp @ #2 Dist. Pipe Outlet	°R	508	505	506	506	503	503	520	520	520	520	506	503	506
T3DP	Temp @ #3 Dist. Pipe Inlet	°R	504	501	501	499	500	498	496	496	496	497	500	499	507
TI-1	Temp @ Igniter Box #1	°R	577	575	576	576	577	574	575	574	574	572	572	572	571
TI-2	Temp @ Igniter Box #2	°R	585	581	581	579	579	578	578	577	576	574	574	575	572
TG-1	Temp, Upstream Gas Flow Nozzle	°R	509	510	510	510	510	507	503	499	495	491	484	471	462
TFS	Temp at Flare Stack	°R	503	503	503	503	503	503	503	503	503	503	503	503	503
TPA-1	Temp @ Pond Area	Btu/s	.614	.590	.680	.581	.894	1.084	1.021	1.108	.969	1.144	1.078	1.286	1.76
TPA-2	Temp @ Pond Area	Btu/s	.181	.148	.160	.130	.248	.359	.423	.420	.344	.4[illegible]	.392	.474	.664

TABLE V (Cont.)

Type Test GH_2 (amb) @ 1, 3, & 4.5 lb/sec

			LAPSE TIME READINGS - SECONDS FS1/FS2 35.6 sec												
PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
ΔPFMGHO	ΔPressure @ Pond Inlet	Psig	1.70	11.37	1.19	1.33	3.77	4.93	5.91	5.95	5.14	7.36	6.52	9.64	10.37
PFMGHO	Pressure @ Pond Inlet	Psia	14.5	14.4	15.2	13.9	13.2	16.1	18.2	17.6	17.2	17.6	24.1	30.2	30.6
P1DP	Pressure @ #1 Dist. Pipe Inlet	Psia	16.2	15.9	17.3	17.1	17.5	15.8	18.3	16.9	16.7	16.6	16.0	16.7	
P2DP-1	Pressure @ #2 Dist. Pipe Inlet	Psia	15.1	15.3	16.0	14.8	15.9	15.8	16.7	16.3	16.5	16.0	18.7	17.3	17.0
P2DP-2	Pressure @ #2 Dist. Pipe Outlet	Psia	15.3	15.5	16.1	14.9	16.2	16.9	18.0	17.6	17.6	17.3	20.9	19.1	18.9
P3DP	Pressure @ #3 Dist. Pipe Inlet	Psia	15.3	15.3	16.1	14.9	16.0	17.1	18.5	17.8	17.7	17.7	21.0	19.3	19.2
PG-1	Pressure, Upstream Gas Flow Nozzle	Psia	200	198	196	195	391	550	562	546	541	538	805	910	906
PG-2	Pressure, Down-stream Gas Flow Nozzle	Psia	166	164.6	163.3	162	319.4	448	458	445	440	438	656	740	737
TFMGHO	Temp @ Pond Inlet	°R	478	478	478	478	478	478	478	478	478	478	478	478	478
TGM	Temp of Mixed Gas	°R	510	510	511	511	514	513	509	506	503	499	493	482	473
ΔPG	ΔPressure of Gas Flow Nozzle	Psia	70.9	70.3	69.8	69.2	138.2	190.1	194.2	188.5	187	186	277.8	311.7	310.8

discharge with most of the gas flowing from Headers 2 and 3 (see Figure 15). Approximately 18 in. of water was lost during the test, most of which went over the pond end nearest Header 3 (Figure 19) in sheet flow. Temperature template stickers and calorimeters positioned in the immediate pond area indicated that temperatures and heat energy output were moderate during the test. The temperature of the pond water increased from 58 to 68°F.

(2) Test 006 (Figures 20 through 23, and Table VI)

To eliminate the impingement of the gas jet on the sloped walls, Headers 1 and 3 were rotated 45° inward toward the center of the pond. Test 006 was then conducted using the same criteria as in Test 005. Pond ignition was again smooth and silent. During the test a 5 mi/hr wind was blowing, with gusts up to 20 mi/hr which affected the flame height (100 ft) and geometry. Template sticker and calorimeter data corresponded to the data from the previous tests.

The movement of the water appeared to be less violent than during the previous test, with most of the 12- to 15-ft geysering toward the center of the pond (Figures 24, 25 and 26). Approximately 12 in. of water was lost during the test. The water temperature was 60°F before and 66°F after the test.

c. Conclusions

The ignition and disposal of hydrogen in this manner presents no apparent problems. The effluent hydrogen gas was easily ignited and continued to burn throughout the entire test. Measured temperatures of less than 110°F at a distance of 50 ft from the pond, indicating that the radiant heat from this quantity of burning gas was moderate. The quantity of water lost during the tests was decreased by rotating the two outer header branches toward the center.

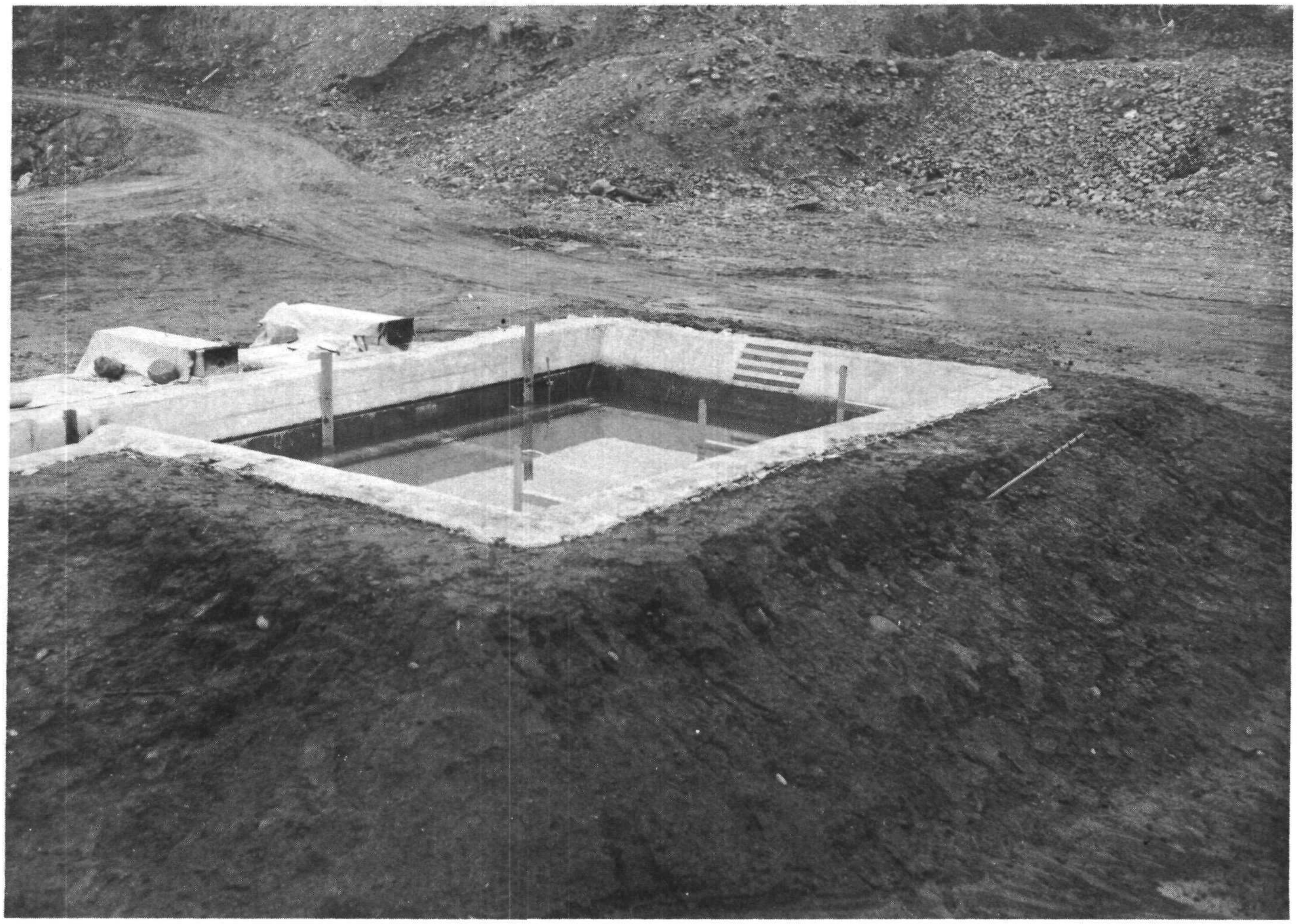


Figure 19

Pond Test Photo, Test No. 005

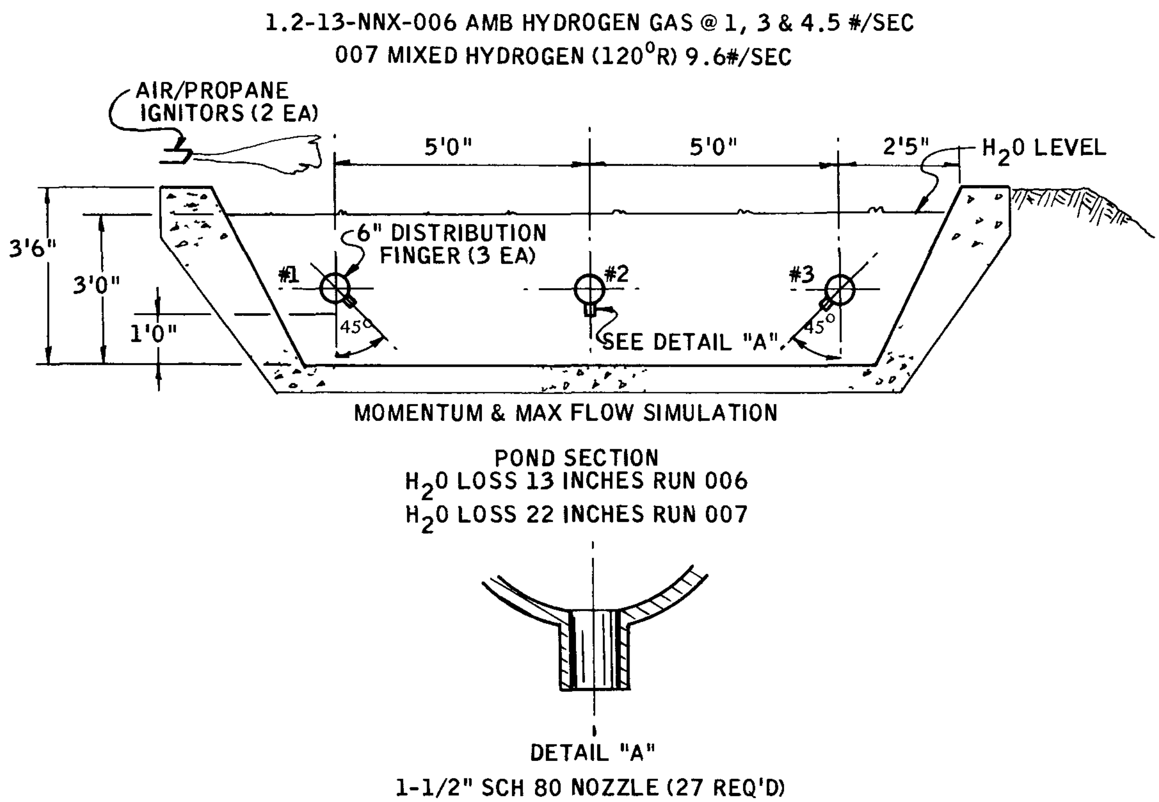
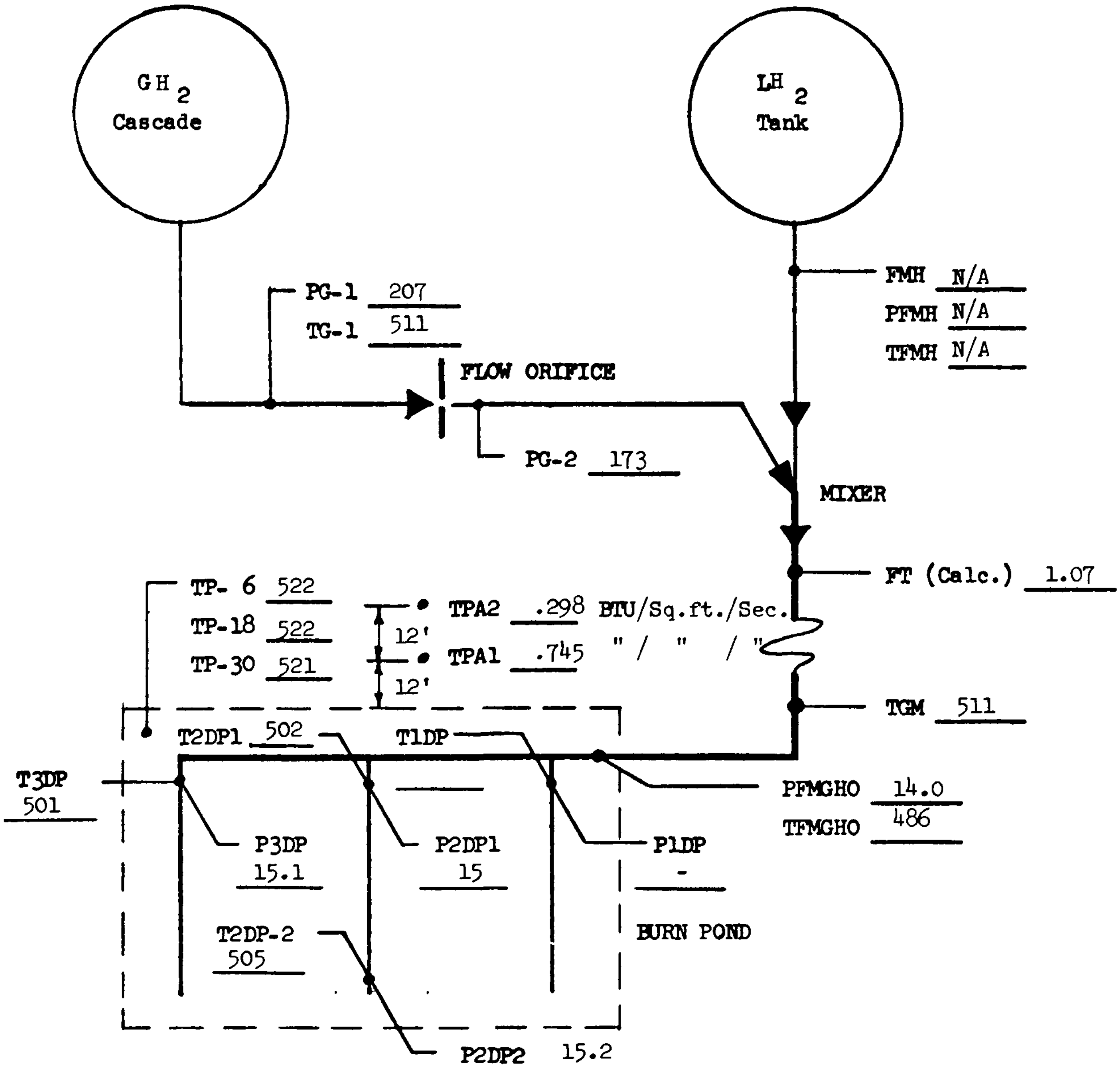


Figure 20

Pond Section, Ambient GH_2 Test No. 006, Mixed H_2 Test No. 007



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

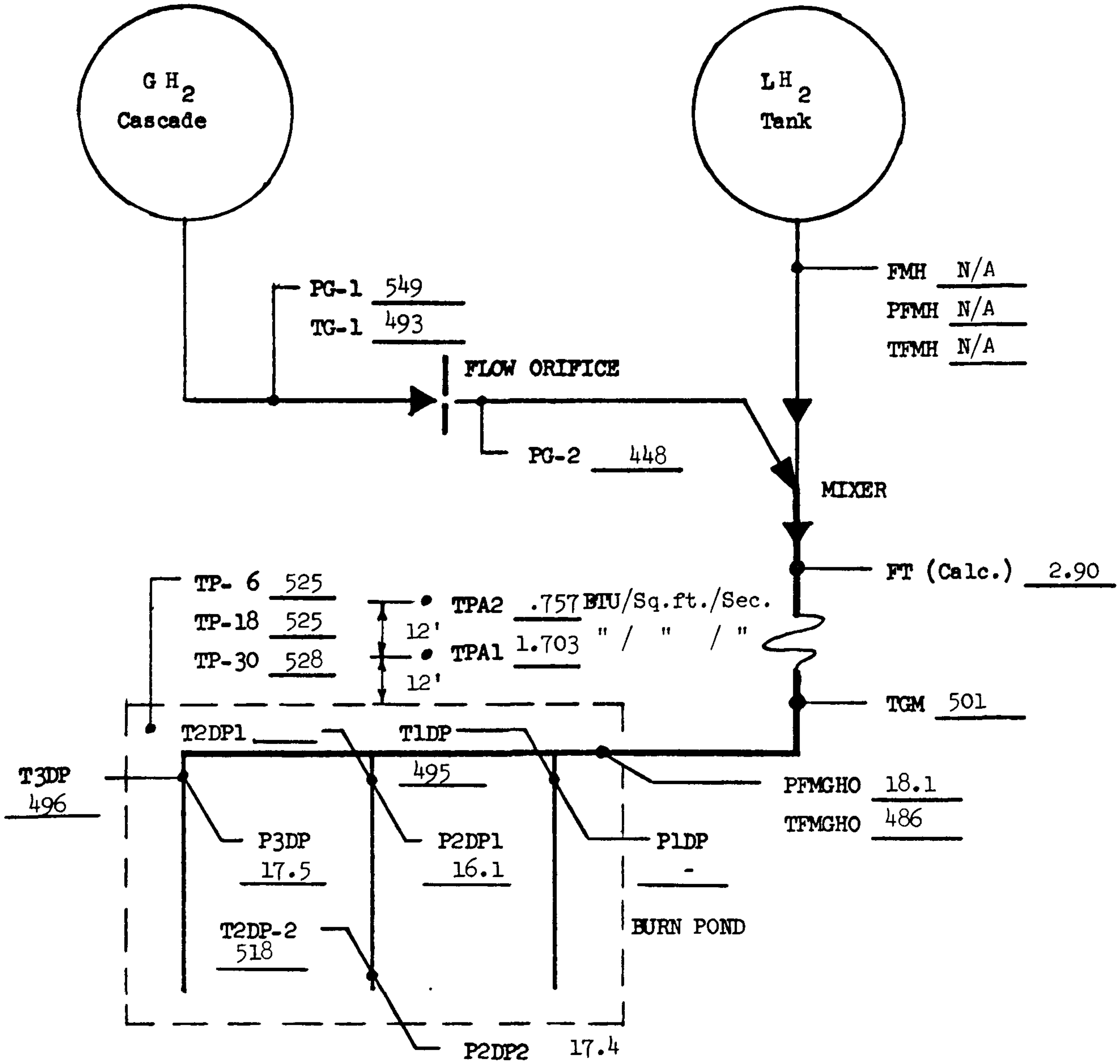
TEST GH_2 Ambient, 1#/sec

RUN # 006 DATE 12/ 6/65

DATA TIME 10 SECS.

Figure 21

Instrumentation Schematic, Summary Test No. 006, @ 10 Seconds



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

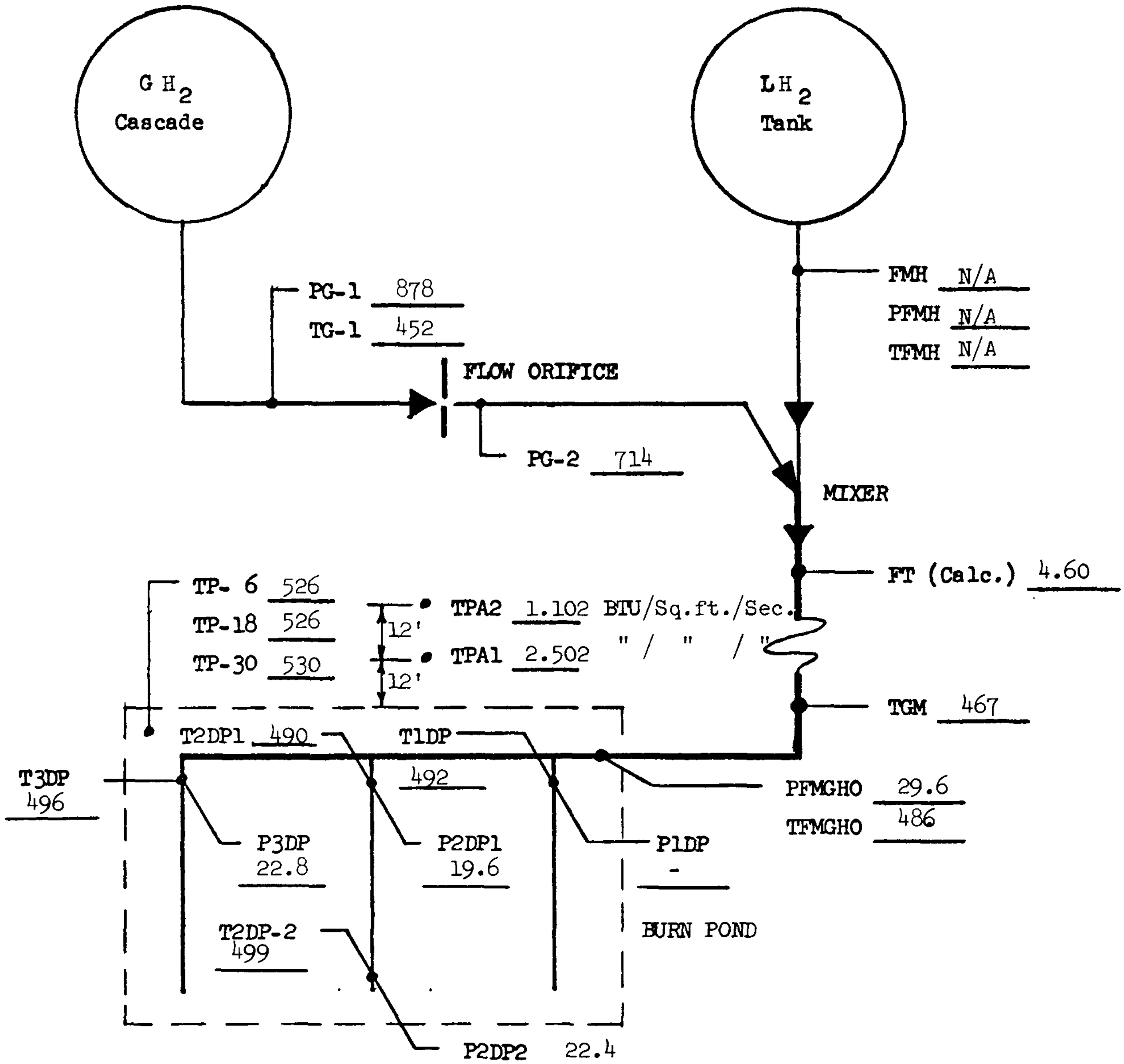
TEST GH_2 Ambient, 3 lb/sec

RUN # 006 DATE 12/6 /65

DATA TIME 40 SECS.

Figure 22

Instrumentation Schematic, Summary Test No. 006, @ 40 Seconds



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST GH_2 Ambient 4.5 lb/sec.

RUN # 006 DATE / /

DATA TIME 60 SECS.

TEST DURATION 60 SECS.

H_2O LOSS 12 IN. FLAME HT. 125 FT.

WIND High and gusty

Figure 23
Instrumentation Schematic, Summary Test No. 006, @ 60 Seconds

TABLE VI

PHOEBUS-2 SCALE BURN POND
INSTRUMENTATION RECAP - RUN # 006 DATE 12/06/65

Type Test GH_2 (Amb) @ 1, 3, & 45 lb/sec

LAPSE TIME READINGS - SECONDS FS1/FS2 33.2 sec

PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
TP-6	H_2O Temp @ 6" Up From Bottom of Pond	°R	520	520	522	522	522	523	523	524	525	526	526	526	526
TP-18	H_2O Temp @ 18" Up From Bottom of Pond	°R	520	520	522	522	522	522	523	525	525	525	525	526	526
TP-30	H_2O Temp @ 30" Up From Bottom of Pond	°R	519	520	521	521	521	521	521	532	528	528	551	556	530
T1DP	Temp @ #1 Dist. Pipe Inlet	°R	506	500	497	497	490	515	502	507	495	500	504	505	492
T2DP-1	Temp @ #2 Dist. Pipe Inlet	°R	507	503	502	500	498	496	495	495	496	496	493	492	490
T2DP-2	Temp @ #2 Dist. Pipe Outlet	°R	506	506	505	503	502	500	500	501	518	520	517	500	499
T3DP	Temp @ #3 Dist. Pipe Inlet	°R	505	503	501	500	498	495	496	496	496	499	499	498	496
TI-1	Temp @ Igniter Box #1	°R	579	579	576	580	578	574	574	574	571	572	568	570	568
TI-2	Temp @ Igniter Box #2	°R	585	584	582	583	582	581	579	578	577	576	574	572	570
TG-1	Temp, Upstream Gas Flow Nozzle	°R	506	508	511	505	503	504	498	495	493	482	472	465	452
TFS	Temp at Flare Stack	°R	502	502	502	502	502	502	502	502	502	502	502	502	502

TABLE VI (Cont.)

Type Test GH_2 (Amb) @ 1, 3, & 4.5 lb/sec

			LAPSE TIME READINGS - SECONDS FS1/FS2 33.2 sec												
PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
TPA-1	Temp @ Pond Area	Btu/s	.775	.688	.745	.622	1.544	1.343	1.709	1.487	1.703	1.751	1.826	2.289	2.502
TPA-2	Temp @ Pond Area	Btu/s	.326	.276	.298	.282	.636	.667	.729	.695	.757	.658	.832	1.030	1.102
ΔPFMGHO	Δ Pressure @ Pond Inlet	Psig	2.15	1.41	1.68	1.68	4.51	7.13	5.82	6.12	7.57	6.12	9.90	10.55	9.73
PFMGHO	Pressure @ Pond Inlet	Psia	14.4	14.2	14.0	13.0	14.8	18.8	18.0	17.7	18.1	24.7	29.0	29.3	29.6
P1DP	Pressure @ #1 Dist. Pipe Inlet	Psia	31.0												31.0
P2DP-1	Pressure @ #2 Dist. Pipe Inlet	Psia	15.0	15.1	15.0	14.5	15.8	16.5	16.4	16.5	16.1	18.7	19.8	19.5	19.6
P2DP-2	Pressure @ #2 Dist. Pipe Outlet	Psia	15.3	15.3	15.2	14.8	16.5	17.8	17.6	17.8	17.4	21.0	22.6	22.2	22.4
P3DP	Pressure @ #3 Dist. Pipe Inlet	Psia	15.4	15.3	15.1	14.7	16.6	18.2	17.9	18.0	17.5	21.1	23.1	22.8	22.8
PG-1	Pressure, Upstream Gas Flow Nozzle	Psia	209	208	207	282	511	584	557	550	549	811	871	869	878
PG-2	Pressure, Downstream Gas Flow Nozzle	Psia	175	174	173	233	417	476	455	449	448	664	709	706	714
TFMGHO	Temp @ Pond Inlet	°R	486												486
TGM	Temp of Mixed Gas	°R	509	510	511	513	513	510	508	505	501	495	485	476	467
PG	Pressure of Gas Flow Nozzle	Psia	73.9	73.6	73.4	99.4	177	201.6	192.4	190.0	189.7	280.4	299.5	299.0	301.4

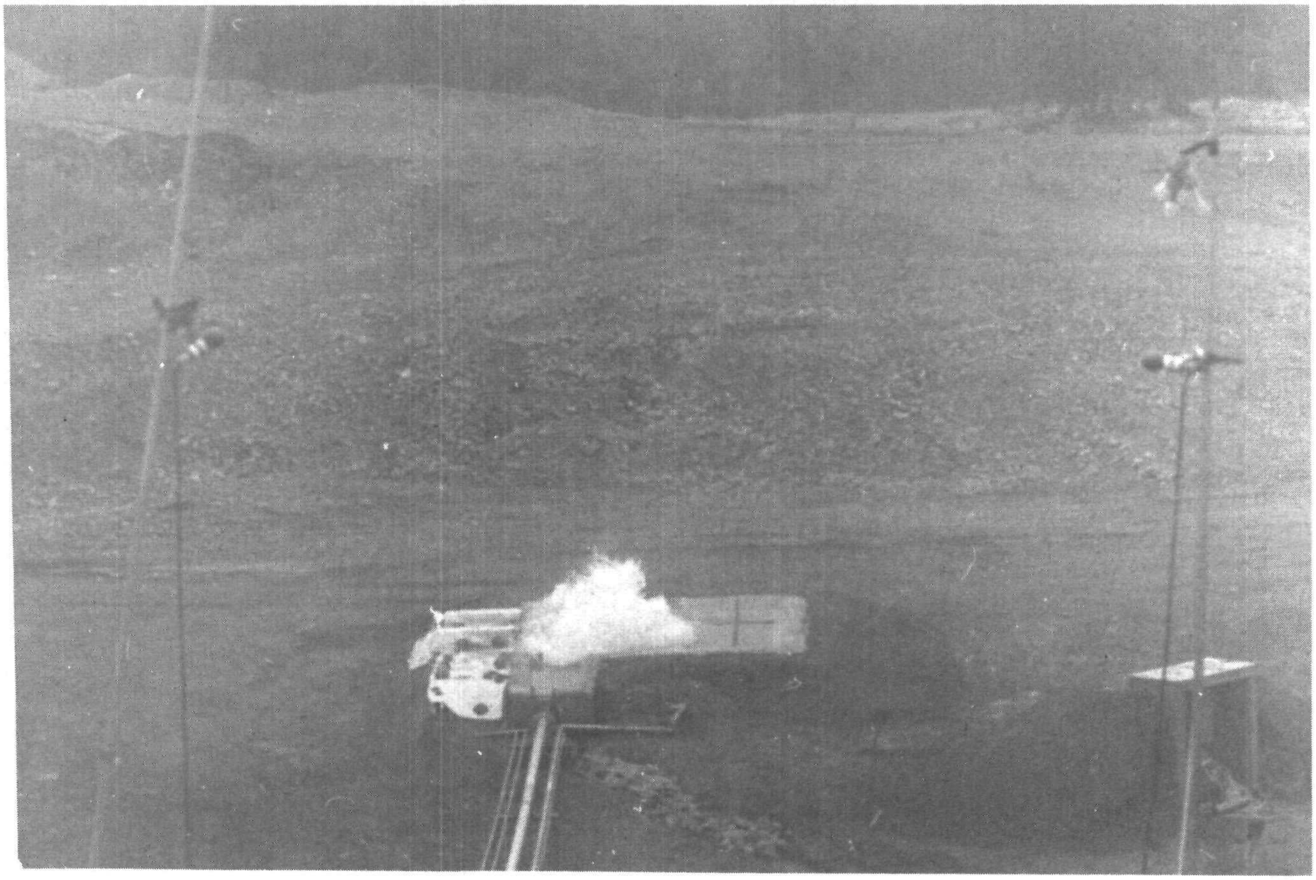


Figure 24
Pond Photo-Start, Shutdown Test No. 006

DECLASSIFIED

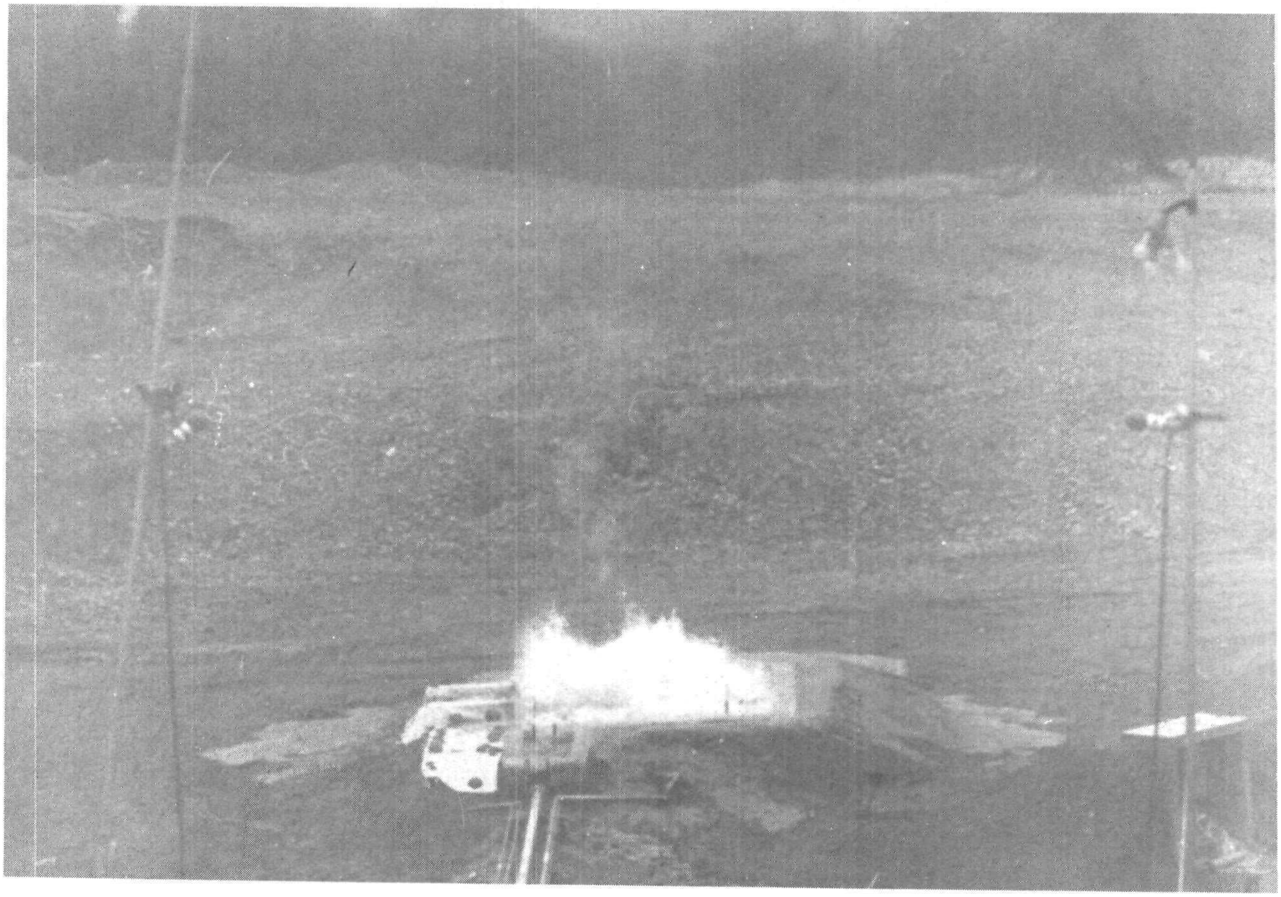


Figure 25
Pond Photo-3 Lb/Sec Flow Rate, Test No. 006

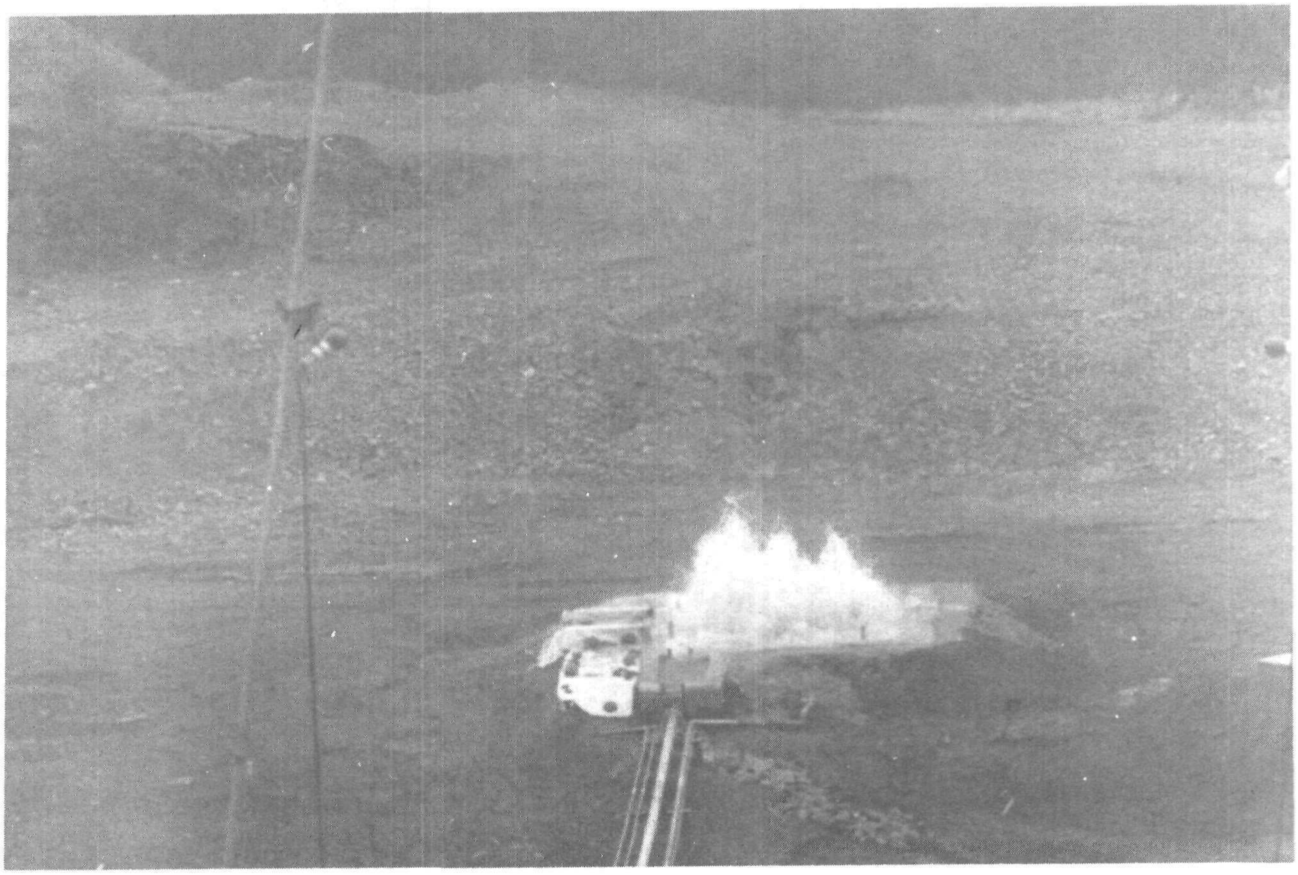


Figure 26

Pone Photo-4.7 Lb/Sec Flow Rate, Test No. 006

of the pond, indicating that the impingement of the gas upon the sloped walls is a problem. This problem, however, is not present in the main pond to the same degree since the edge distance to the outermost branches is approximately twice that of the scale pond. It appears that splash shields extending about 2-1/2 ft out from the pond edge would stop most of the water from being splashed out and would closer simulate the header-pond edge spacing of the main pond.

4. Mixed Hydrogen Testing

a. Test Objectives

This test series used a mass flow rate of 7.8 lb/sec of liquid hydrogen mixed together with 1.8 lb/sec of ambient gaseous hydrogen to give a total mass flow rate of 9.6 lb/sec of hydrogen at approximately 120°R. This is 1/26 of the main pond design flow rate and is at the equivalent predicted temperature.

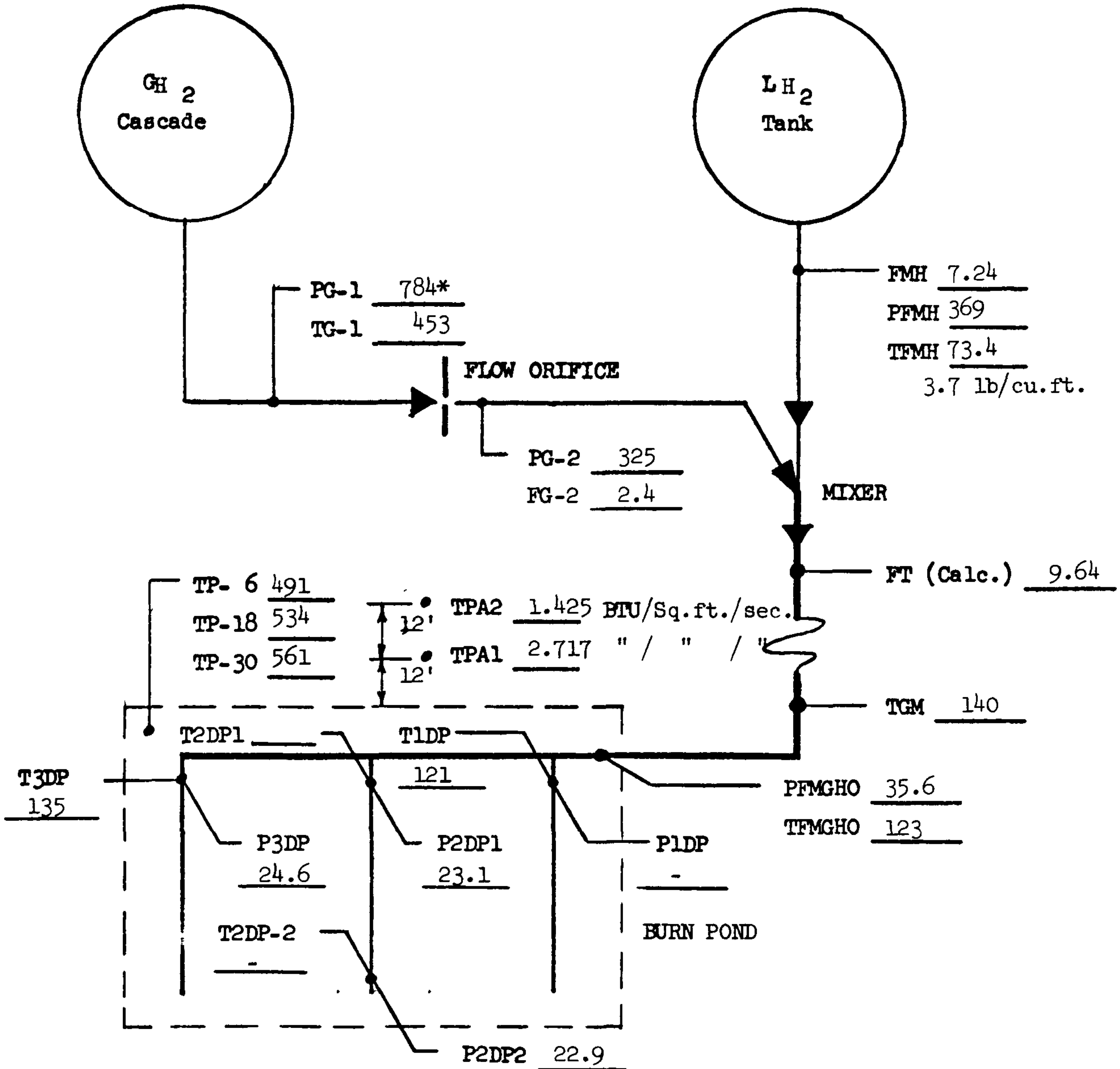
The objectives of this test series were to determine the water effects (buoyancy, turbulence, seal, temperature change) and hydrogen burning characteristics (ignition, flame geometry, and temperature gradients).

b. Test Summaries

(1) Test 007 (See Figures 20 through 27, Table VII)

The configuration of the distribution branches for this test was the same as in Test 006.

The ignition of the pre-conditioned hydrogen was smooth and quiet, as experienced in the previous tests. The steady-state flow condition lasted approximately 20 sec and produced a flame varying from 85 to 115 ft in height. Area temperature and calorimeter data corresponded with Test 006.



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

* NOMINAL VALUE

TEST Mixed H_2 9.6 lb/sec. @ 120°R

RUN # 007 DATE 12 /8 /65

DATA TIME 20 SECS.

TEST DURATION 22 SEC.

H_2O LOSS 22 IN. FLAME HT. 115 FT.

WIND Calm

Figure 27

Instrumentation Schematic, Summary Test No. 007

TABLE VII

PHOEBUS-2 SCALE BURN POND
INSTRUMENTATION RECAP - RUN #007 DATE 12-08-65

Type Test Mixed Hydrogen 9.6 #/sec

			LAPSE TIME READINGS - SECONDS												
PARAMETER	LOCATION	UNITS	0	5	10	15	20	22	30	35	40	45	50	55	60
FMH	LH_2 Flow Meter	GPM	744	820	805	758	-	-							
PFMH	Press. @ Flow Meter	psia	410	448	423	379	365	355							
TFMH-1	Temperature @ Flow Meter (RTT)	°R	45.2	45.3	45.4	45.2	100	153							
TG-1	Temperature Gas @ Flow Nozzle	°R	469	464	460	457	452	450							
PG-1	Pressure Upstream Gas Flow Nozzle	psia	725	786	786	785	783	783							
PG-2	Pressure Downstream Gas Flow Nozzle	psia	313	332	334	327	317	297							
TGM	Temperature Mixed Gas	°R	100	97.3	101	108	170	282							
ΔPFMGHO	Δ Pressure @ Pond Inlet	psig	14.00	15.00	15.00	15.00	14.00	11.0							
PFMGHO	Pressure @ Pond Inlet	psia	37.5	38.5	39.1	36.4	35.2	27.4							
TFMGHO	Temperature @ Pond Inlet	°R	134	126	119	121	123	123							
TI-1	Temperature @ Igniter #1	°R	587	585	586	582	583	582							
TI-2	Temperature @ Igniter #2	°R	549	546	548	548	549	549							

TABLE VII (cont.)

Type Test Mixed Hydrogen 9.6 #/sec

LAPSE TIME READINGS - SECONDS

PARAMETER	LOCATION	UNITS	0	5	10	15	20	22	30	35	40	45	50	55	60
T1DP	Temperature @ #1 Dist. Pipe Inlet	°R	131	119	115	115	118	123							
T2DP-1	Temperature @ #2 Dist. Pipe Inlet	°R	147	134	130	130	132	138							
T3DP	Temperature @ #3 Dist. Pipe Inlet	°R	152	140	132	133	134	139							
P1DP	Pressure @ #1 Dist. Pipe Inlet	psia	16.3	16.1	16.2	15.7	*Went negative								
P2DP-1	Pressure @ #1 Dist. Pipe Inlet	psia	24.1	24.3	25.0	24.0	23.2	20.2							
P2DP-2	Pressure @ #2 Dist. Pipe Outlet	psia	20.8	21.1	21.7	22.0	23.0	23.0							
P3DP	Pressure @ #3 Dist. Pipe Inlet	psia	25.3	25.9	26.4	25.0	24.6	21.0							
TP-6	H_2O Temp @ 6" from bottom of pond	°R	500	495	490	491	491	491							
TP-18	H_2O Temp @ 18" from bottom of pond	°R	500	493	494	490	*	*							
TP-30	H_2O Temp @ 30" from bottom of pond	°R	506	499	537	500	*	*							
TPA1	Temp @ Pond Area - 25'	BTU/S	3.00	3.05	2.80	3.01	2.29	2.19							
TPA2	Temp @ Pond Area - 50'	BTU/S	1.38	1.44	1.50	1.52	1.19	1.19							

Approximately 22 in. of water was lost during the test and an icy slush approximately 1/2 in. thick covered the surface of the pond (see Figure 28).

(2) Test 008 (See Figures 29, 30, 31 and Table VIII)

The splash shields previously mentioned were installed to better simulate the header-pond edge spacing of the main pond (see Figure 29). The two end lateral branches were also rotated to place the discharge nozzles in a vertical attitude. Diffusers (see Figure 30) were installed on 19 of the 27 nozzles to distribute and direct the gas discharge horizontally within the pond (Figure 32). The two igniters were raised to a level 3 ft above the run of the pond. Upon initiation of flow there was a mild explosion resulting from the accumulation of hydrogen below the ignition point. The flame height and area temperature profile corresponded to the previous tests. The steady-state test duration of approximately 25 sec resulted in a loss of about 10 in. of water (Figure 33). It was observed that the agitation of the water appeared to be more severe with the addition of the diffusers.

(3) Test 009 (See Figures 34, 35 and Table IX)

This test was a repeat of Test 008 except that the diffusers were removed and the two outer lateral branches again were rotated inward 45°, as in Tests 006 and 007. One of the igniters was relocated to its original position. The ignition was smooth and only slightly more audible than Run 007. Flame characteristics and temperature data duplicate that of the previous mixed hydrogen test runs. Water agitation was significantly less violent than Test 008 and post-test inspection revealed a total loss of only 5 in. of water for the 25-sec duration test run (see Figure 36).

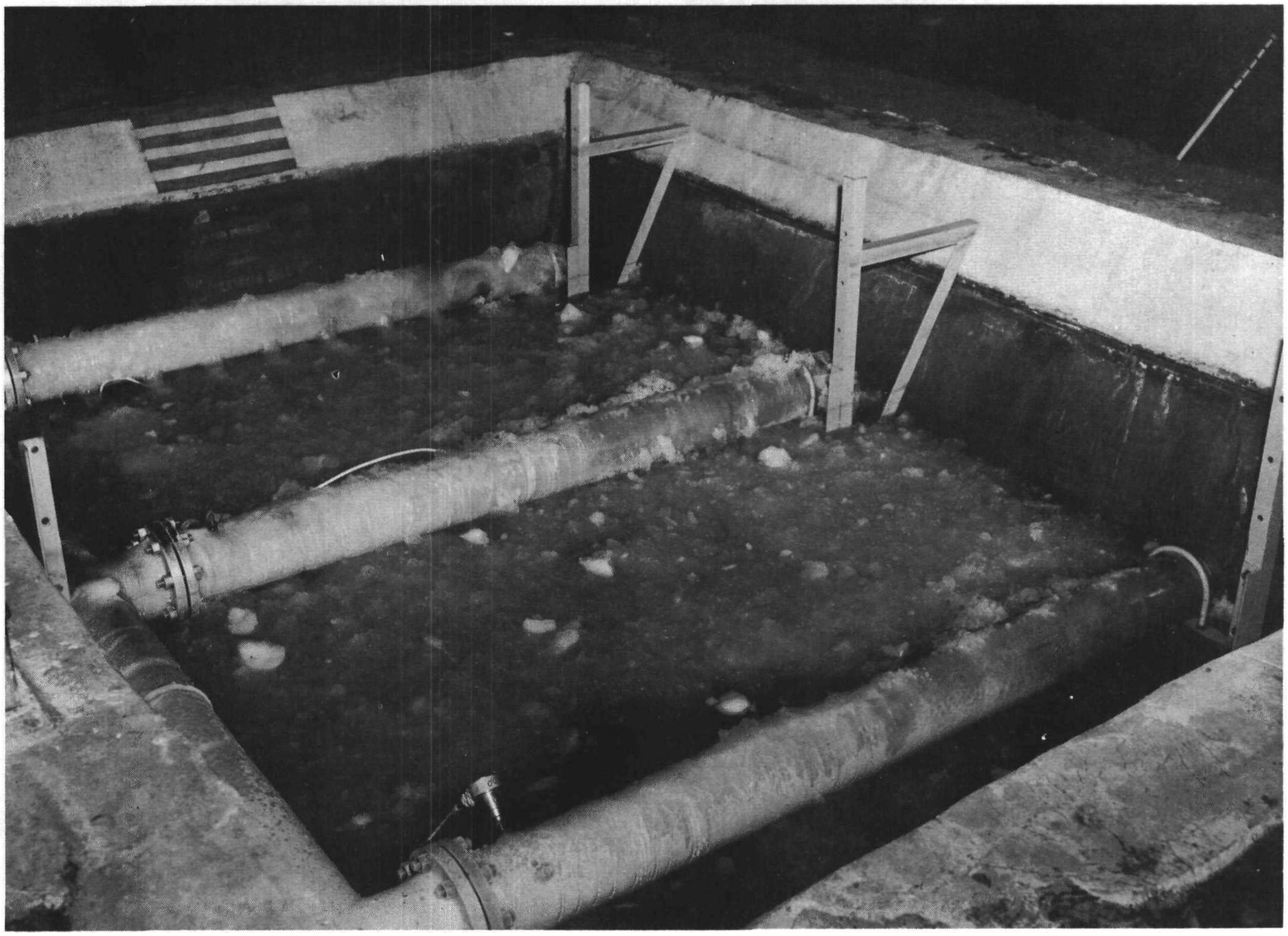


Figure 28

Pond Post Test Photo, Test No. 007

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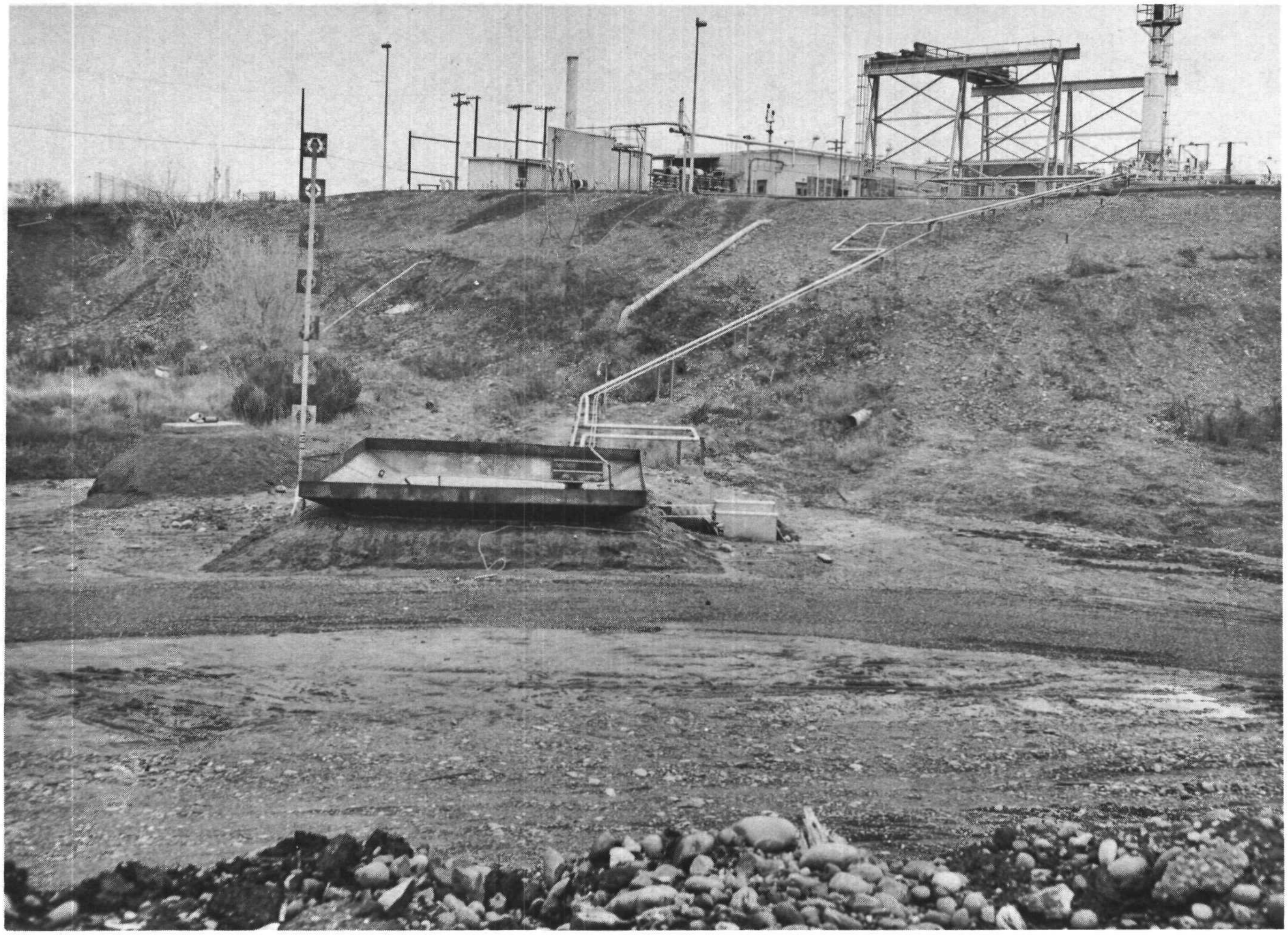


Figure 29

Pond With Side Extensions

DECLASSIFIED

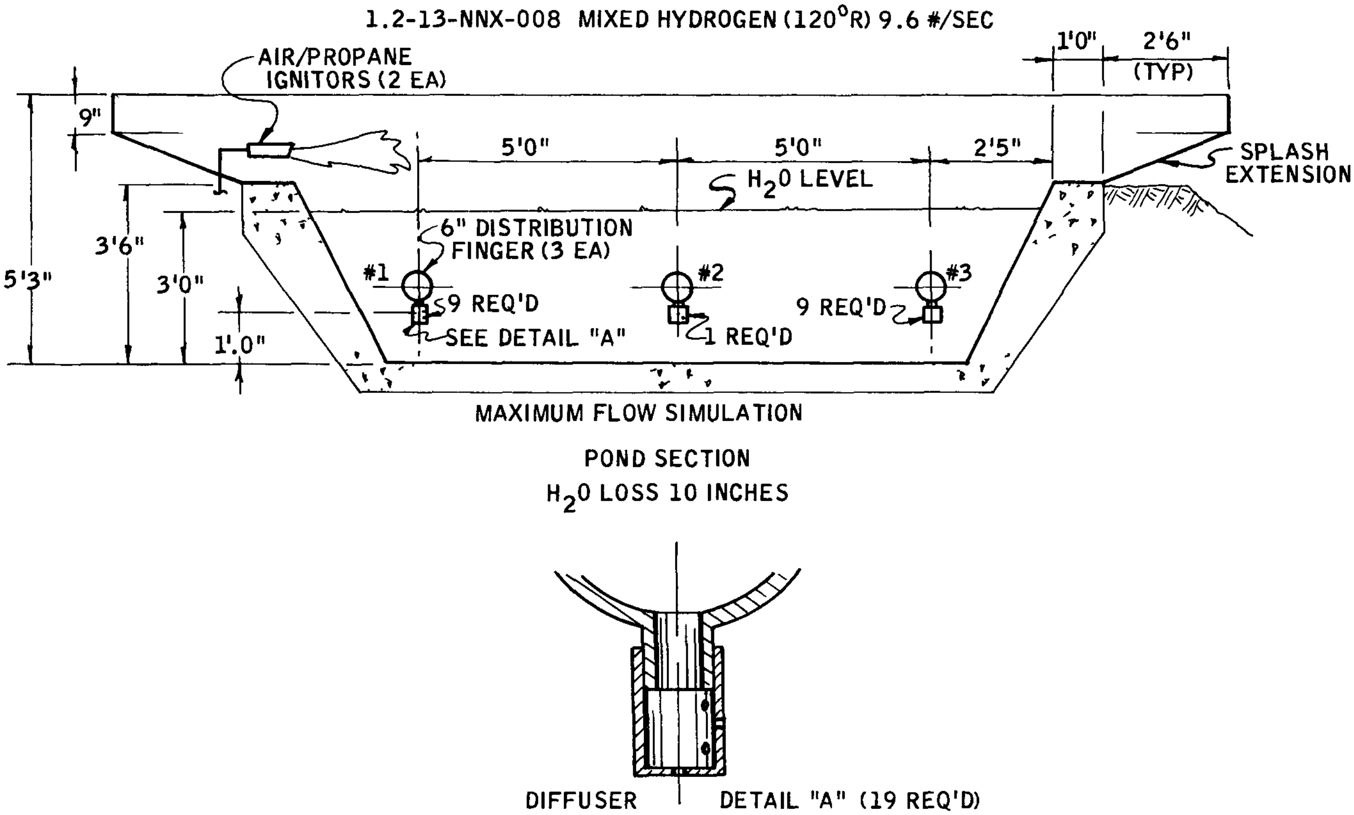
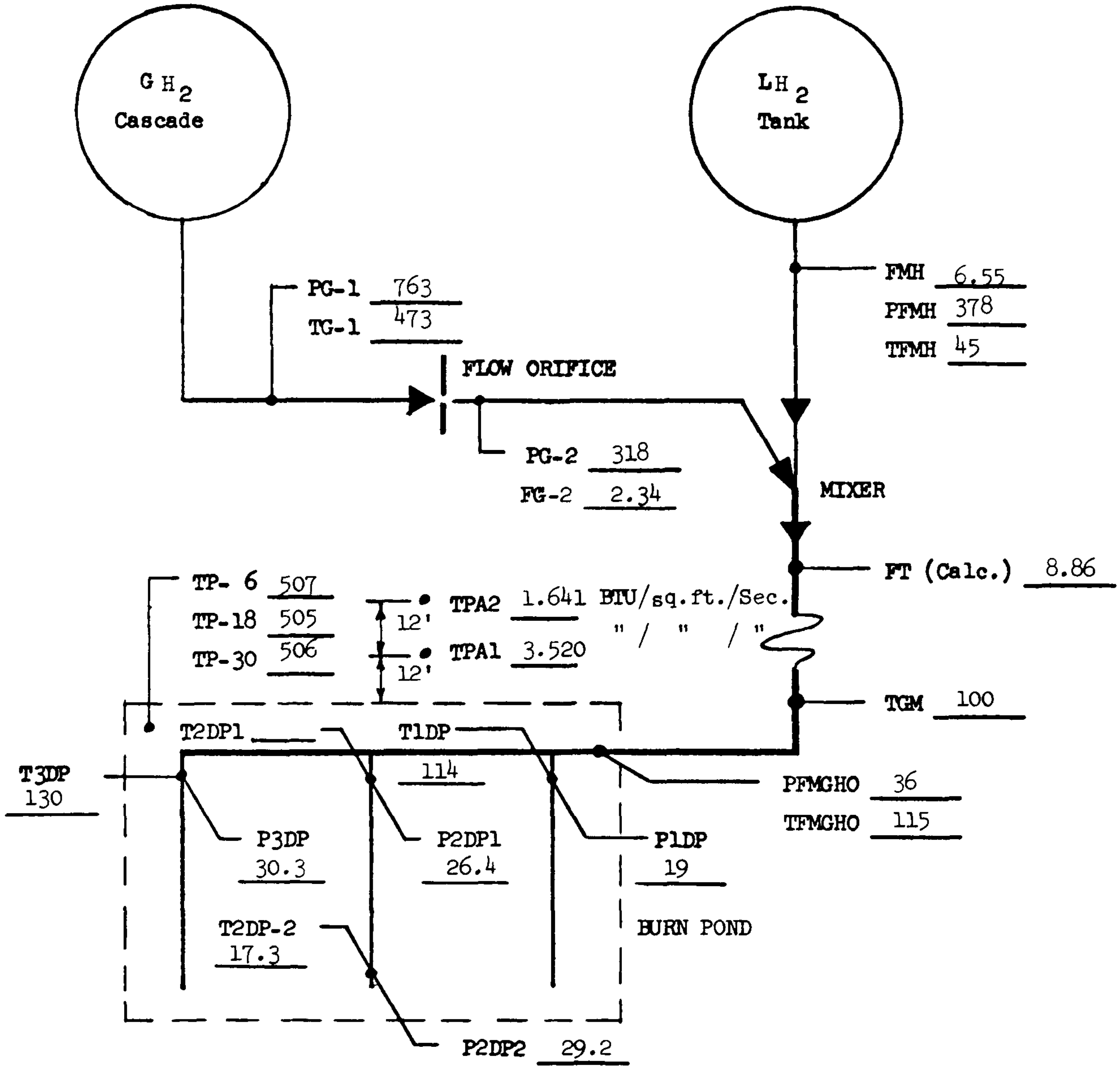


Figure 30

Pond Section, Mixed H_2 Test No. 008



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST Mixed H_2 9.6 lb/sec @ 120°R

RUN # 008 DATE 12/17/65

DATA TIME 25 SECS.

TEST DURATION 25 SECS.

H_2O LOSS 10 IN. FLAME HT. 115 FT.

WIND Calm

Figure 31

Instrumentation Schematic, Summary Test No. 008

TABLE VIII

PHOEBUS-2 SCALE BURN POND
INSTRUMENTATION RECAP - RUN #008 DATE 12-17-65

Type Test Mixed Hydrogen 9.6 #/sec. @ 120°R

			LAPSE TIME READING - SECONDS												
PARAMETER	LOCATION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
FMH	LH_2 Flow Meter	GPM	658	659	659	659	660	658							
PFMH	Press. @ Flow Meter	PSIA	404	397	392	388	385	378							
TFMH-1	Temperature @ Flow Meter (RTT)	°R	45	45	45	44.5	44.5	45.0							
TFMH-2	Temperature @ Flow Meter (TC)	°R	82	79	79	79	81	83							
TG-1	Temperature Gas @ Flow Nozzle	°R	493	490	485	482	477	473							
PG-1	Pressure Upstream Gas Flow Nozzle	PSIA	767	768	768	767	765	763							
PG-2	Pressure Downstream Gas Flow Nozzle	PSIA	325	324	321	320	319	318							
TGM	Temperature Mixed Gas	°R	101	100	100	100	100	100							
ΔPFMGHO	Δ Pressure @ Pond Inlet	PSIG	15.98	14.00	14.0	14	13	14							
PFMGHO	Pressure @ Pond Inlet	PSIA	38	37	37	37	36	36							
TFMGHO	Temperature @ Pond Inlet	°R	123	120	118	117	116	115							
TLT	Temperature of Line - Top	°R	311	293	279	274	267	265							

TABLE VIII (cont.)

Type Test Mixed Hydrogen 9.6 #/sec. @ 120°R

PARAMETER	LOCATION	UNITS	LAPSE TIME READINGS - SECONDS 0	5	10	15	20	25	30	35	40	45	50	55	60
TLB	Temperature of Line - Bottom	°R	273	256	249	258	235	224							
T1DP	Temperature @ #1 Dist. Pipe Inlet	°R	129	124	122	122	117	114							
T2DP-1	Temperature @ #2 Dist. Pipe Inlet	°R	138	135	134	131	129	127							
T2DP-2	Temp. @ #2 Dist. Pipe Outlet	°R	194	184	180	175	177	173							
T3DP	Temp. @ #3 Dist. Pipe Inlet	°R	146	140	137	134	132	130							
P1DP	Pressure @ #1 Dist. Pipe Inlet	PSIA	21.08	20.41	19.50	19.00	19.0	19							
P2DP-1	Pressure @ #2 Dist. Pipe Inlet	PSIA	28.02	27.6	27.3	27.1	26.7	26.4							
P2DP-2	Pressure @ #2 Dist. Pipe Outlet	PSIA	28.3	28.5	28.8	29.0	29.2	29.2							
P3DP	Pressure @ #3 Dist. Pipe Inlet	PSIA	32.1	31.6	31.2	30.9	30.4	30.3							
TP-6	H_2O Temp. @ 6" from bottom of pond	°R	517	512	511	509	509	507							
TP-18	H_2O Temp. @ 6" from bottom of pond	°R	516	512	510	510	507	505							
TP-30	H_2O Temp. @ 30" fr. bottom of pond	°R	517	512	512	509	506	506							

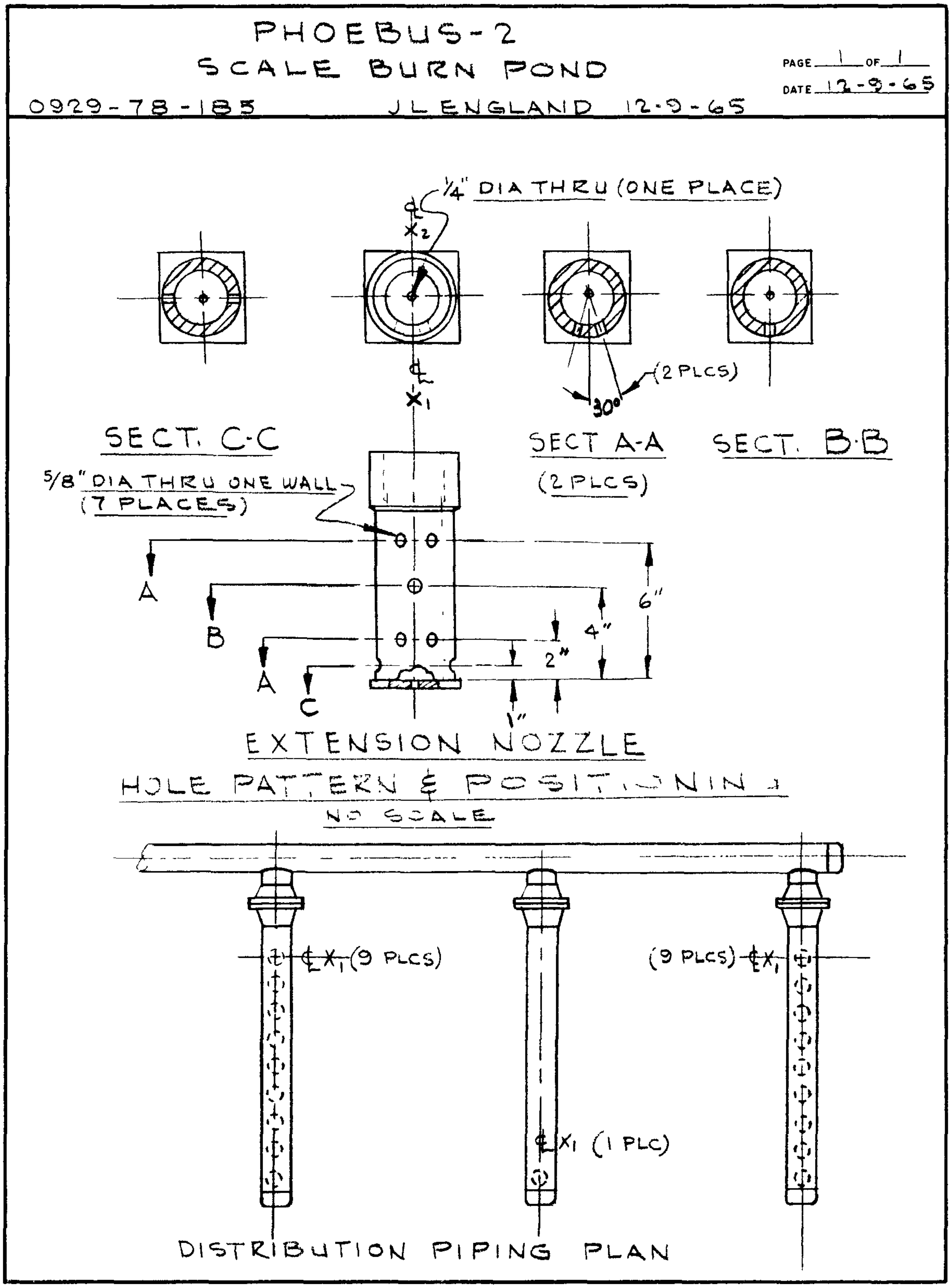


Figure 32
Pond Extension Nozzle

Figure 33
Pond Post Test Photo, Test No. 008

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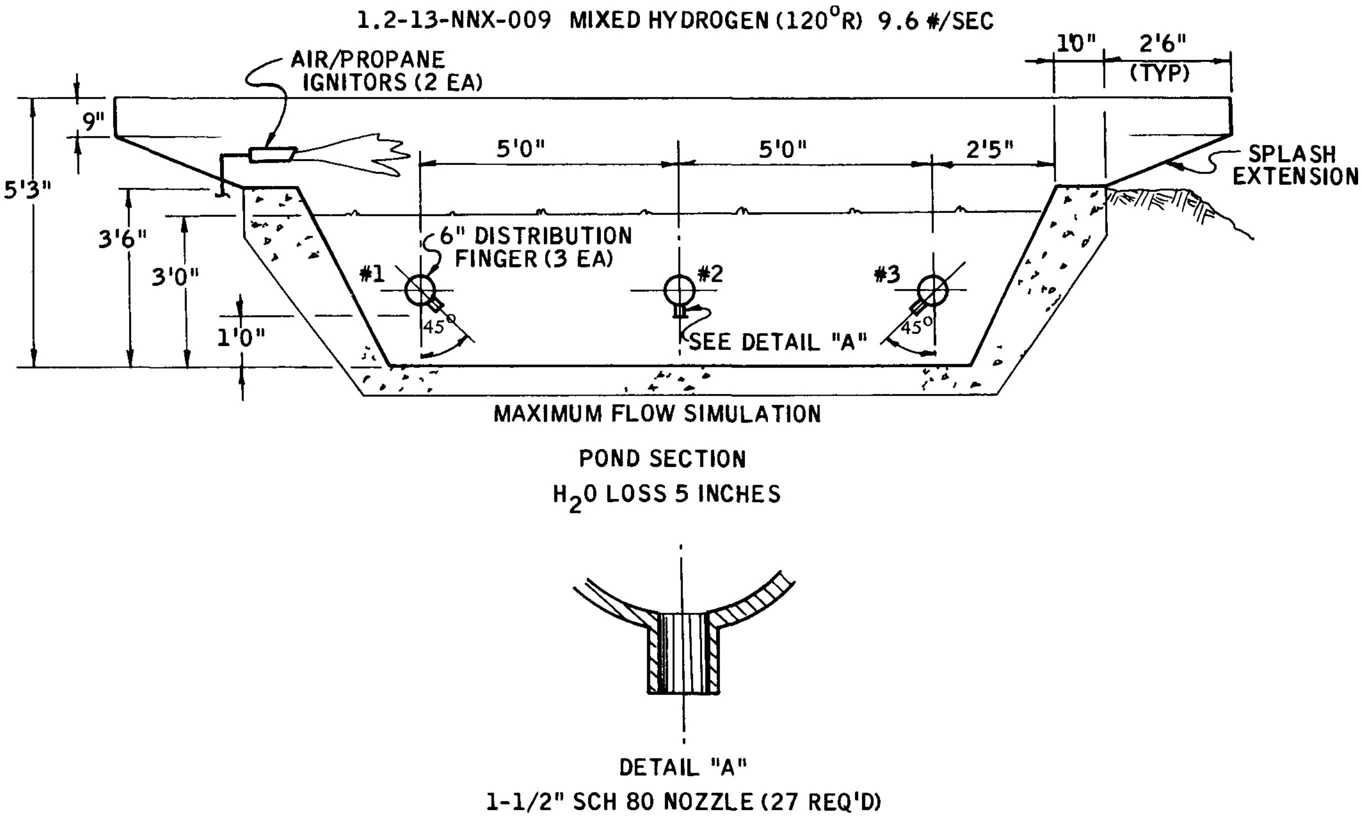
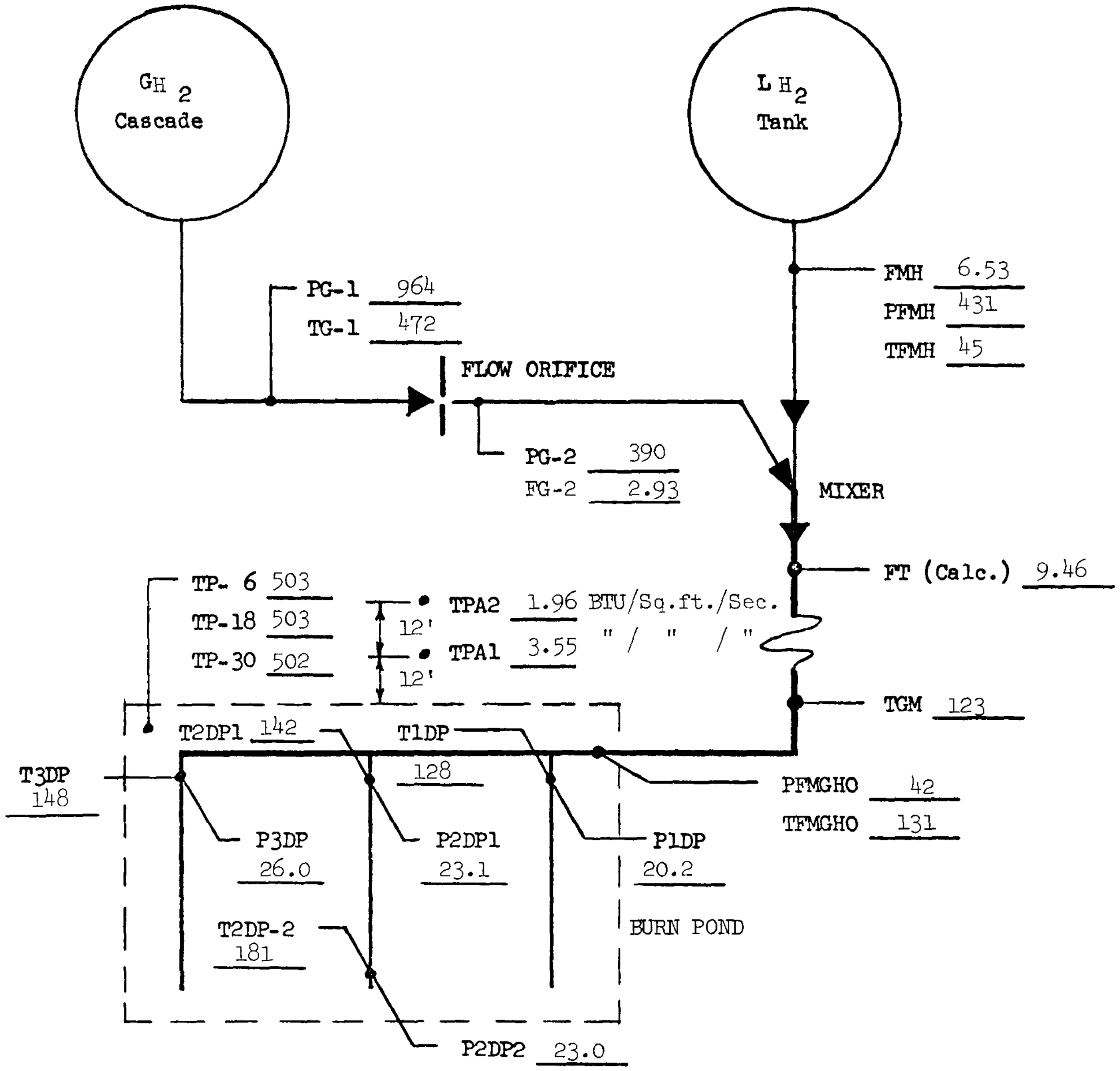


Figure 34

Pond Section, Mixed H_2 Test No. 009



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST Mixed H_2 9.6 lb/sec @ 120°R

RUN # 009 DATE 12 /20/65

DATA TIME 20 SECS.

TEST DURATION 23 SECS.

H_2O LOSS 5 IN. FLAME HT. 115 FT.

WIND Calm

Figure 35

Instrumentation Schematic, Summary Test No. 009

TABLE IX

PHOEBUS-2 SCALE BURN POND
INSTRUMENTATION RECAP - RUN #009 DATE 12-20-65

Type Test Mixed Hydrogen 9.6 #/sec. @ 120°R

			LAPSE TIME READINGS - SECONDS												
PARAMETER	LOCATION	UNITS	0	5	10	15	20	23	30	35	40	45	50	55	60
FMH	LH_2 Flow Meter	GPM	659	660	659	659	659	658							
PFMH	Press.@ Flow Meter	PSIA	463	450	442	436	431	428							
TFMH-1	Temp. @ Flow Meter (RTT)	$^{\circ}$R	45	45	45	45	45	45							
TG-1	Temperature @ Flow Nozzle	$^{\circ}$R	492	487	483	477	472	470							
PG-1	Pressure Upstream Gas Flow Nozzle	PSIA	964	963	963	962	964	963							
PG-2	Pressure Downstream Gas Flow Nozzle	PSIA	404	399	395	391	390	390							
TGM	Temperature - Mixed Gas	$^{\circ}$R	126	125	124	123	123	122							
Δ PFMGHO	Δ Pressure @ Pond Inlet	PSIG	14.6	14	14	15	15	15							
PFMGHO	Pressure @ Pond Inlet	PSIA	46.9	45	43	43	42	42							
TFMGHO	Temperature @ Pond Inlet	$^{\circ}$R	170	148	139	134	131	131							
TLT	Temperature of Line - Top	$^{\circ}$R	366	355	332	315	310	293							
TLB	Temperature of Line - Bottom	$^{\circ}$R	300	284	259	254	245	239							
T1DP	Temperature @ #1 Dist. Pipe Inlet	$^{\circ}$R	167	149	136	133	128	128							

TABLE IX (cont.)

Type Test Mixed Hydrogen 9.6 #/sec. @ 120^{o}R

PARAMETER	LOCATION	UNITS	LAPSE TIME READINGS - SECONDS 0	5	10	15	20	23	30	35	40	45	50	55	60
T2DP-1	Temperature @ #2 Dist. Pipe Inlet	^{o}R	182	162	150	146	142	139							
T2DP-2	Temperature @ #2 Dist. Pipe Outlet	^{o}R	225	206	197	184	181	177							
T3DP	Temperature @ #3 Dist. Pipe Inlet	^{o}R	191	170	159	151	148	145							
P1DP	Pressure @ #1 Dist. Pipe Inlet	PSIA	21.5	21.2	20.5	20.5	20.2	19.8							
P2DP-1	Pressure @ #2 Dist. Pipe Inlet	PSIA	25.4	24.7	23.5	23.3	23.1	22.9							
P2DP-2	Pressure @ #2 Dist. Pipe Outlet	PSIA	22.3	22.4	22.6	22.8	23.0	23.1							
P3DP	Pressure @ #3 Dist. Pipe Inlet	PSIA	28.8	27.9	26.7	26.4	26.0	25.9							
TP-6	H_2O Temp. @ 6" from bottom of pond	^{o}R	513	511	510	506	503	501							
TP-18	H_2O Temp. @ 18" fr. bottom of pond	^{o}R	512	511	508	507	503	501							
TP-30	H_2O Temp. @ 30" fr. bottom of pond	^{o}R	511	509	507	505	502	498							
TPA1	Temp. @ Pond Area - 25'	BTU/S	3.511	5.962	4.15	3.21	3.55	3.35							
TPA2	Temp. @ Pond Area - 50'	BTU/S	1.852	1.707	2.29	1.66	1.96	1.62							

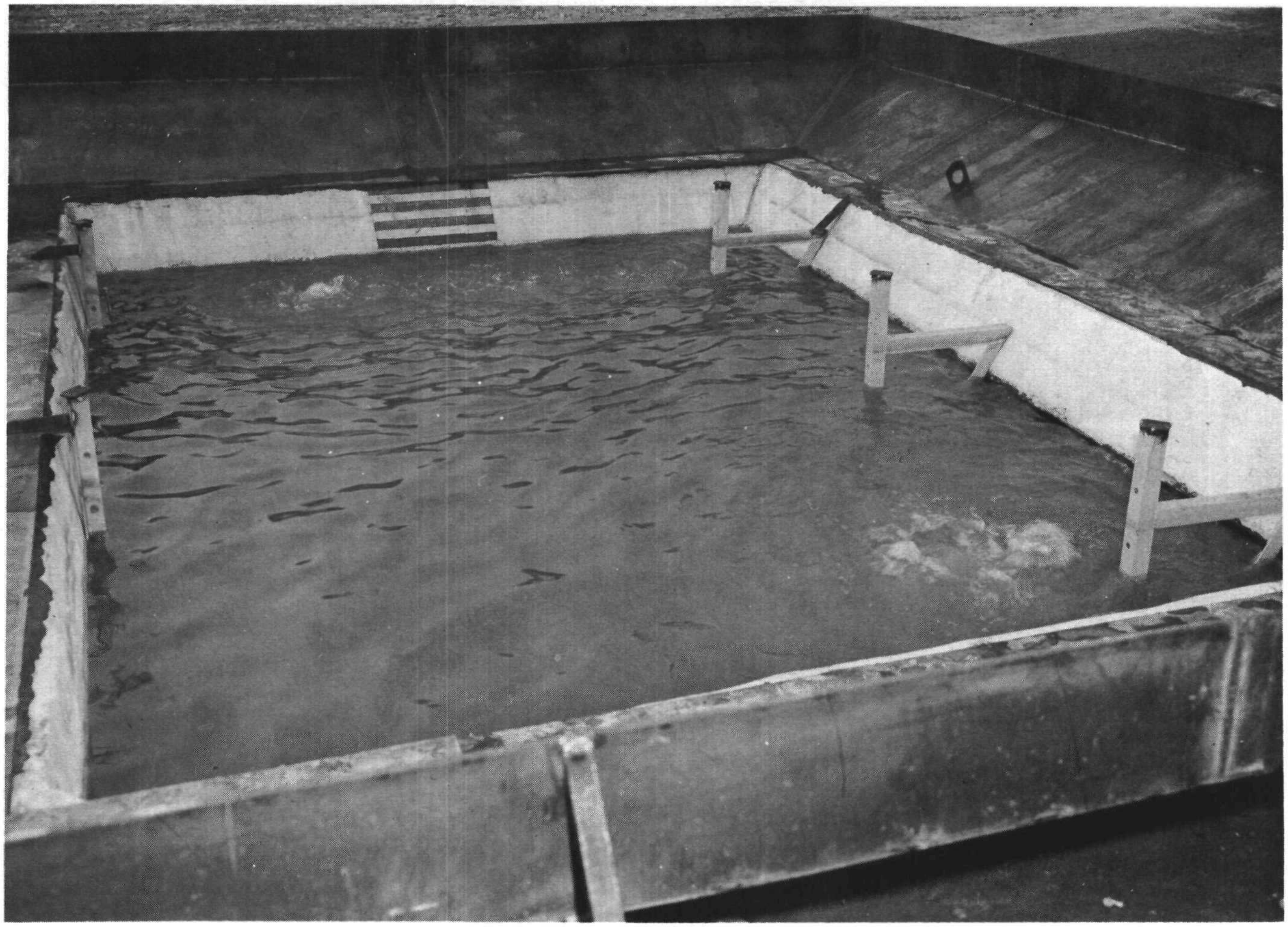


Figure 36

Pond Post Test Photo, Test No. 009

(4) Test 010 (See Figures 37, 38 and Table X)

This test utilized the same test medium, flow rates and procedures as the previous three runs. System modifications included the installation of 1/8-in. dia by 1/2-in. OD square weave screen over the entire pond. The water level was raised 6 in. to a total depth of 3 ft 6 in., with 15 lbs of salt added to obtain flame color. The screen modification was designed to suppress the highly agitated water conditions previously witnessed (these were in the form of geysers to a height of 12 to 15 ft) and to balance the overall water movement within the pond. Ignition was smooth and barely audible. The wind was steady in a southeast direction at a velocity of approximately five knots. These conditions produced a shortened flame height of approximately 50 ft. The flame was very turbulent and was more expansive than recently witnessed. A two-color smoke bomb located at a 20-ft elevation above and immediately adjacent to the pond produced good visual observation of air movement into the fire area. The smoke was drawn inward toward the center of the flame in a downward motion to a height of 10 ft above the pond. It was then carried upward with the combusting gases. The salt added to the water produced color to the flame, permitting good observation of the flame configuration. The screen sufficiently satisfied its designed purpose in suppressing the water action. The water movement in the pond appeared well balanced, with a rise of approximately 3 ft above the screen. Only small amounts of water were observed exiting the pond over the perimeter edge. A total of 6 in. of water loss was experienced for this test during the 20-plus seconds of steady state flow duration. Approximately one dozen pieces of ice, ranging to a maximum size of approximately 6 cubic-in., were observed floating on the water surface immediately following the test. The test was observed from an elevation of 35 ft above the pond and southeast approximately 250 ft directly downwind of the fire. The radiant heat emission to this observation point was not of sufficient magnitude to cause discomfort during the test.

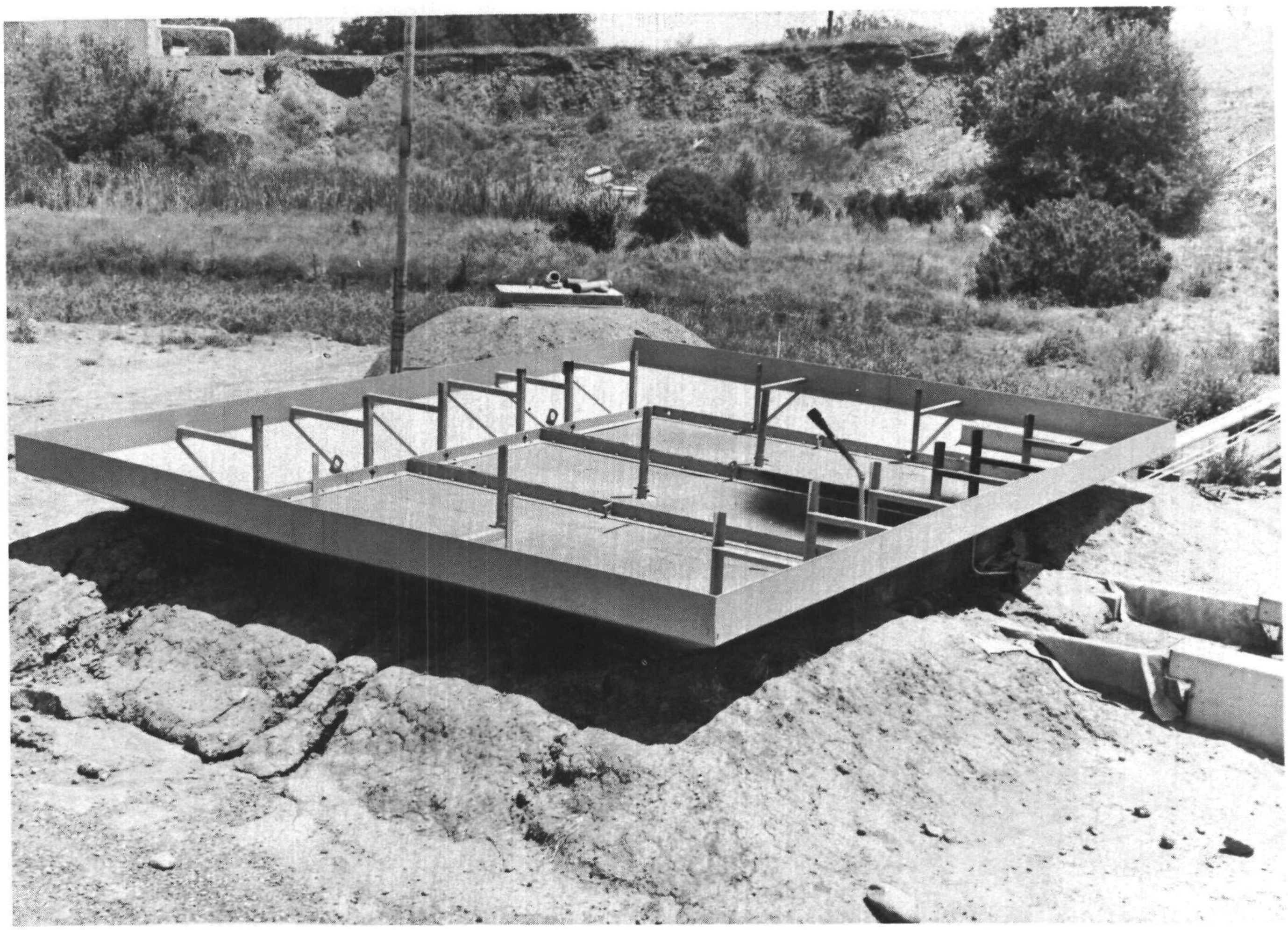
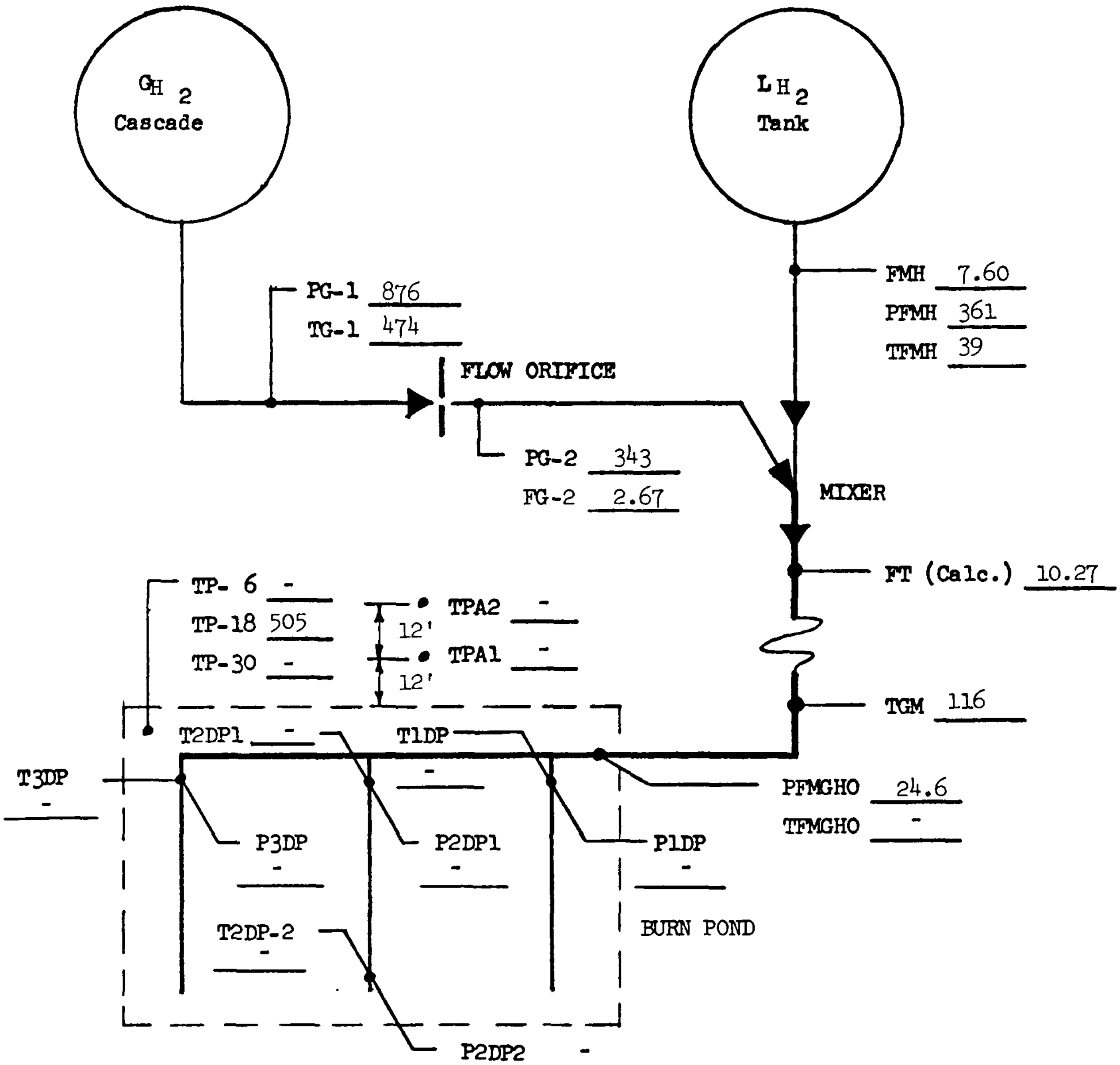


Figure 37
Pond With Screen



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

Note: A-D System Lost

TEST Mixed H_2 9.6 lb/sec @ 120°R

RUN # 010 DATE 1/11/66

DATA TIME 20 SECS.

TEST DURATION 22 SECS.

H_2O LOSS 6 IN. FLAME HT. 60 FT.

WIND 5 Knots, Steady

Figure 38

Instrumentation Schematic, Summary Test No. 010

TABLE X

PHOEBUS-2 SCALE BURN POND
INSTRUMENTATION RECAP

Sheet 1 of 1
Test No. 010

Type of Test Mixed Hydrogen 9.6 lb/sec @ 120°R

PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
FMH	LH_2 Flow Meter	lb/sec	7.60	7.50	7.57	7.60	7.58	7.54							
PFMH	Pressure @ Flow Meter	PSIG	391	379	370	366	361	357							
TFMH-1	Temp. @ Flow Meter	°R	40	40	39	39	39	39							
FG	Flow, Gas	lb/sec	2.06	2.06	2.06	2.06	2.06	2.06							
PG-1	Pressure Upstream Gas Flow Nozzle	PSIA	890	889	891	890	891	891							
TGM	Temperature Mixed Gas	°R	121	120	119	118	116	115							
PFMGHO	Pressure @ Pond Inlet	PSIA	48.0	47.4	41.5	40.1	39.3	38.8							
PG-2	Pressure Downstream Gas Flow Nozzle	PSIA	375	368	364	360	358	357							
TG-1	Temperature @ Gas Flow Nozzle	°R	492	485	484	479	474	470							
TP-18	H_2O Temperature 18" from bottom of pond	°R	510	509	508	506	506	503							

c. Conclusions

The disposal of cold hydrogen gas in this manner appears to be satisfactory. At no time during any of the tests was the flame extinguished or uncontrollable. Wind does affect the flame height and geometric pattern; however, because of the apparent low heat content of fire, this does not present any major problems.

The loss of water was reduced by the installation of the steel splash shields around the periphery of the pond. Future ponds could accomplish this by a concrete apron that slopes back into the pond or by having a larger edge distance (distance from pond edge to outboard discharge parts). The installation of the screen above the pond reduced the flow area above the pond approximately 50%. The screen appears to smooth out the jetting water over the entire area of the pond; water losses, however, were about the same as without the screen.

It is apparent that the ignition source should be close to the surface of the water to prevent an accumulation of gas prior to ignition.

5. <u>Liquid Hydrogen Testing</u>

a. Test Objectives

Although the PHOEBUS-2 disposal system was primarily designed for cold gas, the possibility exists that liquid hydrogen may enter the pond during cold flow testing of the fuel propellant systems. The objective of this test was to determine the performance of the pond while being subjected to liquid hydrogen flow. The pond configuration was the same as in Test 009.

b. Test Summary (Figure 39 and Table XI)

Test 010 was conducted with liquid at a flow rate of 9.6 lb/sec for a duration of 20 sec. The performance of the pond was completely satisfactory. Ignition, flame configuration, and temperature gradients were about the same as in previous tests. The agitation of the water appeared to be more severe. However, only 7 in. of water were lost during the test. Several small pieces of ice were observed floating on the surface following the test.

c. Conclusions

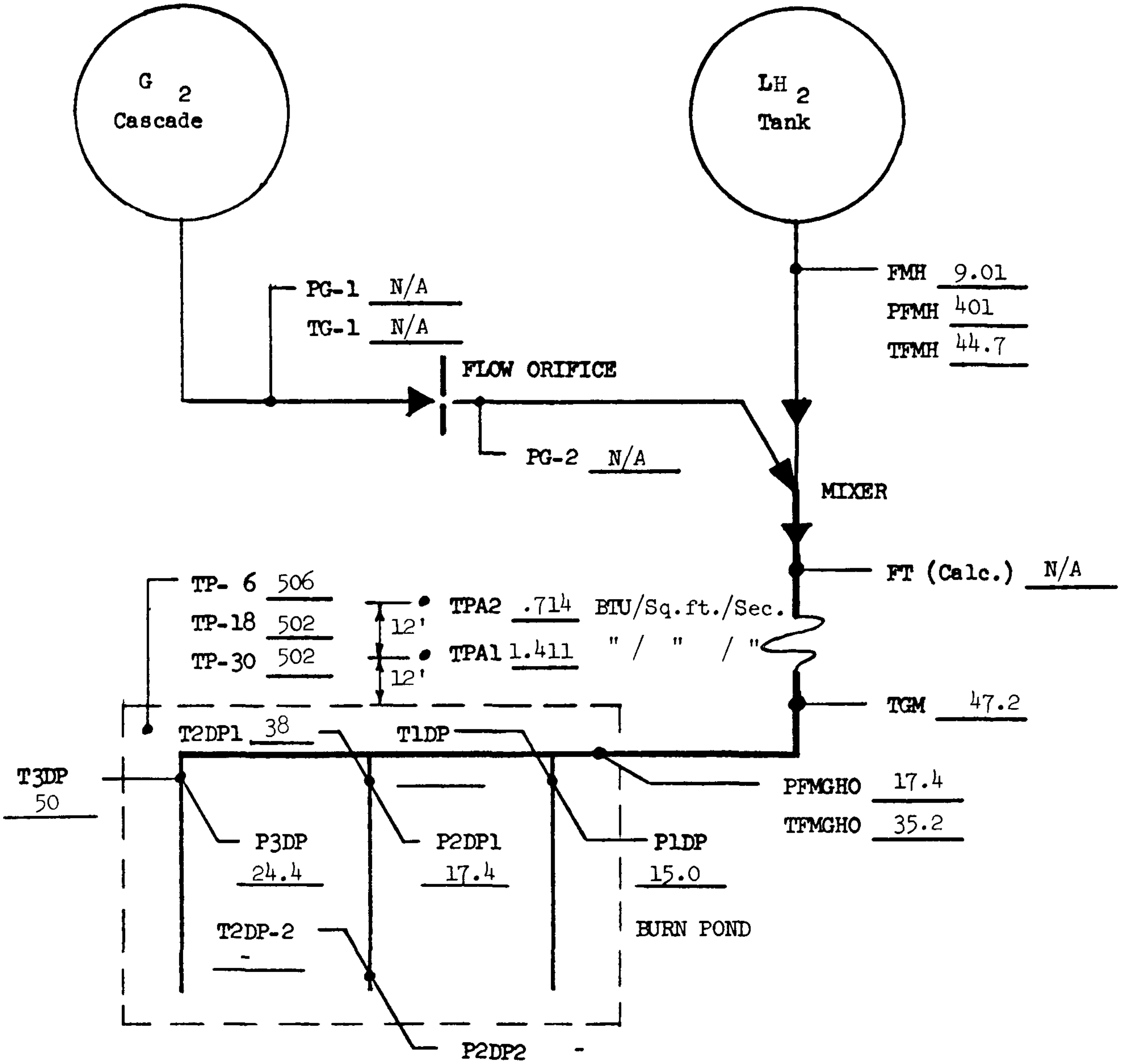
The results of the liquid test were approximately the same as those of the cold gas test. This indicates that no apparent problems exist in the event liquid is flowed into the pond instead of gas.

B. FULL-SCALE HYDROGEN BURN POND TESTING

No full-scale tests have been run on the main PHOEBUS-2 burn pond; however, several reduced-scale tests have been conducted. Some of these tests were specifically to evaluate the pond performance while others, primarily test stand systems checkout, have used the pond as a disposal facility.

One cold-flow test was run in which 100 lb/sec of liquid nitrogen was ducted to the pond for a duration of approximately 300 sec. Water loss was negligible and there was no pond icing.

Three tests were run in which ambient hydrogen gas was ducted to the pond and burned. Flow rates of 44 lb/sec for the first test, 111 lb/sec for the second test, and 156 lb/sec for the third test were achieved. Ignition was smooth in each of the three tests. Visual estimates for the second and third tests place the flame height at about 300 ft. In the last gaseous H_2 test in



LEGEND, 1st LETTER

P PRESSURE, PSIA

T TEMPERATURE, °R

F FLOW LB/SEC

TEST Liquid H_2 Flow

RUN # 012 011 DATE 1/12/66

DATA TIME 20 SECS.

TEST DURATION 21 SECS.

H_2O LOSS 7 IN. FLAME HT. 100 FT.

WIND Calm

Figure 39

Instrumentation Schematic, Summary Test No. 011

TABLE XI

SCALE MODEL HYDROGEN BURN POND INSTRUMENTATION RECAP

Sheet 1 of 2
Test No. 011

Type of Test LH_2 Flow

PARAMETER	FUNCTION	UNITS	0	5	10	15	20	25	30	35	40	45	50	55	60
			SECONDS												
FMH	LH_2 Flow Meter	lb/sec	9.24	9.21	9.10	9.00	8.99	4.60							
PFMH	Pressure @ Flow Meter	PSIA	429	421	412	406	401	133							
TFMH1	Temperature @ Flow Meter	^{o}R	44.7	44.8	44.4	44.5	44.7	44.3							
PFMGHO	Pressure @ Pond Inlet	PSIA	20.3	15.0	19.9	18.3	17.4	18.2							
TF7GHO	Temperature @ Pond Inlet	^{o}R	58.5	43.8	35.7	35.5	35.2	35.7							
T1DP	Temperature @ No. 1 Dist. Pipe Inlet	^{o}R	60.7	48.9	36.2	38.3	36.9	42.2							
T2DP-1	Temperature @ No. 2 Dist. Pipe Inlet	^{o}R	76	55	45	46	38	42							
T3DP	Temperature @ No. 3 Dist. Pipe Inlet	^{o}R	86	68	52.6	54	50	47							
P1DP	Pressure @ No. 1 Dist. Pipe Inlet	PSIA	15.4	19.5	15.0	15.0	15.0	14.7							
P2DP-1	Pressure @ No. 2 Dist. Pipe Inlet	PSIA	18.7	18.2	18.9	18.1	17.4	17.5							
P3DP	Pressure @ No. 3 Dist. Pipe Inlet	PSIA	20.8	21.8	22.5	23.4	24.4	25.5							
TPA-1	Heat Transfer 12' from Pond	BTU/ Ft^2/sec	1.86	1.70	1.29	1.19	1.41	1.93							

TABLE XI - (cont.)

Sheet 2 of 2
Test No. 011

Type of Test LH_2 Flow

PARAMETER	FUNCTION	UNITS	SECONDS 0	5	10	15	20	25	30	35	40	45	50	55	60
TPA-2	Heat Transfer 24' from Pond	BTU/ Ft^2/Sec	.040	.787	.790	.573	.714	1.05							
TP-6	H_2O Temperature 6" from Bottom of Pond	°R	508	506	504	503	506	500							
TP-18	H_2O Temperature 18" from bottom of Pond	°R	509	507	505	502	502	500							
TP-30	H_2O Temperature 30" from bottom of Pond	°R	506	505	508	502	502	503							

which peak flow of 156 lb/sec was achieved, the flow exceeded that required for momentum simulation (124 lb/sec) for 12.3 sec (Figure 40). Visual estimates placed the flame height at about 300 ft. Temperatures in the pond area are shown in Figure 41.

In the latest combustion test, liquid hydrogen at a rate of 140 lb/sec was ducted to the pond for 40 sec. No icing was noted; pond water level dropped about 2 in. Combustion was smooth and well controlled with, however, a distinct crack (like a pistol shot) on ignition.

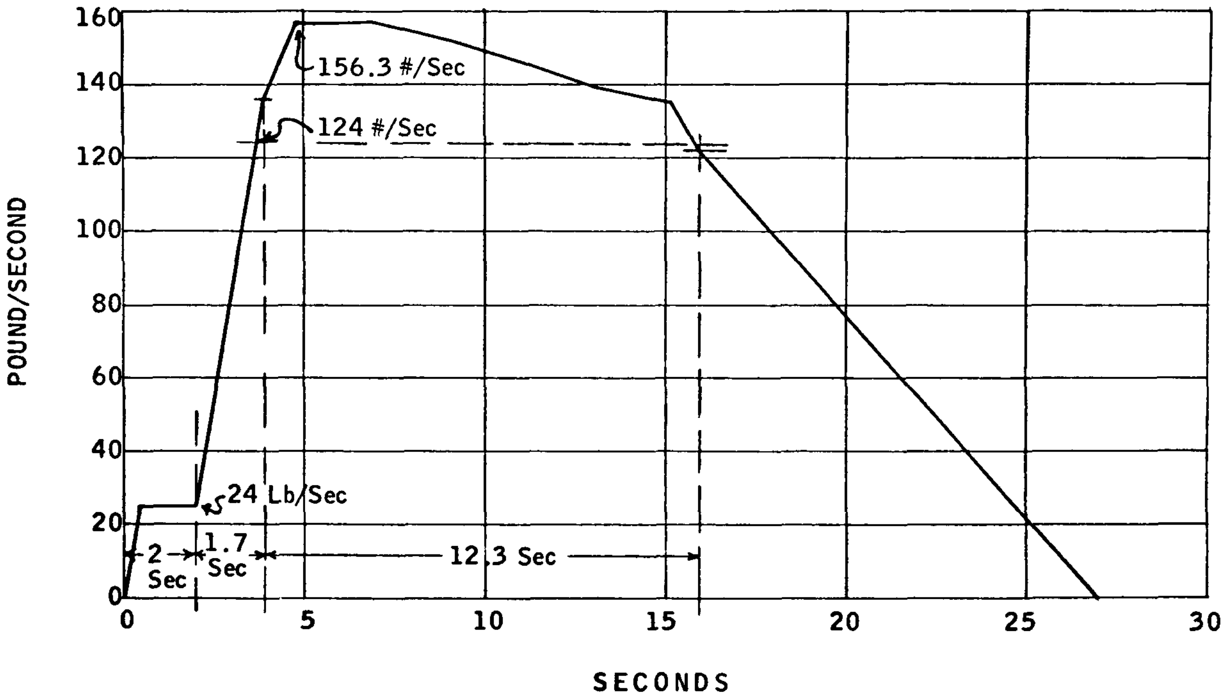


Figure 40

Full-Scale Hydrogen Burn Pond, GH_2 Flow Test (Ambient)

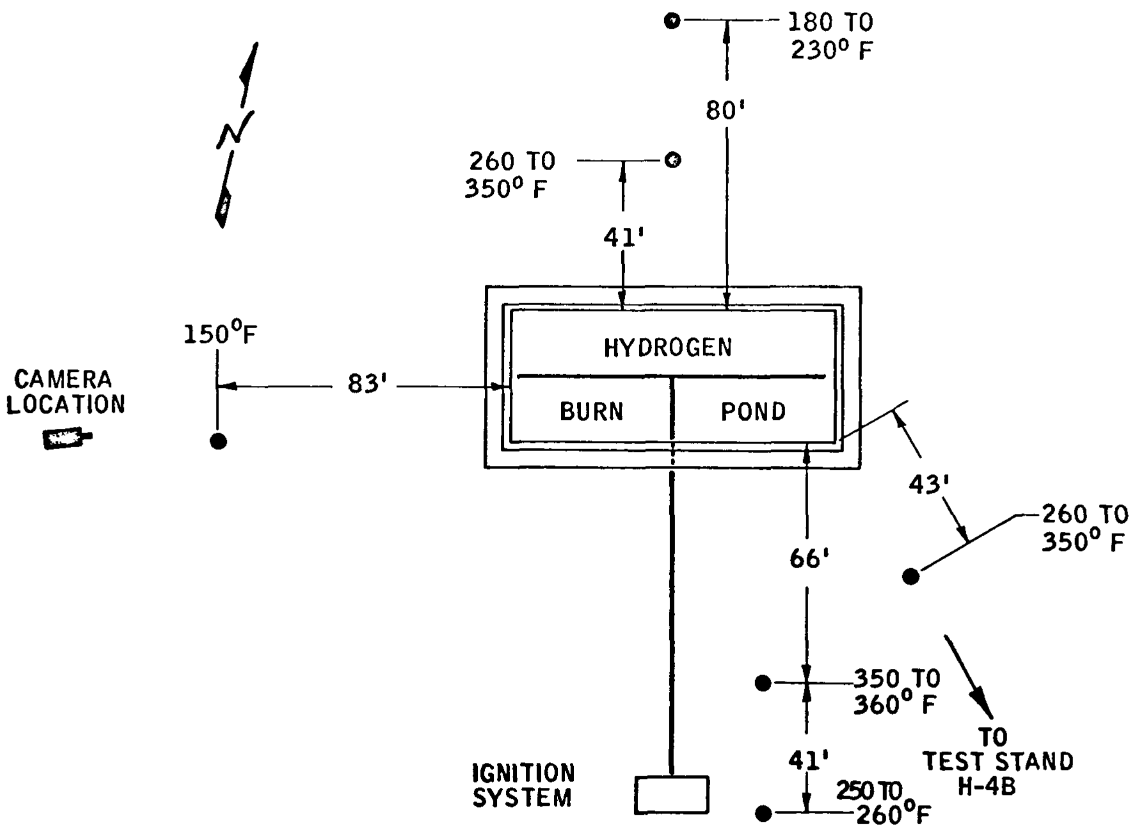


Figure 41

Full-Scale Hydrogen Burn Pond, GH_2 Flow Test, Area Temperatures

VI. CONCLUSIONS

The burn pond concept has been demonstrated as an effective means of disposing of hydrogen at temperatures ranging from ambient to near the critical. Flow rates may vary rapidly from near zero to the condition where all discharge nozzles are flowing sonically, provided ignition sources are located near the pond surface and cover a good portion of its area. For the short run times typical of rocket nozzle tests, rate of water loss is no problem with a pond designed so that surface turbulence does not result in excessive splash loss or overflow. The burn pond concept becomes increasingly attractive as the testing of future generations of propulsion devices requires the safe, controlled disposal of larger flow rates of flammable gases.

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VIII. REFERENCES

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2. Hajek, J. D.; Ludwig, E. E. "How to Design Safe Flare Stacks", Petro/Chemical Engineer, June, 1960.