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1.0 Introduction and Summary

On October 30, 1980, the NRC requested that Mississippi Power & Light Company (MP&L) provide a description of a program to improve the hydrogen control capability of the Grand Gulf Nuclear Station (GGNS). On December 19, 1980, the Nuclear Regulatory Commission (NRC) further requested that an untimate capacity analysis of the GGNS containment be performed.

The basis for these requests is the accident which occurred at TMI Unit 2 resulting in the generation of hydrogen beyond the limits specified in 10 CFR 50.44. This excessive hydrogen generation was primarily due to premature termination of the emergency core cooling system. Mississippi Power & Light (MP&L) believes that measures taken subsequent to the TMI-2 accident, along with the inherent resistance of the BWR 6/Mark III plant to events which could result in a degraded core, effectively precludes the need for further systems to prevent or mitigate the consequences of the generation of large amounts of hydrogen.

The GGNS design features which provide protection against plant damage and release of radioactivity in excess of 10 CFR 100 limits are:

a. Numerous high-and low-pressure pumps which provide makeup water to the reactor vessel.

b. Rapid depressurization capability via the Automatic Depressurization System.

c. Natural circulation internal to the reactor vessel.

d. Two above core spray systems for core cooling.

e. Direct reactor vessel water level measurement.

f. The capacility to vent noncondensible gases from the reactor vessel.

g. A large suppression pool heat sink for decay heat removal.

h. Suppression pool scrubbing of fission products.

i. Secondary containment providing an additional barrier to radioactive releases.

In addition, the existing GGNS Combustible Gas Control System as described in FSAR subsection 6.2.5, is a redundant, safety-grade system designed to meet the requirements of 10 CFR 50.44. It consists of two 100% capacity hydrogen recombiners, a drywell purge system, and a backup containment purge system. The system provides the capability to control the hydrogen which may be generated from a design basis accident. This system fully meets the current requirements in the code of Federal Regulations for combustible gas control.

However in response to both requests, a preliminary report was provided on April 9, 1981. In that report, a number of possible methods of controlling the generation of large amounts of hydrogen was evaluated including:

a. Containment pre-inerting system
b. Additional hydrogen recombiners
c. Halon injection system
d. Purge and filtered-vent system
e. Deluge with and without filtered-vent system
f. Water fog spray system
g. Oxygen depletion system
h. Hydrogen combustion system

The criteria used to assess these various options considered the mitigation effectiveness, consequences of intended or inadvertent operation, reliability, testability, impact on the public health and safety (if any), availability of design and equipment, and cost and schedule impact. The preliminary report concluded that a hydrogen ignition system is the most viable concept for GGNS.

The remaining portions of the preliminary report concerning design of the Hydrogen Igniter System (HIS), degraded core scenario, containment response, and ultimate containment capacity analysis are superceded by the information contained in this report.

2.0 Hydrogen Ignition System

2.1 Design Bases

The Hydrogen Ignition System (HIS) is designed to ignite hydrogen in the unlikely occurrence of an event which results in the generation of excessive quantities of hydrogen from a large metal-water reaction in the reactor pressure vessel. The HIS is designed to burn hydrogen at low concentrations, thereby maintaining the concentration of hydrogen below its detonable limit and preventing containment overpressure failure. The potential for significant pocketing of hydrogen will be precluded by:

a. Utilization of distributed ignition sources;

b. Simultaneous operation of containment sprays;

c. Mixing cuased by turbulence resulting from localized burns.

The HIS is designed with suitable redundancy such that no single active component failure, including power supplies, will prevent functioning of the system. The igniter assemblies are powered from two Class IE ESF power distribution panels. Each panel will supply one-half of the igniter assemblies. The HIS is designed to operate for a minimum of 168 hours following initiation in an accident condition.

2.2 System Description

2.2.1 Location Criteria

a. Hydrogen can be released directly to the containment atmosphere via the safety-relief valves which exhaust to the suppression pool. Therefore, igniter assemblies are located in a ring above the suppression pool as well as at other locations throughout the containment.

b. Hydrogen can be released directly to the drywell atmosphere via a pipe break in the drywell. Therefore, igniter assemblies will be located throughout the drywell.

c. In open areas of the containment below elevation 208'-10" and above elevation 262'-0" and for all areas of the drywell, igniter assemblies are located in accordance with the following criteria:

   1. Assuming only one ESF power distribution panel is functional following an accident, a maximum distance of 60 feet will exist between operable igniters.

2. Assuming both ESF power distribution panels are functional following an accident, a maximum distance of 30 feet will exist between operable itniters.

As discussed in Section 2.1, igniter assemblies located a maximum distance of 60 feet apart will provide adequate coverage of open areas in the containment and drywell and preclude the potential for significant pocketing of hydrogen.

d. For enclosed areas within the containment, two igniter assemblies will be located in each room with each igniter fed from a separate ESF power distribution panel.

2.2.2 Igniter Locations

Based on the criteria discussed in Section 2.2.1, final evaluations have concluded that 96 locations in the containment and drywell will require the installation of igniter assemblies. Figures 2-1 through 2-6 indicate the approximate igniter assembly locations by elevation. The final location of the igniters may be adjusted slightly to account for actual conditions in the vicinity of the assembly. As listed in Table 2-1, 24 igniter assemblies are located in the drywell and 72 are located throughout the containment.

Due to an absence of adequate support members, igniter assemblies will not be located between elevations 208'-10" and 262'-10" of the containment. This configuration will not negatively affect the functioning of the HIS for the following reasons:

a. There exists no major structures in this region which would promote the formation of hydrogen pockets. (For example, the polar crane is not large enough to allow hydrogen to pocket.)

b. The turbulence resulting from localised burns at other elevations and the operation of the containment sprays will promote the movement of any hydrogen in this area to areas supplied with igniters.

2.2.3 Igniter Assembly Description

At the present time, the design process for the HIS has progressed to a point where a specification for the design and qualification of a complete, safety-related igniter assembly has been issued. Therefore, specific design details of the igniter assembly are not available at this time and will be provided at a later date.

The design of the assembly will include the following:

a. A welded metallic enclosure which partially encloses the igniter and contains the transformer and associated electrical wiring;

b. Provisions for access to the interior of the enclosure;

c. A spray shield to protect the igniter from the containment spary;

d. A copper heat shield, if required, to protect the assembly components from high temperatures;

e. An igniter capable of maintaining a 1500 F surface temperature for a minimum of one week;

f. A transformer capable of stepping down 120±10% volts AC power to the required voltage necessary to achieve a minimum igniter operating temperature of 1500 F.

2.2.4 Igniter Supports

The igniter assemblies will be supported to withstand, without loss of function, the loads associated with seismic and hydrodynamic events. Igniter assemblies located in the pool swell and drywell negative pressure regions will be protected from these loads. Table 2-1 indicates the supporting member for each igniter assembly.

2.2.5 Power Supplies

The igniter assemblies will be fed 120 VAC (±10%), 60 Hz power from two ESF power panels, one from each division. These are Class IE power supplies which, in the event of failure of normal power sources, are fed from the station's diesel generators. Power will be fed to terminal boxes in containment, from which power will be distributed to the igniter transformers. Qualified local starters will be provided to permit remote operation of the igniters by means of handswitches in the control room.

Of the 96 igniter assemblies to be installed, 48 of them will be powered from a Division I power panel, and 48 from Division II. Furthermore, for each division, the 48 igniter assemblies will be divided approximately in half, with each half being powered from its own breaker and operated by its own starter. Thus, there are four circuits of approximately 24 igniter assemblies each, two from Division I, and two from Division II. Figure 2-7 provides a one-line diagram of the igniter power supply for one division.

2.2.6 HIC Component Qualification

2.2.6.1 HIS Components

All components of the HIS will be qualified for the following:

a. Seismic events;

b. Hydrodynamic events;

c. Environmental conditions in accordance with IEEE 323-1974 and NUREG-0588;

d. Environmental conditions resulting from successive hydrogen burns and the simultaneous operation of containment sprays.

2.2.6.2 Igniter Qualification

An evaluation of research efforts and test programs related to glow plug hydrogen ignition is underway. The results of this evaluation will determine whether additional testing will be required to verify that the HIS will function. This effort is further described in Section 5.4.

2.3 System Operation

The HIS is designed to prevent the accumulation of detonable concentrations of hydrogen. The containment sprays of the residual heat removal system will be operated in conjunction with the HIS. The HIS is not required for events which result in the generation of hydrogen less than or equal to the amounts and release rates considered in the design of the present combustible gas control system as described in FSAR subsection 6.2.5. It is intended, though, that the HIS be manually actuated for all event sequences which possess the potential to generate excessive amounts of hydrogen. The design of the HIS is such that planned or inadvertent actuation of the system will not adversely affect the operational safety of the plant nor increase the severity of a particular event.

2.3.1 Initiation Criteria

The HIS will be energized by a control room operator in accordance with Emergency Operating Procedures.

2.3.2 Duration of Operation

The HIS will be capable of operation for a minimum of 7 days following initiation in an accident condition.

2.4 Tests and Inspection

2.4.1 Preoperational Testing

The HIS will be preoperationally tested to ensure correct functioning of all controls, instrumentation and wiring, transformers and igniters. The test will consist of energizing one of the two ESF power distribution panels from the control room and verifying that all igniters powered from the associated panel are functional. The identical procedure will be followed for the remaining igniters powered off the remaining ESF panel.

2.4.2 Surveillance Tests

During plant operation, the igniter assemblies, power distribution panels, instrumentation, and associated wiring can be visually inspected (outside the drywell) and operationally tested at any time. During each refueling period, all igniter assemblies will be tested to verify operability. The test procedure will be identical to the preoperational test procedure discussed in Section 2.4.1.

2.5 Instrumentation and Controls

The HIS is manually initiated from the control room. Instrumentation for the HIS consits of two control room handswitches, one for each of the two Class IE power divisions. Each handswitch energizes the igniters in its respective division.

GGNS

TABLE 2-1

HYDROGEN IGNITER LOCATIONS

Floor Elevation	Azimuth (degrees)	Dimensions to Centerline of Containment	Supporting Member	Bottom of Supporting Elevation	Equipment Number
100'-9"	0	27'-7"	W10x15	113'-6 1/4"	D100
100'-9"	60	20'-0"	W10x15	113'-6 1/4"	D101
100'-9"	125	30'-2"	W10x15	113'-6 1/4"	D102
100'-9"	180	23'-6"	W10x15	113'-6 1/4"	D103
100'-9"	240	25'-9"	C10x15.3	113'-4 1/2"	D104
100'-9"	310	29'-10"	W10x15	113'-6 1/4"	D105
120'-10"	20	51'-9"	Conc.Slab	(B.O. Conc/Deck) 136'-0"	D124
120'-10"	47	53'-0"	W27x114	132'-11"	D125
120'-10"	75	51'-9"	Conc.Slab	(B.O. Conc/Deck) 134'-4"	D126
120'-10"	107	51'-9"	Conc.Slab	(B.O. Conc/Deck) 134'-4"	D127
120'-10"	135	51'-9"	W30x116	132'-10"	D128
120'-10"	165	51'-9"	W30x116	132'-10"	D129
120'-10"	195	51'-9"	W30x116	132'-10"	D130
120'-10"	220	60'-0"	C10x15.3	145'-7"	D131
120'-10"	253	51'-9"	Conc.Slab	(B.O. Conc/Deck) 134'-4"	D132
120'-10"	285	51'-9"	Conc.Slab	(B.O. Conc/Deck) 134'-4"	D133
120'-10"	317	52'-8"	W12x27	134'-2 1/4"	D134
120'-10"	349	51'-9"	Conc.Slab	(B.O. Conc/Deck) 136'-0"	D135
114'-6"	0	22'-10"	W12x19	146'-3 7/8"	D106

TABLE 2-1

HYDROGEN IGNITER LOCATIONS

Floor Elevation	Azimuth (degrees)	Dimensions to Centerline of Containment	Supporting Member	Bottom of Supporting Elevation	Equipment Number
114'-6"	63	29'-3"	SG-13	145'-7"	D107
114'-6"	120	29'-8"	W14x30	146'-2"	D108
114'-6"	180	26'-3"	W6x12	147'-1"	D109
114'-6"	240	29'-1 1/2"	W24x100	145'-7"	D110
114'-6"	313	25'-1 1/4"	NG-6	145'-7"	D111
135'-4"	16	51'-9"	Conc.Slab	(B.O. Conc/Deck) 166'-0"	D136
135'-4"	36	53'-6"	W18x50	160'-4"	D137
135'-4"	70	51'-9"	Conc.Slab	(B.O. Conc/Deck) 157'-10"	D138
135'-4"	100	51'-9"	Conc.Slab	(B.O. Conc/Deck) 157'-10"	D139
135'-4"	135	51'-2 1/4"	W18x40	160'-4"	D140
135'-4"	164	51'-9"	Conc.Slab	(B.O. Conc/Deck) 155'-10"	D141
135'-4"	196	51'-9"	Conc.Slab	(B.O. Conc/Deck) 155'-10"	D142
135'-4"	226	61'-4"	C10x25	165'-0 1/4"	D143
135'-4"	260	54'-2"	W18x50	160'-4"	D144
135'-4"	285	51'-5"	W30x108	159'-4"	D145
135'-4"	321	51'-5"	W30x108	159'-4"	D146
135'-4"	344	51'-9"	Conc.Slab	(B.O. Conc/Deck) 166'-0"	D147
147'-7"	0	27'-3 3/8"	W14x38	160'-7 7/8"	D112

TABLE 2-1

HYDROGEN IGNITER LOCATIONS

Floor Elevation	Azimuth (degrees)	Dimensions to Centerline of Containment	Supporting Member	Bottom of Supporting Elevation	Equipment Number
147'-7"	60	29'8-3/4"	W10x29	160'-11 3/4"	D113
147'-7"	135	27'-0 3/8"	W18x50	160'-4"	D114
147-7"	180	26'-10"	W10x19	160'-11 1/2"	D115
147'-7"	232	26'-1"	W18x50	160'-6"	D116
147'-7"	324	26 [illegible] 5/8"	W16x40	160'-6"	D117
161'-10"	0	26'-3 3/4"	W14x78	179'-0"	D118
161'-10"	65	26'-3 3/4"	W14x78	179'-0"	D119
161'-10"	125	26'-3 3/4"	W14x78	179'-0"	D120
161'-10"	185	26'-3 3/4"	W14x78	179'-0"	D121
161'-10"	245	26'-3 3/4"	W14x78	179'-0"	D122
161'-10"	305	26'-3 3/4"	W14x78	179'-0"	D123
161'-10"	30	61'-0"	W18x96	182'-9 7/8"	D148
161'-10"	40.844	37'-0"	Wall	167'-8"	D149
161'-10"	70	46'-2 1/16"	Wall	168'-10" / 178'-10"	D150/D152
161'-10"	109	51'-5 1/2"	Wall	178'-10" / 168'-10"	D153/D151
161'-10"	136	51'-9"	W27x145	182'-3 3/4"	D154
161'-10"	254	55'-9 1/4"	W24x68	182'-4 1/4"	D155
161'-10"	278	47'-7 3/4"	W12x27	183'-4 1/4"	D156
161'-10"	293	58'-11 1/4"	W24x130	182'-4"	D157
161'-10"	320	53'-2"	W12x50	183'-4"	D158

TABLE 2-1

HYDROGEN IGNITER LOCATIONS

Floor Elevation	Azimuth (degrees)	Dimensions to Centerline of Containment	Supporting Member	Bottom of Supporting Elevation	Equipment Number
184'-6"	20.956	50'-4"	Wall	202'-0"	D159
184'-6"	31.6075	41'-11 3/4"	Wall	202'-0"	D160
184'-6"	59.3702	44'-1 15/16"	W12x27	207'-9 1/8"	D161
184'-6"	73.842	55'-8 3/8"	Wall	202'-0"	D162
184'-6"	88.210	48'-0"	Wall	202'-0"	D163
184'-6"	0	11'-0"	Wall	202'-0"	D169
184'-6"	0	34'-0"	Wall	202'-0"	D168
184'-6"	0	37'-0"	Wall	202'-0"	D167
184'-6"	0	45'-0"	Wall	202'-0"	D166
184'-6"	91.789	48'-0"	Wall	202'-0"	D164
184'-6"	106.157	55'-8 3/8"	Wall	202'-0"	D165
184'-6"	134.593	49'-10 1/4"	W14x61	207'-7 1/2"	D170
184'-6"	209.673	49'-5 7/8"	C8x11.5	208'-4 3/4"	D171
184'-6"	241.675	26'-8 3/8"	W36x300	204'-10 15/16"	D172
184'-6"	256.361	53'-8 5/8"	W36x300	204'-0"	D173
184'-6"	283.638	53'-8 5/8"	W36x300	204'-10 15/16"	D174
184'-6"	298.325	26'-8 3/8"	W36x300	204'-10 15/16	D175
184'-6"	309.610	56'-5 9/16	W12x27	207'-9 1/8"	D176
184'-6"	341.075	55'-0 15/16"	Wall	202'-0"	D177

TABLE 2-1

HYDROGEN IGNITER LOCATIONS ABOVE EL. 208'-10"

Elevation	Azimuth (degrees)	Hanger Support Member	Equipment Number
262'-0"	5.49	Q1E12G018C34	D178
283'-10"	33.53	Q1E12G017C18	D187
262'-0"	48.07	Q1E12G018C36	D179
283'-10"	81.29	Q1E12G017C20	D188
262'-0"	90.65	Q1E12G018C38	D180
283'-10"	127.57	Q1E12G017C23	D189
262'-0"	140	Q1E12G018C42	D181
283'-10"	151.70	Q1E12G017C24	D190
295'-0"	158.48	Q1E12G017C06	D195
262'-0"	182.58	Q1E12G018C44	D182
283'-10"	198.96	Q1E12G017C26	D191
262'-09"	225.16	Q1E12G018C46	D183
282'-10"	242.41	Q1E12G017C28	D192
262'-0"	267.74	Q1E12G018C48	D184
283'-10"	285.87	Q1E12G017C13	D193
262'-0"	332.9	Q1E12G018C32	D185
295'-0"	349.06	Q1E12G017C01	D194
283'-0"	349.48	Q1E12G017C16	D186

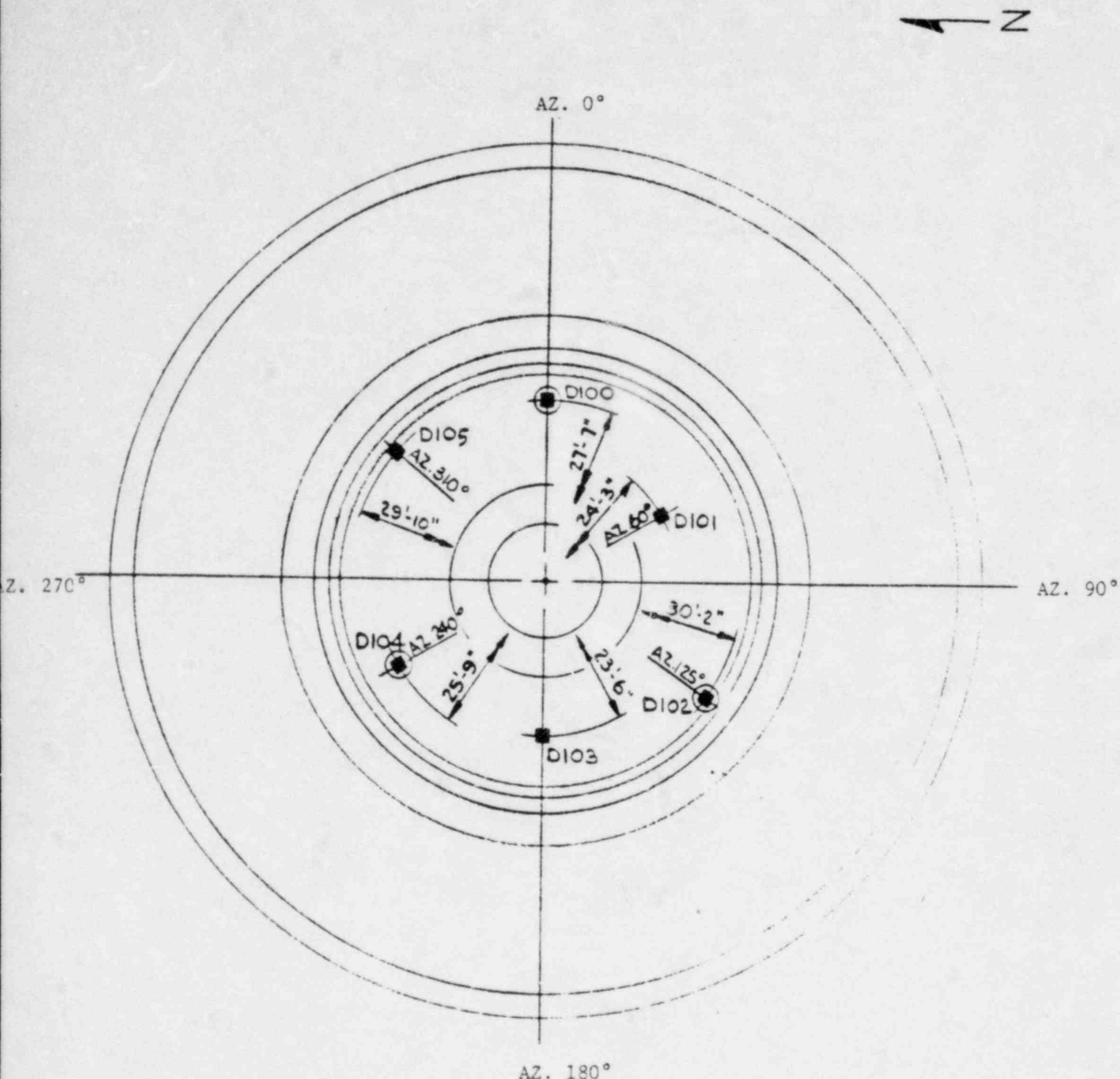


Figure 2-1
Hydrogen Igniter Locations
El. 93'-0" and El. 100'-9"

Powered from Division I

Powered from Division II

POOR ORIGINAL

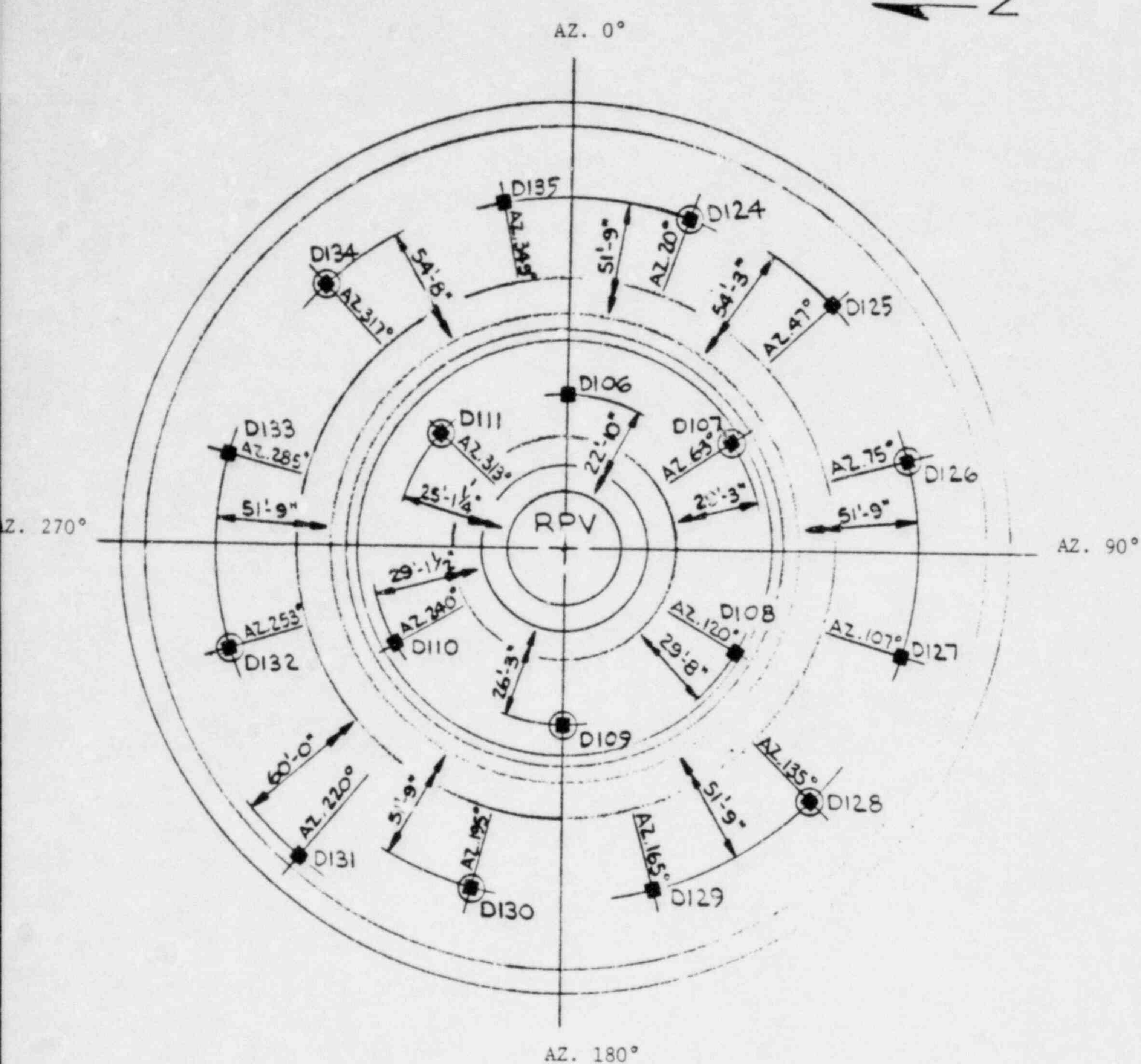


Figure 2-2
Hydrogen Igniter Locations
El. 120'-10" and El. 114'-6"

POOR ORIGINAL

◎ Powered from Division I

□ Powered from Division II

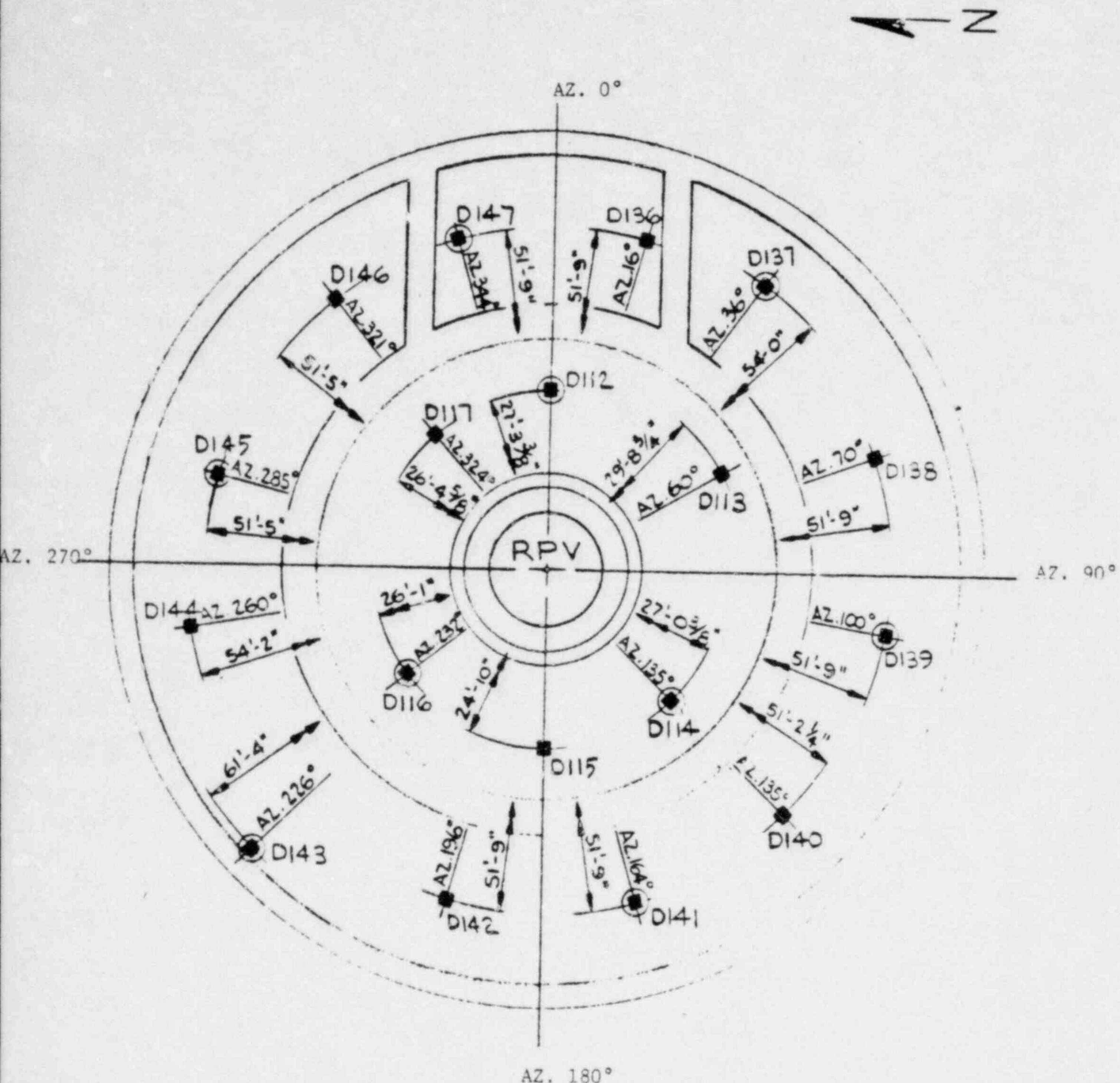


Figure 2-3
Hydrogen Igniter Locations
El. 135'-4" and El. 147'-7"

Powered from Division I

Powered from Division II

POOR ORIGINAL

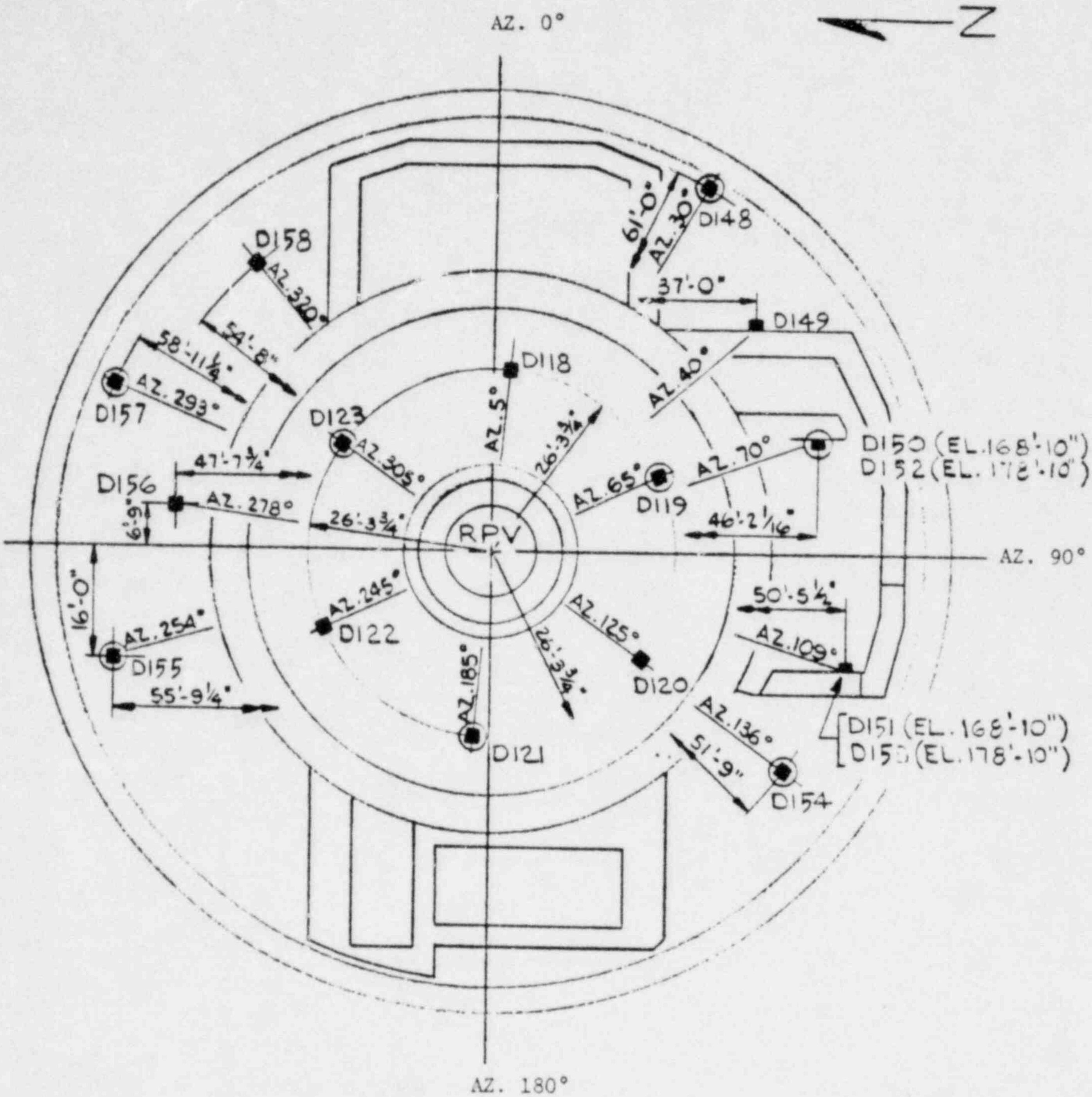


Figure 2-4
Hydrogen Igniter Locations
El. 161'-10"

Powered from Division I

Powered from Division II

POOR ORIGINAL

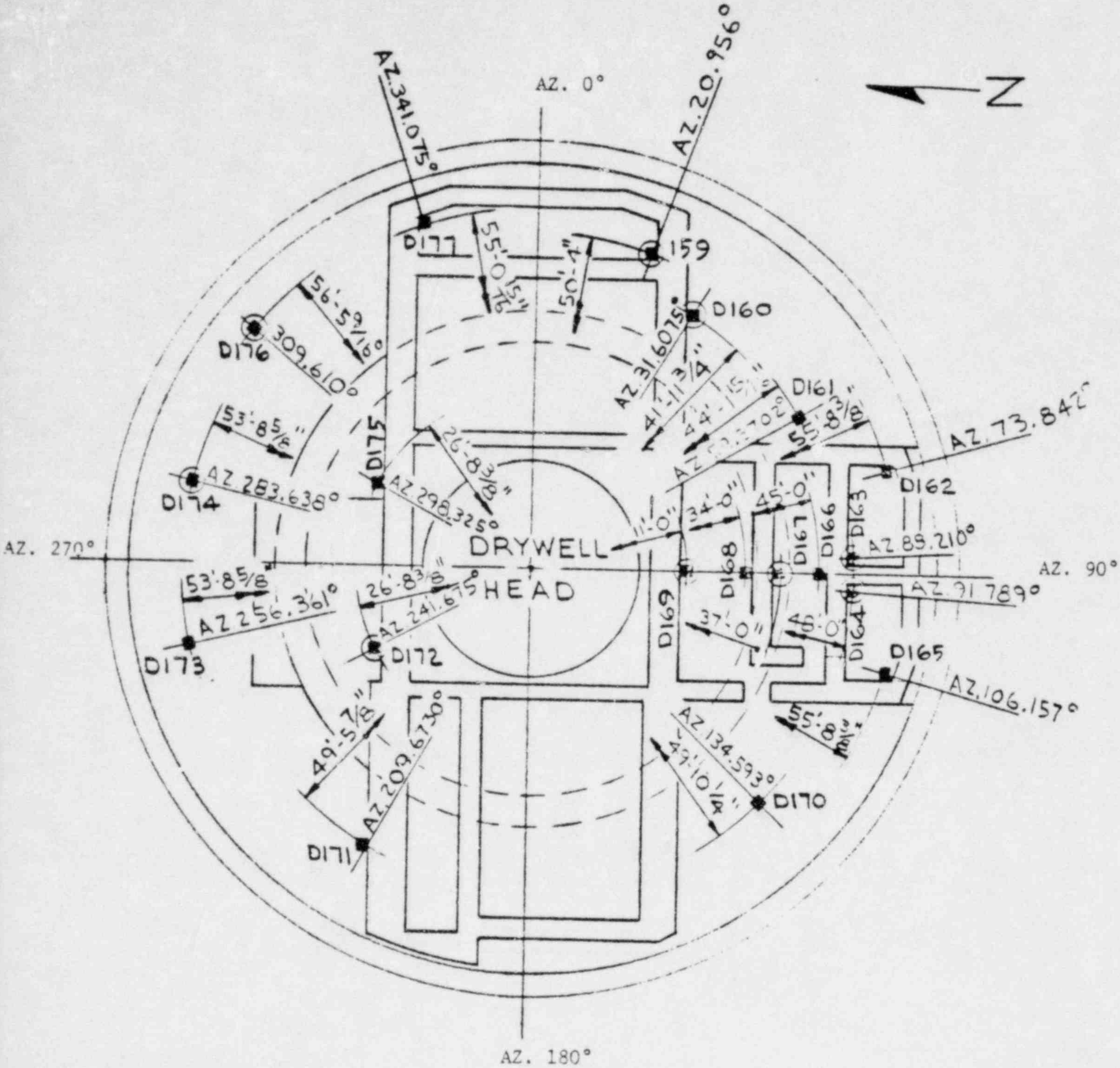


Figure 2-5
Hydrogen Igniter Locations
El. 184'-6"

◎ Powered from Division I

□ Powered from Division II

POOR ORIGINAL

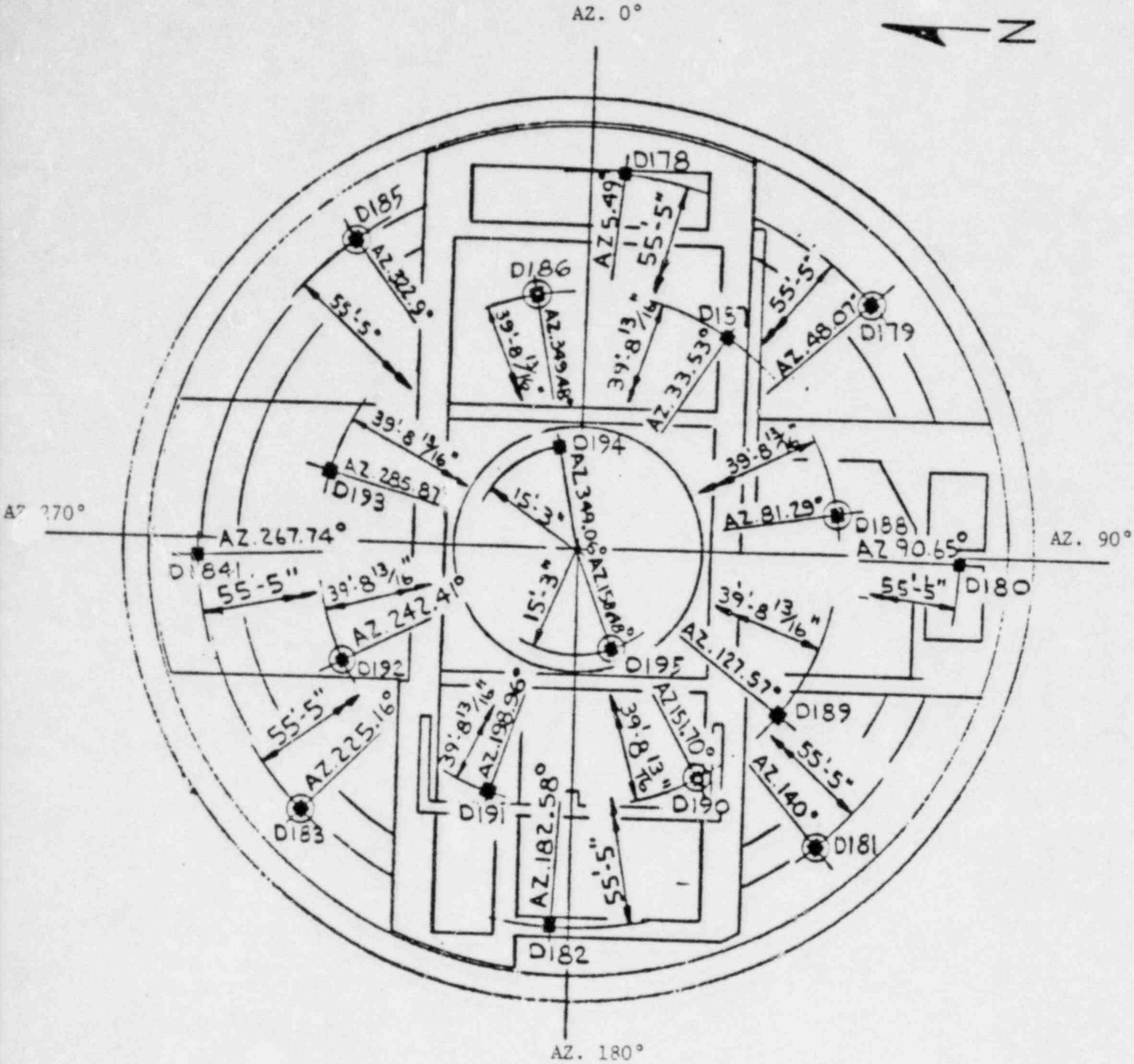
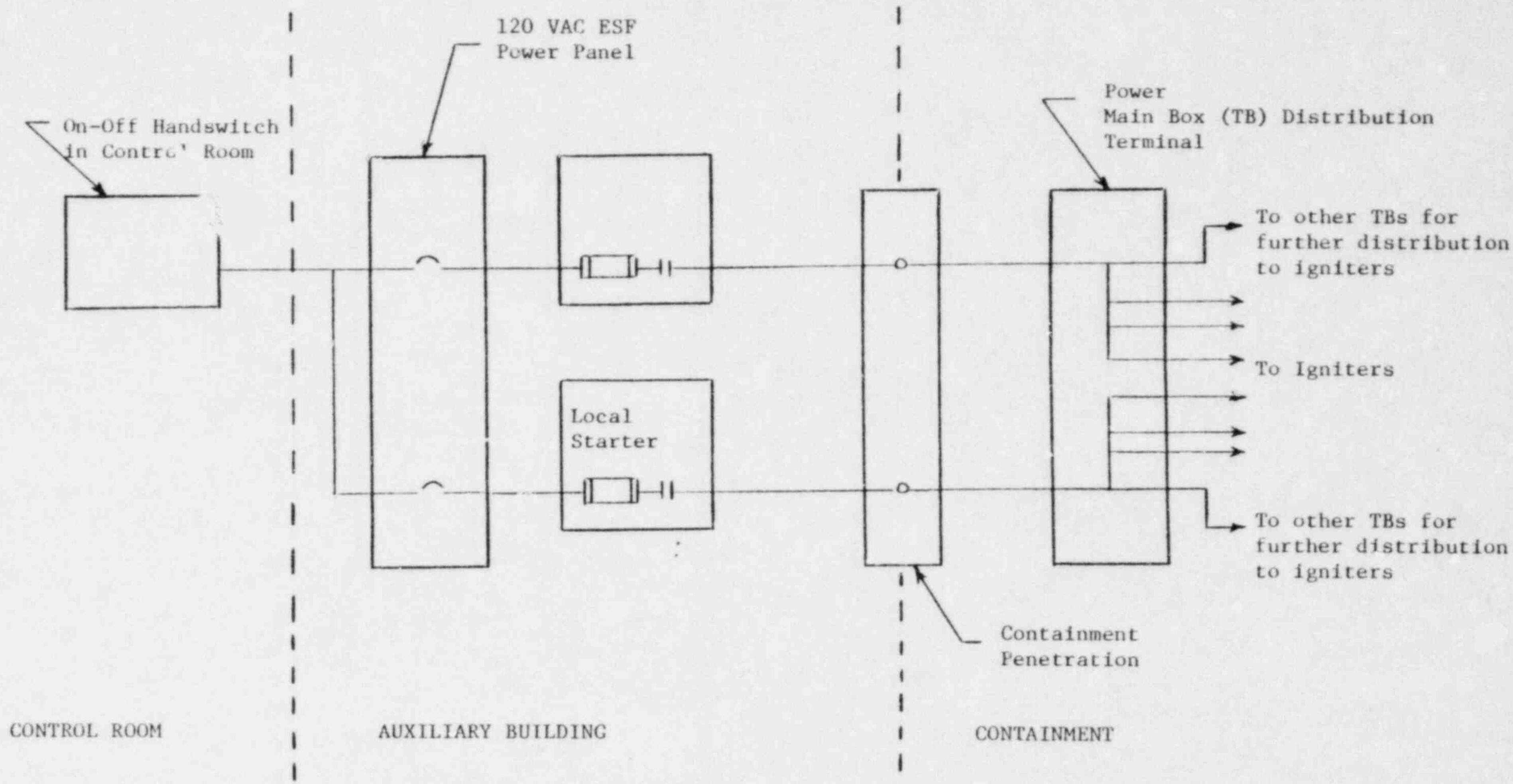


Figure 2-6
Hydrogen Igniter Locations
El. 208'-0"

◎ Powered from Division I

□ Powered from Division II

Figure 2-7
One Line Diagram
Igniter Power Supply for One Division



3.0 Design Evaluation

3.1 Containment Ultimate Capacity

In a letter dated December 19, 1980, the NRC requested that MP&L perform an ultimate capacity analysis for the GGNS containment. Details of the analysis and results are described in Appendix A.

3.2 Accident Scenario

The evaluation of containment pressure and temperature response was done for two different accident scenarios: a transient followed by a stuck open relief valve and a small break LOCA in the drywell. These scenarios were selected to provide a basis for evaluating the viability of the proposed GGNS HIS to prevent catastrophic containment failure as a result of the generation of large amounts of hydrogen from a degraded core. As discussed in Appendix D, the blowdown and hydrogen generation rates are obtained from modified output results from MARCH. The same data are used for both scenarios but with different release points. In both scenarios, containment spray is actuated following the first hydrogen burn. Prior to core slump, it is assumed that it becomes possible to recover from the failure (or unavailability) of the ECCS and water is injected into the core providing adequate cooling to prevent core slump.

3.2.1 Transient with Stuck Open Relief Valve

This event is the base case evaluation and, because of the relatively high probability of a stuck open relief valve, is believed to represent one of the dominant event sequences which could lead to a degraded core.

A transient occurs which causes one or more safety relief valves to lift. As reactor pressure returns to normal, a single safety relief valve fails to reseat. It is further assumed that the Power Conversion System is unavailable to remove heat from the vessel (as would be the case if the initiating transient is a loss of offsite power). There is a further failure of ECCS to provide flow to the vessel.

This event is discussed as Cases 2 and 3 in Section 5 of Appendix D.

3.2.2 Small Break LOCA

In addition, an evaluation was done for a small break LOCA in the drywell leading to a containment isolation and followed by a failure to provide flow to the vessel from ECCS. This event is discussed in Cases 1 and 4 of Appendix D, Section 5.

3.3 Containment Response

The containment response to the small break LOCA and the stuck open relief valve transients leading to a degraded core condition have been analyzed for the Grand Gulf containment using the CLASIX-3 computer program. A summary description of the program and the analytical results are discussed below.

3.3.1 CLASIX-3 Computer Program

The CLASIX-3 computer program, as discussed in more detail in Appendix B, consists of a number of control volumes connected by flow paths. The unique feature of the program is the model of the pressure suppression pool which is necessary to adequately represent the BWR Mark III containment. The program is also capable of representing other engineered safeguards, such as containment spray and drywell purge system, and passive systems, such as passive heat sinks and vacuum breakers.

The major purpose of the program is to track the concentrations of each gas in each compartment and, upon ignition, calculate the effects of burning of the hydrogen.

As discussed in more detail in Appendix C, "Verification of CLASIX-3", a significant amount of work has been accomplished in verifying the program. This verification includes comparison with hand calculations as well as comparison with transient results produced by other computer programs. In addition, rather extensive sensitivity studies indicate changes in the calculated response that are reasonable consequences of the changes in the input parameters.

The CLASIX computer program has been used extensively in the analysis of ice condenser containments. Although there are significant differences between CLASIX and CLASIX-3, there is also a significant commonality between the two programs, and the ice condenser experience lends credence to the results produced by CLASIX-3.

3.3.2 CLASIX-3 Results

Four CLASIX-3 runs were made for Grand Gulf. A brief description of each is given below, with a more detailed description provided in Appendix D.

Cases 1, 2, and 3 differ only in the burn parameters and transient type. A 10 v/o (volume percent) hydrogen ignition point was used in Cases 1 and 2 with 100% burnup allowed. Case 1 is a small break LOCA while Case 2 is a stuck open relief valve case. Case 3 is also a stuck open relief valve case, however, the hydrogen ignition volume fraction was reduced to 8 v/o with only 85% burnup allowed.

Case 4 begins at the end of Case 1 and is intended to evaluate the potential for and consequences of a hydrogen burn in the drywell. Hydrogen, steam, and fission product mass and energy release rates were assumed to fall to zero as a result of coolant injection into the core. A "spray" was added in the drywell to model the water leaving the break.

Of the four cases studies, as described in Appendix D, Case 4 was the worst case in which seventeen seconds of continuous burning produced pressures of 42.0 psig. For the other cases peak pressures were much lower. A maximum pressure of 15.5 psig was reached in Case 1 which was a small break LOCA in the drywell with 10 volume precent hydrogen ignition. Cases 2 and 3, both of which were stuck open relief valve cases, reached similar maximum pressures of 8.3 psig and 8.1 psig, respectively. The ignition points, however, were 10 v/o hydrogen and 8 v/o, respectively.

Peak temperatures experienced during burns in Cases 1 and 2 were similar (1500 F) due to identical hydrogen ignition concentrations. Case 3 experienced a lower peak temperature of 1062 F due to a lower ignition concentration. During Case 4, when burning was occurring in both the containment and the wetwell simultaneously, the sprays were evaporated before they reached the wetwell, thus allowing the temperature to peak at 2712 F.

Of the first three cases which began at time zero, the drywell break, Case 1 had the least amount of hydrogen burned. Only approximately 28% of the hydrogen released, burned. Of the two stuck open relief valve cases, Case 3, with the lower hydrogen ignition point, burned the most hydrogen with 74% as compared to Case 2 with 71% of the hydrogen released, burned. Case 4 burned 60% of the hydrogen released. It was noted from the results that fewer burns are experienced in small break LOCA cases than in stuck open relief valve cases. Also reducting the hydrogen ignition concentration, as expected, produces more burns with lower temperature and pressure peaks.

4.0 Equipment Survivability

The burning of hydrogen in the GGNS containment would result in large temperature spikes of short duration. An analsyis of the ability of essential equipment to survive this environment is underway. The anticipated completion date of this evaluation is December 1981.

4.1 Criteria for Equipment Selection

Section 4.2 provides a list of systems and equipment which may be required to function post-accident following a hydrogen burn. All systems in the containment and drywell were considered; those chosen as necessary were selected based on the following criteria:

a. Systems which must function to recover the core, maintain the containment pressure boundary, and mitigate the consequences of the event;

b. Systems or components whose function should not be negatively affected;

c. Systems whose function might be desirable (e.g., to monitor the course of the event).

4.2 Summary Equipment List

The following is a list of systems and equipment which may be required to function after a hydrogen burn and will be included in the GGNS equipment survivability program:

1. Containment isolation valves, penetrations, locks and hatches
2. Hydrogen igniter system
3. Hydrogen recombiners
4. Containment spray (CS) system
5. Safety relief valves
6. LPCS, LPCI and RHR systems
7. Reactor level and pressure instruments
8. Hydrogen analyzers
9. Containment pressure and high-range radiation instruments
10. Containment and suppression pool temperature instruments

11. Drywell pressure insurement

12. Associated instruments and controls

13. Associated power and control cables

14. LPCS, LPCI, RHR, CS and containment isolation valve position indications

4.3 Description of Program

The following is an outline of major milestones included in the GGNS equipment survivability program:

a. Generate Survivability Environments

   1. Establish burn temperature profiles
   2. Develop heat transport driving functions

b. Identify Essential Equipment Parameters

   1. Determine external ometry, casing composition, and surface emissivities
   2. Determine equipment temperature qualification
   3. Identify equipment's internal composition and material properties
   4. If necessary, determine equipment locations and existing thermal shielding
   5. If necessary, identify vital or limiting component and thermal failure mechanism.

c. Use analytical methods to determine thermal response of essential equipment to successive hydrogen burns.

d. Evaluate survivability based on the following criteria:

   1. Surface temperature response below qualification temperature
   2. Temperature response of vital or limiting component below qualification temperature
   3. Temperature response of vital or limiting component below thermal failure threshold

e. Propose and evaluate modifications to enhance equipment survivaiblity

   1. Modification to equipment surfaces
   2. Addition of thermal shielding
   3. Relocation of equipment
   4. Replacement of equipment

f. Benchmark analytical method against components subjected to actual hydrogen burns.

5.0 Generic Testing Programs

The HIS, which consists of ignition sources (glow plugs) distributed throughout the containment and drywell, is designed to burn volumetric quantities of hydrogen at low concentrations. The design of the Grand Gulf HIS is similar to the McGuire, Sequoyah, and D. C. Cook designs.

Numerous testing programs to determine the performance, ability to function and overall effectiveness of a low plug hydrogen ignition system have been completed, are currently ongoing, or are proposed throughout the industry. The majority of completed testing programs were initiated to investigate deliberate ignition systems intended as a supplemental means of hydrogen control in PWR ice condensers. However, many of the results and conclusions of these tests can be satisfactorily extrapolated to provide useful information relative to the design characteristics peculiar to the Grand Gulf H In particular, testing performed at Tennessee Valley Authority's (TVA) Singleton Labs, Fenwal, Inc., and Lawrence Livermore Laboratory (LLL) has provided a high level of confidence in the overall ability of the HIS. The results and conclusions of these tests are briefly summarized in the following sections.

5.1 Singleton Laboratory Tests

As part of an effort by TVA to determine the performance characteristics of commercially available glow plugs, testing was performed at TVA's Singleton Laboratory.[1,2] The primary purpose of the tests was: to evaluate glow plug surface temperatures; to determine the effects of overvoltage on glow plug life and temperature; and to investigate the effects of extended operation at high temperatures. Based on the results of these tests, a GMAC Model 7G glow plug was shown to be capable of achieving the desired minimum surface temperature of 1500 F for a range of voltages. Additionally, a degree of confidence was gained on the performance of the glow plug for extended periods at high temperatures.

5.2 Fenwal Tests

Hydrogen burn testing, sponsored by TVA, Duke Power, American Electric Power (AEP), and Westinghouse was performed at Fenwal, Inc.[2,3,4] The primary purpose of the tests was to determine the ignition capability of the GMAC igniter in various mixtures of hydrogen, air, and steam. Fan-induced turbulence and water spray effects were simulated. The results of the testing indicated that:

a. The igniters will initiate limited combustion for hydrogen concentrations of 6-8 percent. Completeness of combustion is somewhat dependent on the ability to promote mixing.

b. For hydrogen concentrations of 8-9 percent, a transition zone to complete combustion will exist.

c. For hydrogen concentrations of 10-12 percent, provided sufficient oxygen is present, a complete burn condition consuming all hydrogen present in the atmosphere will exist.

d. Operation of sprays has little effect on the ability of the glow plug to initiate combustion. At low hydrogen concentrations of 6-8 percent, water spray tends to promote more complete hydrogen combustion.

e. Steam concentrations of up to 40 percent by volume do not affect the ability of the igniter to initiate combustion and tend to suppress peak pressures generated by a burn.

f. The igniter can initiate hydrogen burning under transient conditions of continuous injection of hydrogen and steam.

5.3 Lawrence Livermore Laboratory Tests

To support the NRC review effort of the Sequoyah Interim Distributed Ignition System (IDIS), igniter tests were performed at Lawrence Livermore Laboratory.[2,4] This short-term test program centered upon the performance of the glow plugs under varying conditions of hydrogen, air, and steam. The results of this testing indicate the following:

a. Glow plug igniters are capable of burning low concentrations of hydrogen (6-10 percent) in dry air. Partial combustion occurred at lower concentrations of 6-8 percent and a complete burn was observed at higher concentrations. This is in good agreement with the Fenwal test results.

b. Glow plus igniters are capable of burning a mixture of as low as 8 percent hydrogen concentration and 30 percent and 40 percent steam. At 30 percent and 40 percent steam concentration, the glow plug always ignited the mixture. However, anomalous results were obtained for steam fractions of 50 percent.

c. Throughout the test procedure, there was no evidence of degradation in the ability of the glow plug to initiate combustion.

d. The glow plug consistently initiated combustion in dry mixtures at between 1310 F and 1370 F, and in steam tests between 1360 F and 1480 F.

e. Mixing or turbulence enhances combustion, most apparently at lower hydrogen concentrations.

5.4 Conclusions and Future Efforts

The Singleton, Fenwal, and LLL tests indicate that the glow plug igniter will function effectively when required under conditions expected in the GGNS containment and drywell. The Fenwal and LLL test results agreed well with published data on hydrogen flammability. Additionally, the results of these tests further justify the conclustion reached in our preliminary report that a hydrogen ignition system is the most viable concept to supplement the present GGNS hydrogen control capability.

A program is underway to further investigate test programs and research related to glow plug hydrogen ignition. The scope of this study encompasses the following efforts:

a. Compile a list of organizations sponsoring or performing research/experiements and obtain copies of available communiques, reports, proposals, etc.;

b. Review and evaluate information obtained for suitability, content and impact on the HIS design and operation;

c. Sponsor or perform additional testing as necessary for phenomena not previously or adequately covered.

The following is a list and brief description of major research and/or test programs (completed, active, or proposed) which are currently being evaluated:

1. AGENCY: Battelle Columbus Laboratory

   SPONSOR: NRC

   LOCATION: Battelle Columbus Laboratory

   Research focused on analytical modeling of subcompartment hydrogen concentrations as well as containment temperatures and pressures associated with a hydrogen burn.

2. AGENCY: Los Alamos National Laboratory (LANL)

   SPONSOR: NRC (Proposed)

   LOCATION: LANL

   Research is proposed which would analyze ignition from an engineering standpoint. Emphasis would be placed on equipment survivability and mixing within the containment.

3. AGENCY: Energy, Inc.

SPONSOR: Potentially IDCOR

LOCATION: Energy, Inc.

Proposed research would evaluate the following areas in a general sense:

- hydrogen generation
- control of hydrogen burn effects through mitigation
- control of hydrogen concentrations; i.e., mixing

4. AGENCY: Westinghouse

SPONSOR: PASNY/Com. Edison

LOCATION: Westinghouse Nuclear, Pittsburgh, PA

Research involves some combustion physics work for Indian Point/Zion plants. Study involves evaluation of conditions necessary to propagate a burn, effects of turbulence from containment sprays on mixing and hence ignition. Operability and survivability will also be evaluated.

5. AGENCY: EPRI

SPONSOR: TVA/Duke/AEP

LOCATION: Whiteshell (Canada)

Research involves a probabilistic analysis of detonation for varying hydrogen-air-steam ratios. Additional research involves a study of the effect of turbulence on combustion. In this phase of testing, the effect of fans, fans and perforated grates, and perforated grates alone will be studied. The perforated grates will be used to simulate the presence of a variety of obstacles. Bench scale comparison of igniters will also be accomplished.

6. AGENCY: EPRI

SPONSOR: TVA/Duke/AEP

LOCATION: Hanford

The primary purpose of this research will be the investigation of mixing, stratification and distribution of hydrogen in large open volumes. Factors affecting these conditions will be studies; i.e., effects of sprays, steam, natural and forced convection. The facility has the capability to consider various containment configurations.

7. AGENCY: EPRI

   SPONSOR: TVA/Duke/AEP

   LOCATION: Rockwell International

   Various igniter designs will be bench tested. Research will concentrate on operability.

8. AGENCY: EPRI

   SPONSOR: TVA/Duke/AEP

   LOCATION: Acurex

   Research will involve a comparison of several types of igniters as well as the effects of varying environments on igniter performance. Research will focus on equipment operability/survivability.

9. AGENCY: Lawrence Livermore Laboratory

   SPONSOR: NRC

   LOCATION: LLL

   Research efforts have focused on igniter operability. Although future research in the area of mixing due to containment sprays was rumored, no definite plans exist for any futher research. The LLL project should be complete within approximately two months.

10. AGENCY: Sandia National Laboratories

    SPONSOR: NRC

    LOCATION: SNL

    Sandia has been a major contributor to research efforts in the field of hydrogen ignition. Sandia has recommended that any mitigation scheme be enhanced through utilization of hydrogen detectors or monitors. They are also recommending that water fogging be used concurrent with igniters to effect pressure suppression within the containment. Research has been conducted which involved investigation of equipment survivability, ope ility, and mixing due to turbulence. The inf rmation contained in NUREG/CR-1762 represents a thorough evaluation of Sandia's on-going and proposed efforts.

11. AGENCY: Acurex

    SPONSOR: TVA/Duke/AEP

    LOCATION: Acurex

    Research will focus on the density of fog and droplet size required to effect pressure suppression within the containment.

12. AGENCY: Factory Mutual Research

    SPONSOR: TVA/Duke/AEP

    LOCATION: Factory Mutual Research

    Research investigates the effect of fog density on combustibility of hydrogen-air-steam mixtures.

In addition, information contained in References 6 through 14 is being evaluated.

6.0 References

1. Tennessee Valley Authority, Sequoyah Nuclear Plant Core Degradation Program, Volume II, Report on the Safety Evaluation of the Distributed Ignition System, December 15, 1980.

2. U.S. Nuclear Regulatory Commission, Supplement No. 4 to the Safety Evaluation Report for the Sequoyah Nuclear Plant, Units 1 and 2, NUREG-0011, USNRC, January 1981.

3. L. M. Mills, Tennessee Valley Authority, Letter to Mr. A. Schwencer, Chief Licensing Branch No. 2, Division of Licensing, USNRC, November 13, 1980.

4. W. G. Dalzell, "Determination of Ignition Performance Characteristics of Glow Plug Hydrogen Igniter for Westingthouse Electric Corporation," Report No. PSR-914, Fenwal Incorporated, Ashland, Massachusetts, November 10, 1980.

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6. M. Berman, et al., "Analysis of Hydrogen Mitigation for Degraded Core Accidents in the Sequoyah Nuclear Power Plant, NUREG/CR-1762, SAND 80-2714, Sandia National Laboratories, Albuquerque, New Mexico, January 1981.

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8. R. A. Strehlow, "Evaluation of the Glow Plug Igniter Concept for Use in the Sequoyah Nuclear Plant", prepared for Mr. James Milhoan, P.E., Office of Policy Evaluation, Nuclear Regulatory Commission, Washington, D.C., January 9, 1981.

*9. A. B. Rothman, et al., "An ANL Proposal for Investigation of concepts for Hydrogen Control under LWR Accident Conditions", Argonne National Laboratory, Argonne, Illinois, January 1981.

10. A. L. Berlad, et al., "Containment Building Hydrogen Control Methods Related to Degraded Core Accidents, BNL-NUREG-28976, Brookhaven National Laboratory, Upton, New York, November 1980.

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*13. L. Thompson, "EPRI Hydrogen Research Program", Electric Power Research Institute, Palo Alto, California, January 1981.

14. J. O. Henrie, et al., "Flame and Detonation Initiation and Propagation in Various Hydrogen - Air Mixtures, with and without Water Spray", Rockwell International, Canoga Park, California, March 24, 1980.

*Presented at Workshop on the Impact of Hydrogen on Water Reactor Safety, Albuquerque, New Mexico, January 1981.

Appendix A

Containment Ultimate Capacity

A.1 Design Pressure

The containment design pressure is 15 psig as stated in FSAR subsection 3.8.1.3.5b-1. The drywell internal design pressure is 30 psid as stated in FSAR subsection 3.8.3.3.1.5b-3.

A.2 Calculated Static Pressure Capacities

The ultimate capacity is defined as that pressure at which a general yield state is reached at a critical structural section. Analytical results indicate that the ultimate capacity of the containment is calculated to be 56 psig; this number is based on the specified strength of the materials used for reinforcement. Based on the actual reinforcement material strength indicated by certified mill test reports, the containment ultimate capacity is established to be 67 psig, 62 psig, and 70 psig for the mean, lower bound and upper bound, respectively.

The actual material strengths of the reinforcement are determined based on the method presented in Reference 1. The yield strengths of the hoop reinforcement in the critical structural section were examined. The mean material strength is the average strength of the population. The lower and upper bound strengths are the values corresponding to the standard deviation of 2.0 and 1.4 respectively from the mean as described in Reference 1. The mean, lower, and upper bound capacities of the containment are directly proportional to the material strengths of the reinforcement.

The ultimate capacity of the drywell structure is evaluated to be 67 psig (positive; i.e., drywell pressure above containment pressure) based on the specified strength of the materials used for reinforcement. The negative pressure capability is higher than the positive pressure capability.

The ultimate pressure retaining capacities of containment hatches and air locks are:

Hatch or Air Lock	Calculated Pressure (psig)
Containment Equipment Hatch	206.5
Lower Containment Personnel Air Lock	77.6
Upper Containment Air Lock	32.7*
Drywell Personnel Air Lock	72.9

*An evaluation of strengthening the Upper Containment Air Lock is in progress.

These calculated pressure capacities are derived from the initiation of yielding in the bulkhead door structural configuration based upon the specified material strengths.

Penetration closure plates have a calculated pressure retaining capacity of 60 psig based upon initiation of yielding at the specified material strengths. Piping has been evaluated as capable of retaining 75 psig external pressure.

A.3 Calculated Dynamic Pressure Strength

As stated in a MP&L letter (AECM-81/38) to R. L. Tedesco of the NRC, dated January 21, 1981, the Grand Gulf containment analysis does not consider dynamic pressure effects. As stated in Section 2.1, the design bases of the HIS prohibits conditions leading to a hydrogen detonation. This eliminates the narrow pressure spike which accompanies the detonation. MP&L investigations of hydrogen conbustion indicate that approximately 20-30 seconds are required for a flame front to propagate through the containment. The pressure increases associated with hydrogen combustion take place too slowly for dynamic effects to be of concern. Pressure decreases due to the effects of such things as heat sinks are even slower, on the order of several minutes. A dynamic pressure analysis, therefore, provides little additional information and is not likely to affect the conclusions of the analysis.

Equipment which forms part of the containment pressure boundary has also been evaluated. Equipment in this category can withstand a containment pressure of 70 psig.

A.4 Failure Modes

Analytical results from the containment statis non-linear finite element analysis indicates that the hoop reinforcement in the containment cylinder is the highest stressed element. The liner plate yields first, followed by the inner hoop reinforcement and finally the outer hoop reinforcement. This general yield state is reached at a pressure of 56 psig corresponding to the specified material strength of the reinforcement.

As stated in Section A.2, the evaluation of the drywell and drywell bulkhead, considering both positive and negative pressures, indicates that their ultimate cpacities are higher than the containment shell.

A.5 Original Design Criteria

Original containment analyses and design methods are specified in FSAR subsections 3.8.1.4.1.1 and 3.8.1.4.1.2, with applicable design codes listed in subsection 3.8.1.2. A further discussion of design criteria is found in the response to NRC question 130.29.

Original .rywell analyses nd design methods are specified in FSAR subsection 3.8.3.4.1, with applicable design codes listed in subsection 3.8.3.2. A further discussion of design criteria is found in the response to NRC question 130.33.

Original containment liner plate analyses and design methods are specified in FSAR subsection 3.8.1.4.2.

Original analyses and design methods for the containment and drywell personnel air locks and containment equipment hatch were in accordance with the requirements of Sections III, II and IX of the ASME Boiler and Pressure Vessel Code, 1974 Edition.

A.6 Analyses Details

The containment ultimate capacity analysis was performed using a finite element model (as shown in Figure A-1) and the Bechtel proprietary computer code FINEL. This code has the capability of modeling concrete cracking in tension and calculating the redistribution of forces and moments for the statically indeterminate structure. The finite element model consists of the containment dome and a portion of the containment cylinder. This portion of the containment structure was selected because this section of the cylinder has the least amount of hoop reinforcement, and when the general yield state is reached, the hoop reinforcement is the limiting element.

The drywell ultimate capacity analysis was performed using classical methods of closed form solution, considering both internal and external pressures. Since the drywell is a much stronger cylindrical shell than the containment, the drywell will not be the limiting structural element.

The airlocks and equipment hatch ultimate capacity analysis was performed using classical methods of closed form solution, considering both internal and external pressures as well as elastic and inelastic stability.

Piping and penetrations were evaluated for a specified external pressure of 75 psig in accordance with the provisions of subsections NC-3133 and NB-3133 of ASME Boiler and Pressure Vessel Code. The results of this analysis showed that all applicable piping can withstand an external pressure of 75 psig and thus is not the limiting structural element. Penetration closures show a limiting pressure of 60 psig.

A.7 Verification Drawings

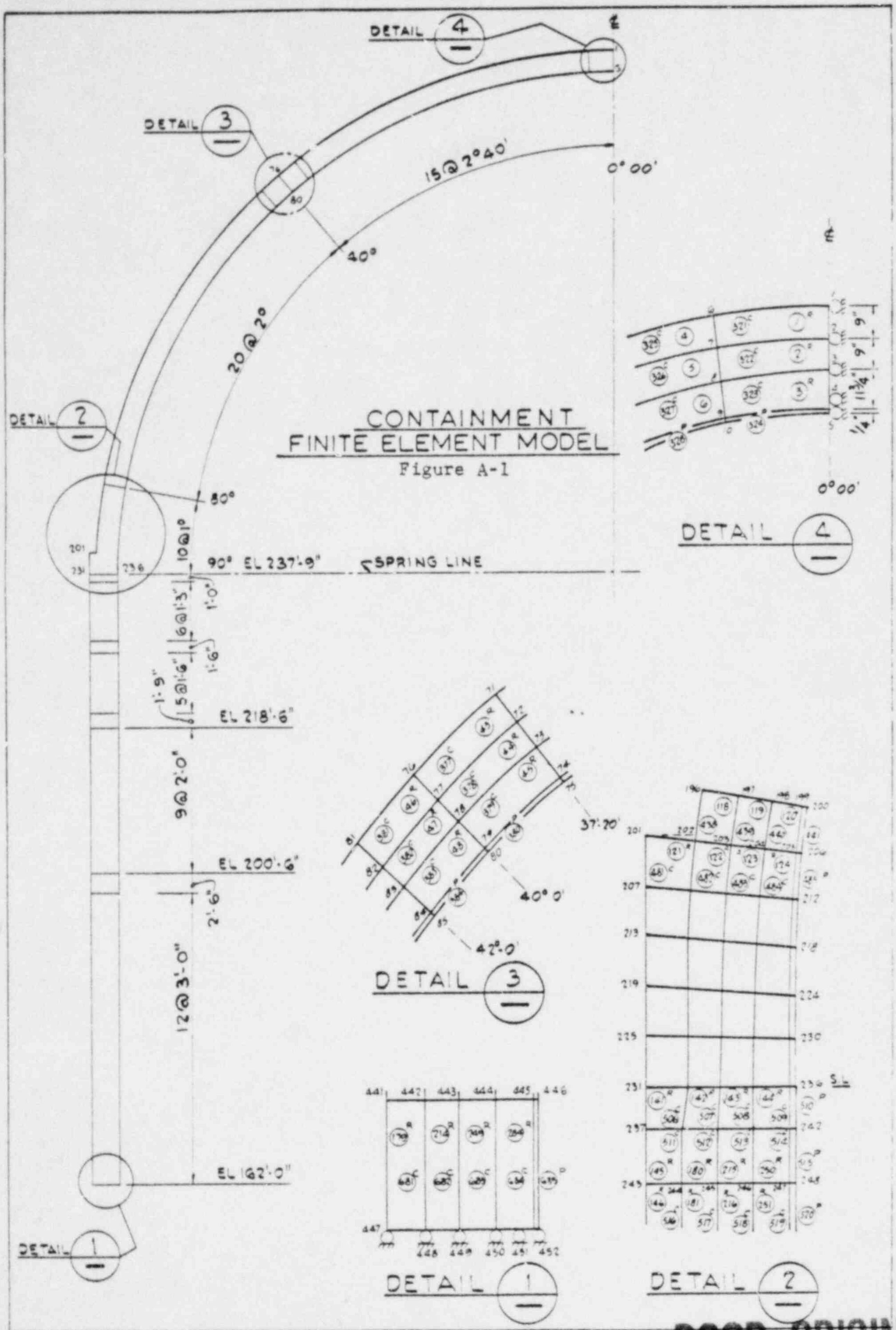
The drawings needed to allow verification of the modeling used and to evaluate the analyses employed for penetrations are Figure A-1 of this report and Figure 3.8-1 through 3.8-9 and 3.8-58 through 3.8-60 of the FSAR.

A.8 Conclusions

The containment structure, the drywell structure, and components which form part of the containment boundary (with the exception of the upper containment air lock) can withstand the peak pressures experienced during a hydrogen burn event as described in Section 3.3. The vendor for the containment air lock has been requested to increase the lock capacity to 60 psig.

A.9 References

1. Mirza, S. A. and MacGregor, J. G., "Variability of Mechanical Properties of Reinforcing Bars," Journal of Structural Division, ASCE, ST5, May 1979.



CONTAINMENT
FINITE ELEMENT MODEL
Figure A-1

Appendix B

CLASIX-3 Computer Program

B.1 Introduction

As a result of the incident at Three Mile Island, Offshore Power Systems began the development of an analytical capability to investigate the response of a reactor plant containment to a degraded core condition and the subsequent ignition and deflagration of the hydrogen released to the containment. The initial effort was directed toward the analysis of the ice condenser containment. The original CLASIX computer program with the representation of the ice condenser as well as the preliminary ice condenser containment analytical results are presented in Reference 1. Additional references to the CLASIX computer program and analytical results can be found in the submittals to the Nuclear Regulatory Commission and the Advisory Committee on Reactor Safeguards by the Tennessee Valley Authority for the Sequoyah Plant, Duke Power for the McGuire Plant, American Electric Power for the Cook Plant, and Offshore Power Systems for the manufacturing license for the Floating Nuclear Power Plant.

The original CLASIX program has been modified to be capable of adequately representing the BWR Mark III Pressure Suppression Containment System with its associated suppression pool. This version of CLASIX has been designated CLASIX-3.

B.2 Major Assumptions

The computer program is based on the following major assumptions:

1. The non-condensible gases (oxygen, nitrogen, hydrogen) are perfect gases governed by the perfect gas law and having constant specific heats.

2. In each control volume, all gases are instantaneously and perfectly mixed.

3. The combustion in a control volume occurs at a uniform, constant rate.

4. Inertia of the gas is negligible.

B.3 Program Capabilities

The primary capabilities of CLASIX-3 are shown in Table B-1 and are discussed below.

The basic analytical model consists of a number of control volumes connected by flow paths. In each control volume or compartment an inventory is maintained of the masses of the constituent gases and the total internal energy. Based on the assumptions of perfect mixing and perfect gases and using the ASME steam tables, the compartment temperature and the partial pressure of each gas can be determined.

Each basic flow path is represented by a flow loss coefficient and a flow area. In selected flow paths, a door or check valve may be specified to further restrict the flow. In these flow paths, the critical pressure ratio for transition to critical or "chocked" flow is assumed to have a constant value of 0.5 regardless of the constituents of the source compartment atmosphere.

Special flow paths may also be designated for which the volumetric flow rate as a function of differential pressure may be externally specified in tabular form. These flow paths may be restricted to operating only during a portion of the transient. These flow paths are capable of representing fans and/or other "pumps" flow.

Hydrogen and nitrogen additions from external sources along with their associated enthalpies are added directly to the compartment inventories. Heat additions (subtractions) are also added directly to the compartment inventory. Superheated liquid additions (break flow) are expanded against the total compartment pressure with the equilibrium amount of steam with its enthalpy being added directly to the inventory of the gas phase of the compartment.

Sprays may be specified for selected compartments. The spray drop size and fall time are assumed to be constant for a given spray but the flow rate, temperature, and film coefficient of heat transfer may be specified as functions of time. A fraction of the spray at the end of its fall time in one compartment may also be treated as a spray entering another compartment. For this option, the spray temperature, flow rate and drop size are dependent on the history of spray in the source compartment, but the fall time and film coefficient as a function of time in the second or receiving compartment must be specified.

One dimensional heat transfer to passive heat sinks is available in any or all compartments. Multiple layers of different materials may be specified, with interfacing film coefficients of heat transfer. The surface exposed to the compartment ambient conditions may use one of the internal film coefficient correlations or the coefficient may be externally specified as a function of time or as a function of the temperature difference between the ambient and the wall surface temperatures. The "exterior" surface of the wall may be adiabatic or exposed to a constant temperature heat sink. An emmissivity and effective beam length may be specified for the internal surface to calculate radiant heat transfer to and from the ambient atmosphere.

The suppression pool of the General Electric Mark III Pressure Suppression Containment System as described in Reference 2 has been included in the CLASIX-3 program. The system of equations given in the reference is intended to describe the hynamic behavior of the liquid in the suppression pool during a design basis accident resulting in the rapid pressurization of the drywell in the containment system. Since a hydrogen burn can occur anywhere in the containment, the equations were modified to account for flow in either direction through the vents rather than only from the drywell to the containment. A further modification was required by the long transient times associated with the small break analysis. Small imbalances in flow, which would be negligible over the short transients of the design basis accident, are cumulative and significant for the long term of the small break analysis. Therefore, explicit equations for continuity were added to the system of equations to eliminate this difficulty. The suppression pool model calculates the water levels in the drywell and wetwell and the gas flow through the suppression pool vents when it occurs. The water levels are further used in evaluating the transient net free volumes of the compartments.

Any gas flowing through the suppression pool vents is assumed to achieve thermal equilibrium with the pool. The condensate and heat removed from the non-condensibles are added to the pool inventories. Because of reverse pressurization, the pool may overflow the wier wall in the drywell. This phenomenon, as well as draining from the drywell back into the pool, is modeled.

A refueling pool is simulated in the containment to allow draining a given volume of water to the suppression pool over a given period of time at a specified time in the transient. Net free volume changes as well as water level changes in the suppression pool are accounted for by the program.

To simulate a stuck open relief valve transient, breakflow and noncondensible gases may be introduced into the wetwell side of the suppression pool.

The burn control parameters which may be externally specified are shown in Table B-2. When the volume percent of hydrogen and the volume percent of oxygen both exceed the values specified for ignition, deflagration is assumed to be initated. Based on the percent of hydrogen specified to be consumed and the burn time, a constant rate of combustion of hydrogen is determined. In a physical chamber, the flame front will proceed at some velocity from the point of ignition to the furthest extremity of the chamber. The time required for the flame to transit this distance is the burn time. The rate of combustion of the hydrogen is assumed to be constant until the requisite amount of hydrogen is consumed or until the volume percent of oxygen decreases below the volume percent specified as being required to support combustion.

As discussed above, the flame proceeds at some velocity through the chamber. It will also propagate through openings and conduits to adjoining compartments. The time elapsed for the flame to reach the adjoining compartment from the point of ignition is defined as the propagation delay time for the given flow path. Upon entering the adjoining chamber, the volume percent of hydrogen for propagation and the volume percent of oxygen are examined to determine if the flame propagates into the chamber or is extinguished.

Internal to the program, the hydrogen combustion process is treated as a flow process. The oxygen and hydrogen and their associated enthalpies are subtracted from the compartment inventory and the appropriate amount of water and the heat of combustion are added.

During the course of the transient, the program can, upon command, write a file of all pertinent parameters necessary to restart the transient at the time the file is written. This "restart" feature permits examination of the analytical results from a given set of input, modification the input and continuation of the transient. An option for the restart capability is to write a restart file after a specified time in the computer (CPU time).

B.4 Program Description

A simplified flow diagram of the CLASIX-3 computer program is shown in Figure B-1. The input to the program may be a complete set of input or it may be a restart file with some modified input. In either case, a complete input edit is generated.

Upon completion of the input edit, a finite difference integration loop is entered which continues until one of the stops is achieved. If a transient is being initiated, an output edit of initial conditions is generated, otherwise, the output is only written at specified intervals. After each output edit, it is determined if the transient is to be terminated.

Based on the water levels in the suppression pool and the differential pressure across the pool, the rate of gas flow through the vents is calculated. Then using the flow path parameters and the differential pressures, the volumetric flow rates in the flow paths are calculated. Using the upstream or source volume conditions, the volumetric flow rates are converted to mass and energy transfer rates.

From the wall (passive heat sink) surface temperature, the ambient conditions and the appropriate heat transfer correlations, the heat transfer rates, including radient heat transfer, between ambient and the walls are calculated.

The spray flow rate, temperature and film coefficient of heat transfer are either linearly interpolated from the input tables or determined from the source compartment conditions. If the inlet spray temperature is above the saturation temperature corresponding to the total pressure of the compartment, a sufficient quantity of spray is vaporized to reduce the spray temperature to the saturation temperature. This is assumed to occur in one differential time step. The drop size is reduced and the vapor and its associated enthalpy are treated as additions to the compartment gas inventory.

From the drop size, temperatures and film coefficient, heat transfer rates are calculated. During those periods when the spray temperature is below the saturation temperature, only the heat transfer rate needs to be calculated. However, heat transfer to the drop when it is at the saturation temperature will result in vaporizing at least some of the mass of the drop. Mass as well as energy rates must then be calculated and the spray drop size reduced. Heat transfer to the spray ceases when the fall time is exceeded or then the spray has completely vaporized.

The heat, hydrogen and nitrogen addition rates are linearly interpolated and added to the comprtment inventories.

The break mass and energy flow rates are linearly interpolated from the specified input. If the break flow enthalpy is above the saturated vapor enthalpy corresponding to the total pressure of the break compartment, the rates are added directly to the compartment atmosphere inventory. If the breakflow enthalpy is below the saturated liquid enthalpy, the breakflow has no effect on the atmospheric conditions. If the breakflow enthalpy is between the saturation enthalpies, the breakflow is assumed to achieve instantaneous equilibrium with the vapor and its associated energy is added to the gas phase inventory.

Based on the relative concentrations of the constituents in the compartment atmosphere and the burn control parameters, it is determined if ignition occurs. If the propagation delay time from an adjacent compartment has been exceeded, conditions are also checked to determine if ignition due to propagation occurs. If ignition occurs, timers are initialized to calculate propagation delay times to adjacent compartments. The burn rate and the amount of hydrogen to be burned are also calculated.

With all rates of change calculated, a simultaneous iteration i initiated on the stability of the selected time step and the final conditions in the compartment. Once the iteration to a satisfactory convergence is complete, all parameters are updated to their final values at the end of the time step. This includes temperatures inside the walls, suppression pool levels and checks on the completion of burns due to depletion of hydrogen or oxygen.

B.5 Conclusion

The preceeding provides a brief description of the CLASIX-3 computer program. Although not exhaustive, it does provide an understanding of the internals of the program.

B.6 References

1. "Tennessee Valley Authority, Sequoyah Nuclear Plant, Core Degradation Program, Volume 2", December 15, 1980.

2. "The General Electric Mark III. Pressure Suppression Containment System Analytical Model", W. J. Bilamin, NEDO-20533, June 1974.

TABLE B-1

CLASIX-3 CAPABILITIES

1. MULTIPLE COMPARTMENTS
2. FLOW PATHS
3. VACUUM BREAKERS
4. DRYWELL PURGE
5. INDIVIDUAL REPRESENTATION OF O_2, H_2, N_2 and H_2O
6. SATURATED AND SUPER-HEATED STEAM
7. SPRAYS (WITH CARRYOVER)
8. H_2, N_2 AND HEAT ADDITIONS
9. BREAK FLOW
10. WALLS
11. SUPPRESSION POOL
12. REFUELING POOL
13. BURN CONTROL

TABLE B-2

BURN CONTROL PARAMETERS

1. $^{V}/O$ H_2 IGNITION
2. % H_2 CONSUMED
3. $^{V}/O$ O_2 IGNITION
4. $^{V}/O$ O_2 SUPPORT COMBUSTION
5. BURN TIME
6. $^{V}/O$ H_2 PROPAGATION
7. PROPAGATION DELAY TIME

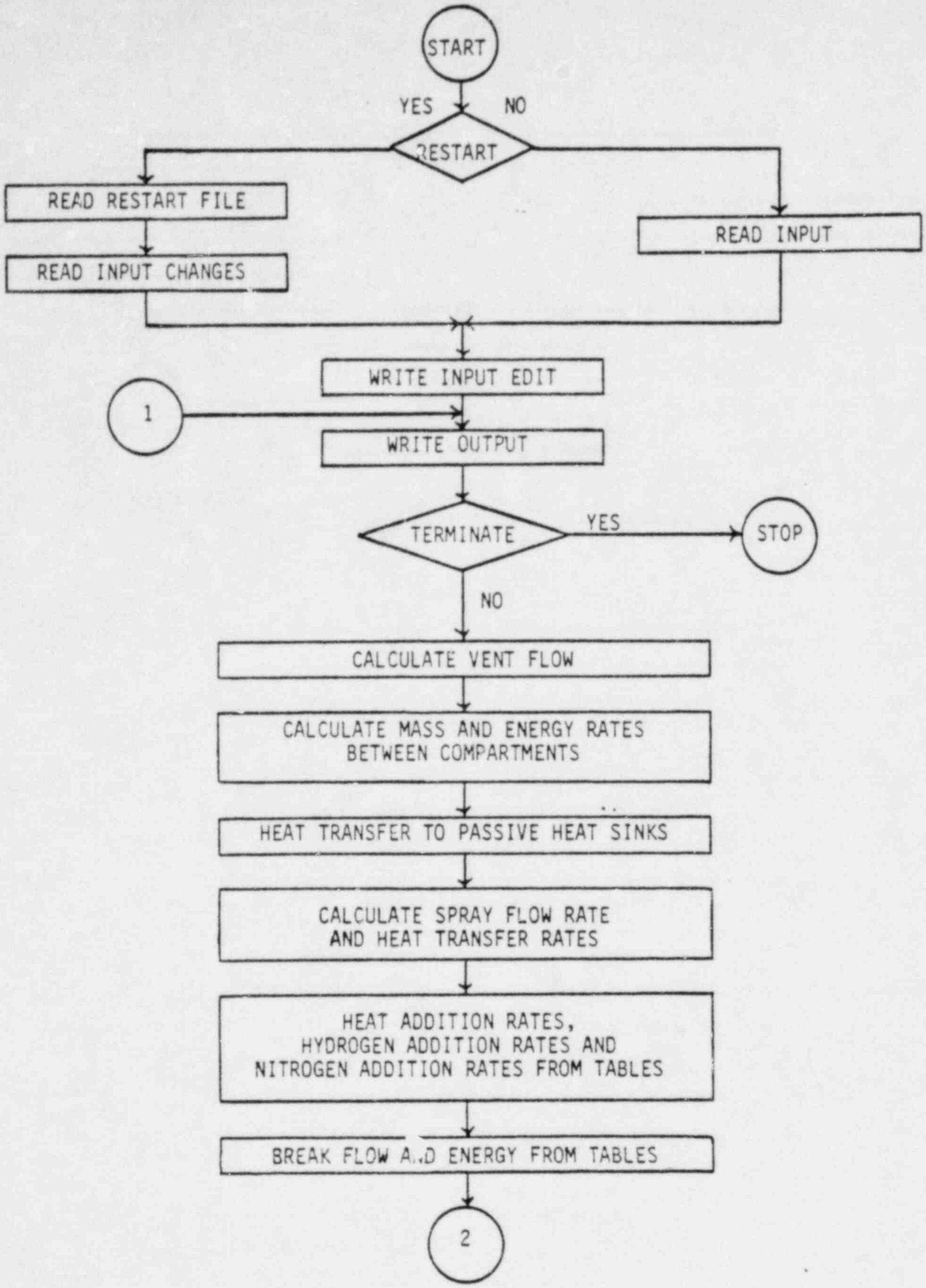

START
YES
NO
RESTART
READ RESTART FILE
READ INPUT
READ INPUT CHANGES
WRITE INPUT EDIT
1
WRITE OUTPUT
TERMINATE
YES
STOP
NO
CALCULATE VENT FLOW
CALCULATE MASS AND ENERGY RATES BETWEEN COMPARTMENTS
HEAT TRANSFER TO PASSIVE HEAT SINKS
CALCULATE SPRAY FLOW RATE AND HEAT TRANSFER RATES
HEAT ADDITION RATES, HYDROGEN ADDITION RATES AND NITROGEN ADDITION RATES FROM TABLES
BREAK FLOW AND ENERGY FROM TABLES
2

FIGURE B-1

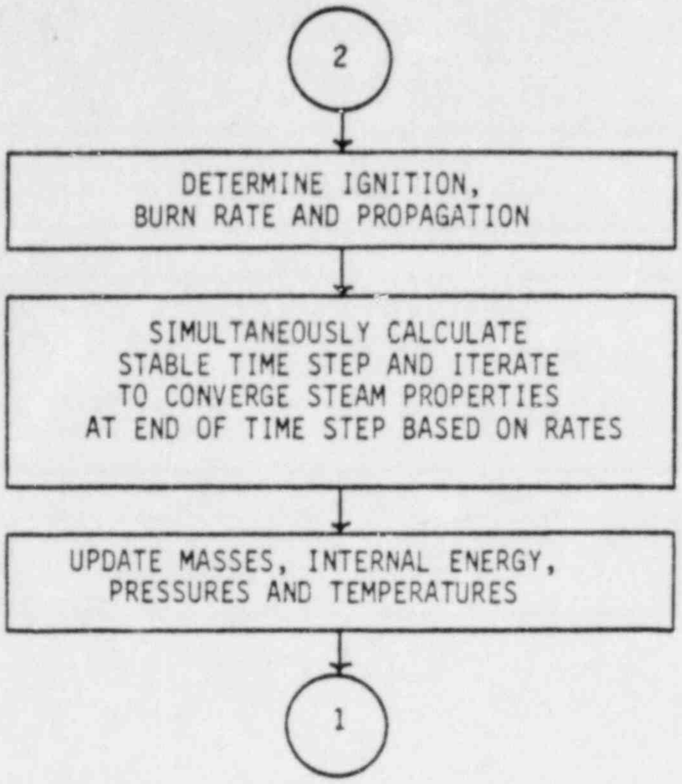


FIGURE B-1 (CONT.)

Appendix C

Verification of CLASIX-3

C.1 Introduction

The purpose of this appendix is to establish a level of confidence in the analytical results produced by the CLASIX-3 computer program. As indicated in the program description in Appendix A, the only fundamental difference between CLASIX and CLASIX-3 is that the latter was specifically developed for the analysis of an ice condenser containment and that the former was modified to incorporate a suppression pool and an upper pool dump for the analysis of a pressure suppression containment as CLASIX-3. Thus, the verification of either program, exclusive of the specific differences, is verification of the other.

The verification has been accomplished by comparison of the anlytical results with hand calculations and the results of other computer programs and by sensitivity studies. In addition, there is a significant amount of experience using the CLASIX program to analyze several ice condenser containments.

C.2 Hand Calculations

The detailed printout from the program provides sufficient information to permit verification of the conservation of mass and energy during the course of the transient. For example, prior to a burn, the mass of oxygen within the containment should be constant. It is simple to calculate the integral of the hydrogen and nitrogen addition tables to check against the inventory in the containment. (The amount of hydrogen burned is also printed out.) Subsequent to a burn, the amount of oxygen consumed can also be checked.

Since the steam conditions are based on the ASME steam tables, the partial pressure, temperature, and specific volume of the steam can be checked. Using the perfect gas law the partial pressure, density, and temperatures of the non-condensibles can also be checked.

These and many other hand calculations and checks have been performed to assure that the equations have been properly programmed.

C.3 Sensitivity Studies

Extensive, although not exhaustive, sensitivity studies of input values have been completed and the results published. All results indicate changes in the calculated response that are reasonable consequences of the changes in the input parameters.

C.4 Comparison with Other Programs

Some comparison have been made between CLASIX and the TMD and COCO computer programs which are proprietary programs developed by Westinghouse Electric Corporation. These programs are for the containment design analysis and the programs have been accepted as valid by the Nuclear Regulatory Commission.

Both the CLASIX and TMD programs are multicompartment analytical models. A significant difference between the programs is in the treatment of the flashing of the break flow as it enters the containment. Since TMD is intended for the large break LOCA analyses, great turbulence can be expected in the break compartment during the few seconds analyzed by TMD. Because of this, the liquid portion of the breakflow would be expected to be intimately mixed with the gases during the short period of the blowdown and that the gases and liquid would all be at the same temperature. This automatically forces saturated steam conditions in the compartment. Since CLASIX is oriented toward small break LOCAs, the blowdown is much less turbulent and the liquid and gas phases can be assumed to separate with the breakflow flashing against the instantaneous total pressure in the compartment. This assumption will result in higher temperatures and pressures in the compartment than those predicted by TMD.

Figures C-1 and C-2 present the temperature and pressure response of a two volume containment during a constant blowdown rate of 10,000 pounds per second of water with an enthalpy of 500 Btu/pound. As expected from the preceding discussion, the CLASIX predictions of temperature and pressure in the break volume are consistantly higher than those predicted by TMD. In the non-break volume, the CLASIX temperature predictions initially lag the TMD temperature and then exceeds it. This effect is attributable to the density differences in the flow early in the transient. However, characteristics of the responses of the two programs are the same with CLASIX providing conservatively high predictions of temperature and pressure.

To minimize the effect of mixing the liquid portion of the blowdown with the gas phase in TMD, the enthalpy of the blowdown was increased to be in the slightly superheated region. The initial low temperature in the break compartment will condense a small amount of the blowdown as thermal equilibrium is achieved. However, because this amount of condensation is small, the results of the two programs would be expected to be very similar. The results of this transient are shown in Figures C-3 and C-4. The pressure results are negligibly different. As expected, the temperature results in the non-break compartment are negligibly different and the small difference in the break compartment is due to some condensation.

The COCO program is a single volume containment program designed for the analysis of dry containment response to a LOCA. This program was modified to include the effects of hydrogen and was designated COCOCLASS9.

The assumption of perfect mixing between the liquid and gas phases during blowdown used in TMD is also used in COCO. Thus, differences in the analytical results between CLASIX and COCO can be expected. The transient analyzed in Figures C-5 and C-6 is for a 10,000 pound per second blowdown of 500 Btu/pound water for 200 seconds followed by 100 seconds of no forcing function, then 100 seconds of hydrogen generation at 10 pounds/second followed by hydrogen combustion at 50 pounds per second. As with TMD, the transient was rerun with 1205 Btu/pound blowdown. This latter transient is shown in Figures C-7 and C-8.

The heat transfer within a wall was compared with a standard one-dimensional heat transfer program for a step change in surface temperature. CLASIX and the heat transfer program produced identical results.

C.5 Conclusions

Comparisons with hand calculations and accepted standard computer programs, sensitivity studies, and the large body of CLASIX and CLASIX-3 calculations performed to date have not produced any anomalous analytical results. Based on this evidence, a high level of confidence can be placed in the analytical results produced with the CLASIX-3 computer program.

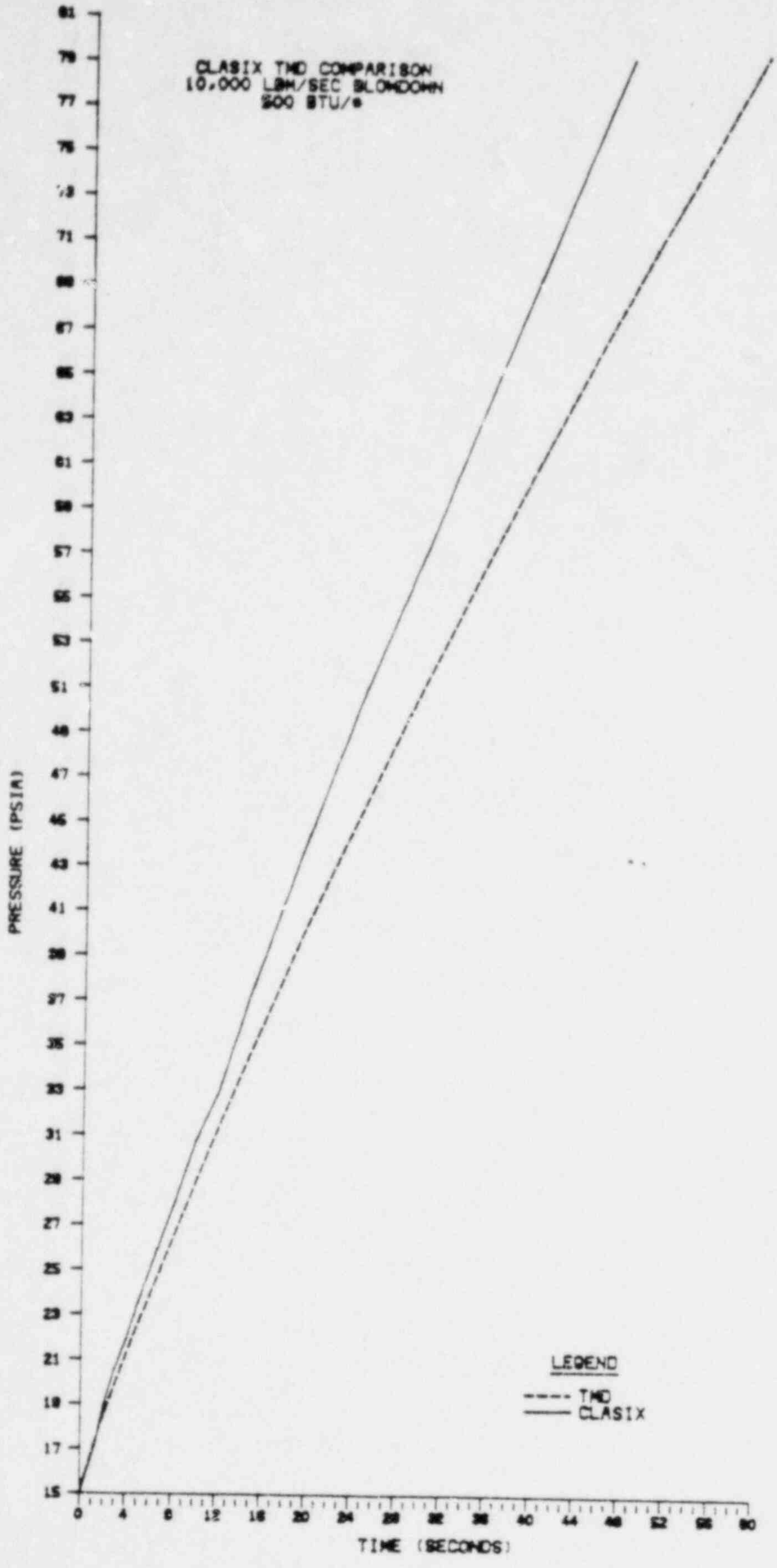


Figure C-1

POOR ORIGINAL

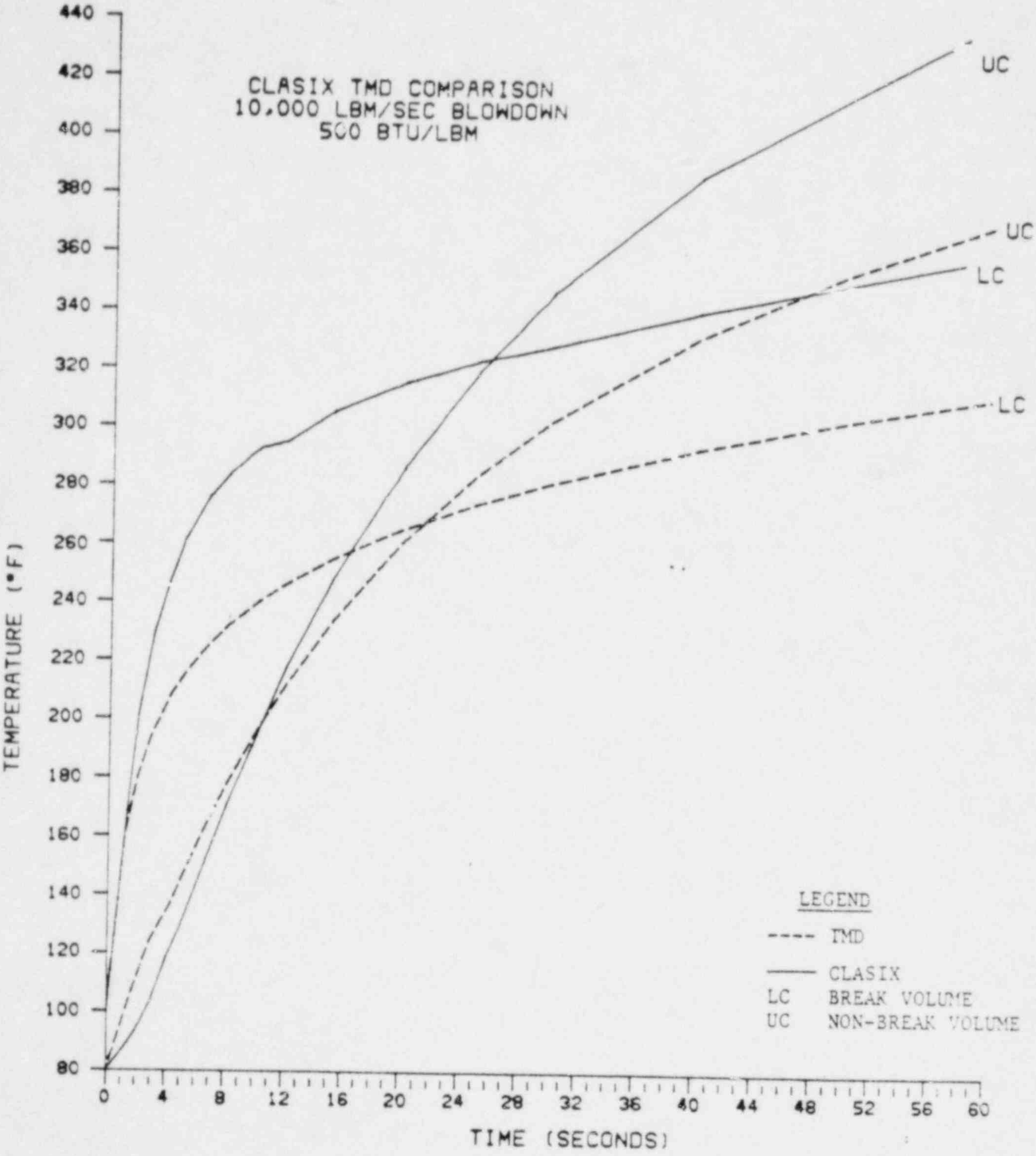


Figure C-2

POOR ORIGINAL

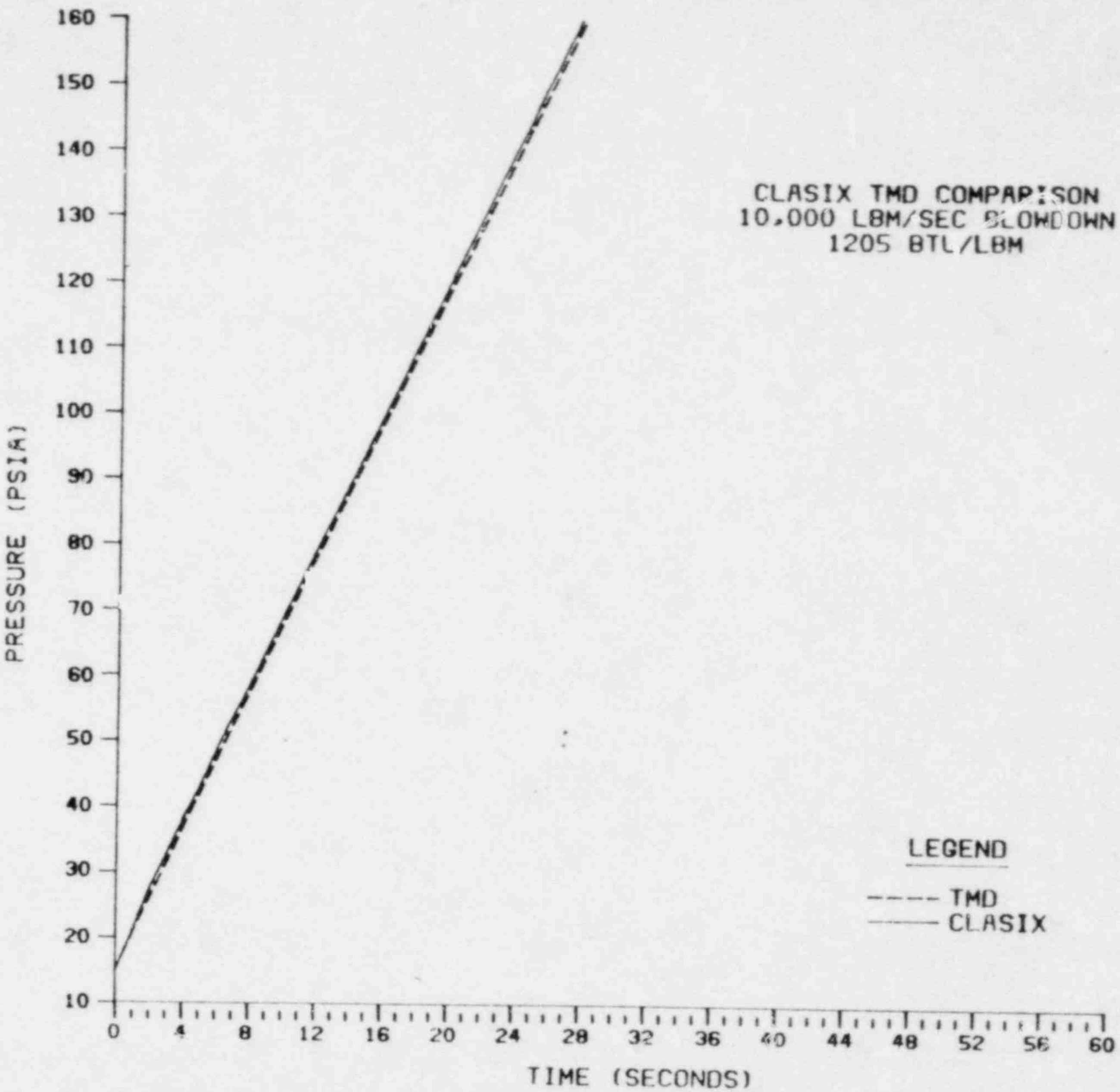

CLASIX TMD COMPARISON
10,000 LBM/SEC BLOWDOWN
1205 BTL/LBM
LEGEND
TMD
CLASIX
PRESSURE (PSIA)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
TIME (SECONDS)
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60

Figure C-3

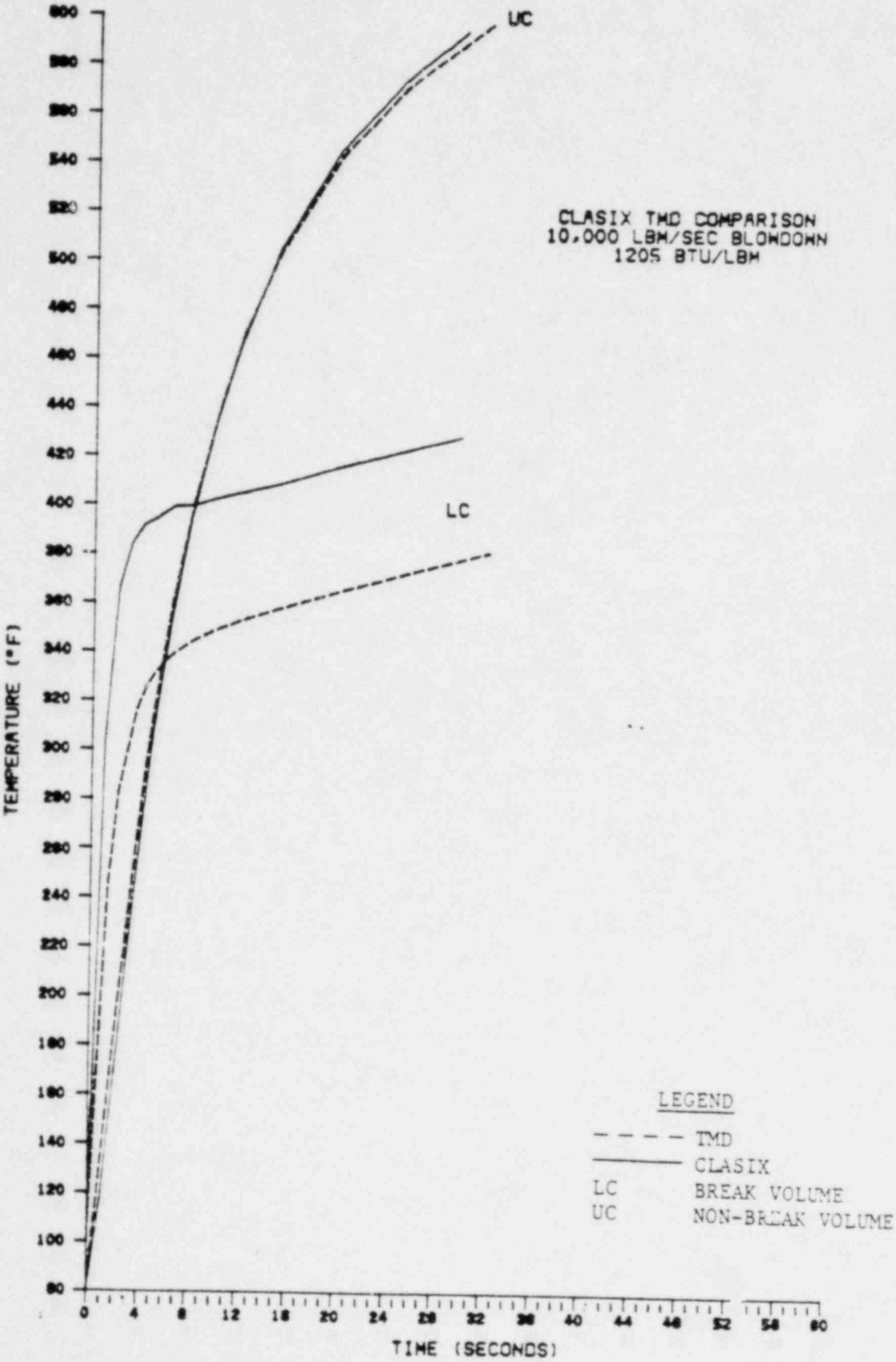


Figure C-4

POOR ORIGINAL

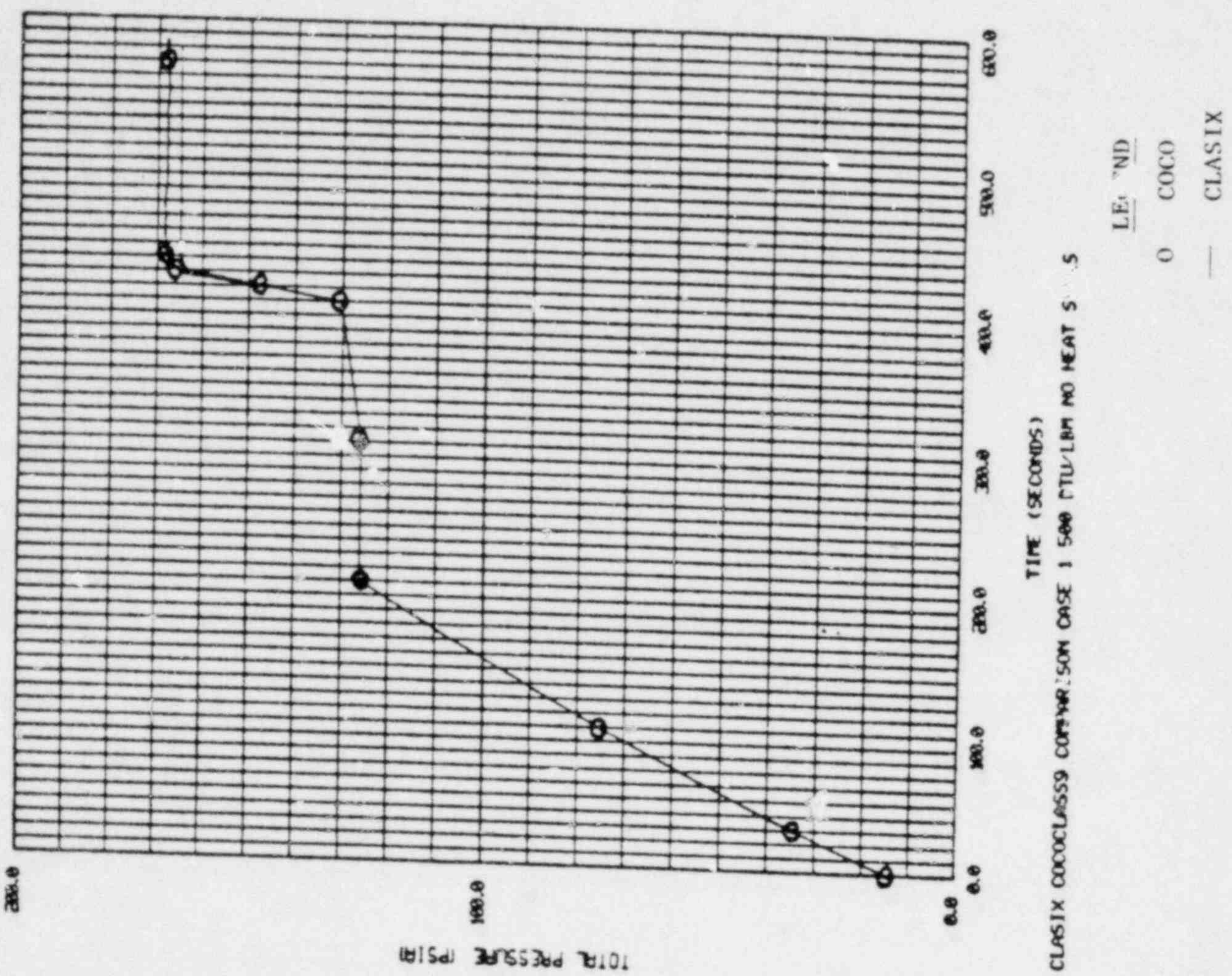

TIME (SECONDS)
0.0
100.0
200.0
300.0
400.0
500.0
600.0
TOTAL PRESSURE (PSIA)
0.0
100.0
200.0
O COCO
— CLASIX

Figure C-5

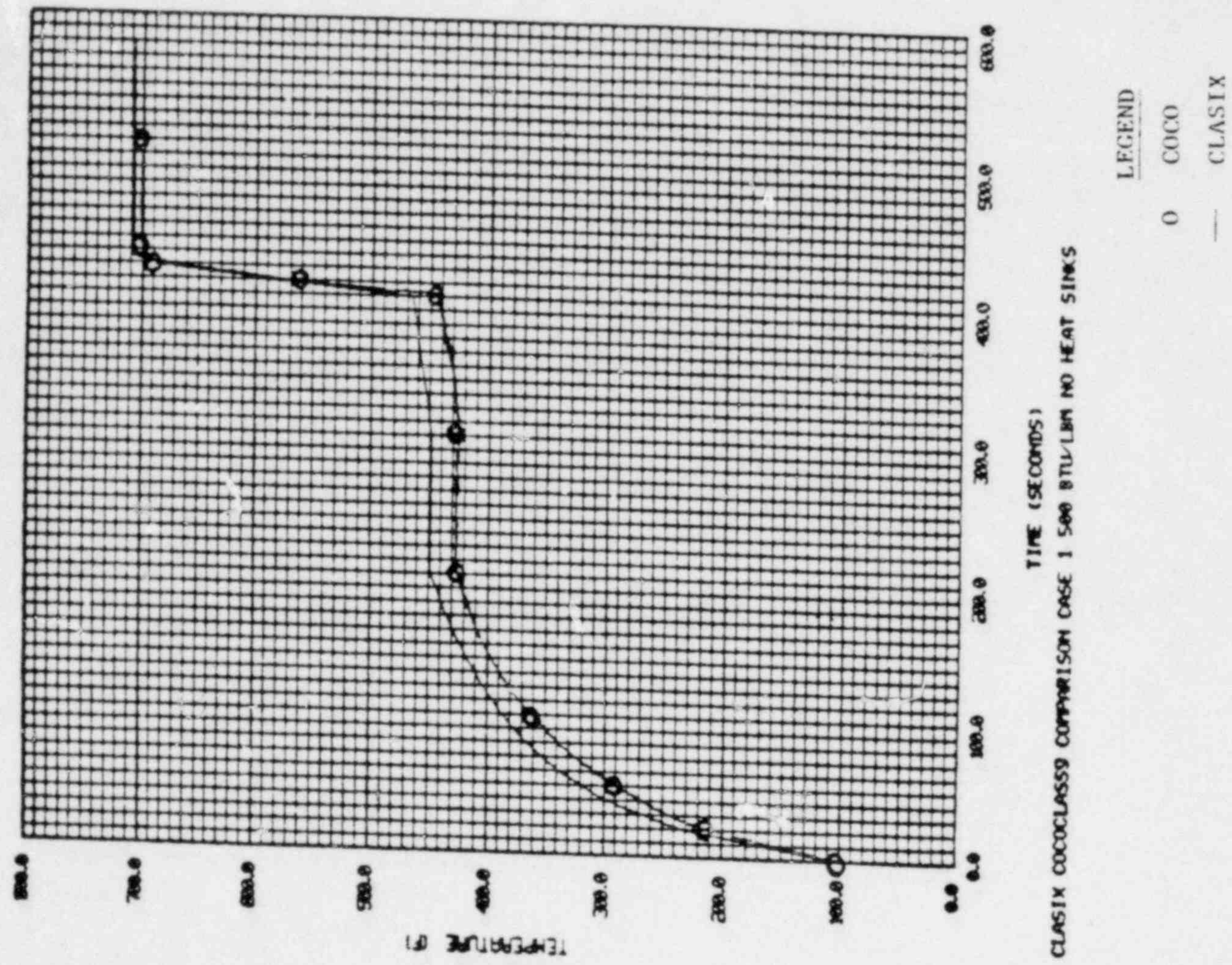

TEMPERATURE (F)
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
TIME (SECONDS)
CLASIX COCOCLASS9 COMPARISON CASE 1 500 BTU/LBM NO HEAT SINKS
LEGEND
O COCO
— CLASIX

Figure C-6

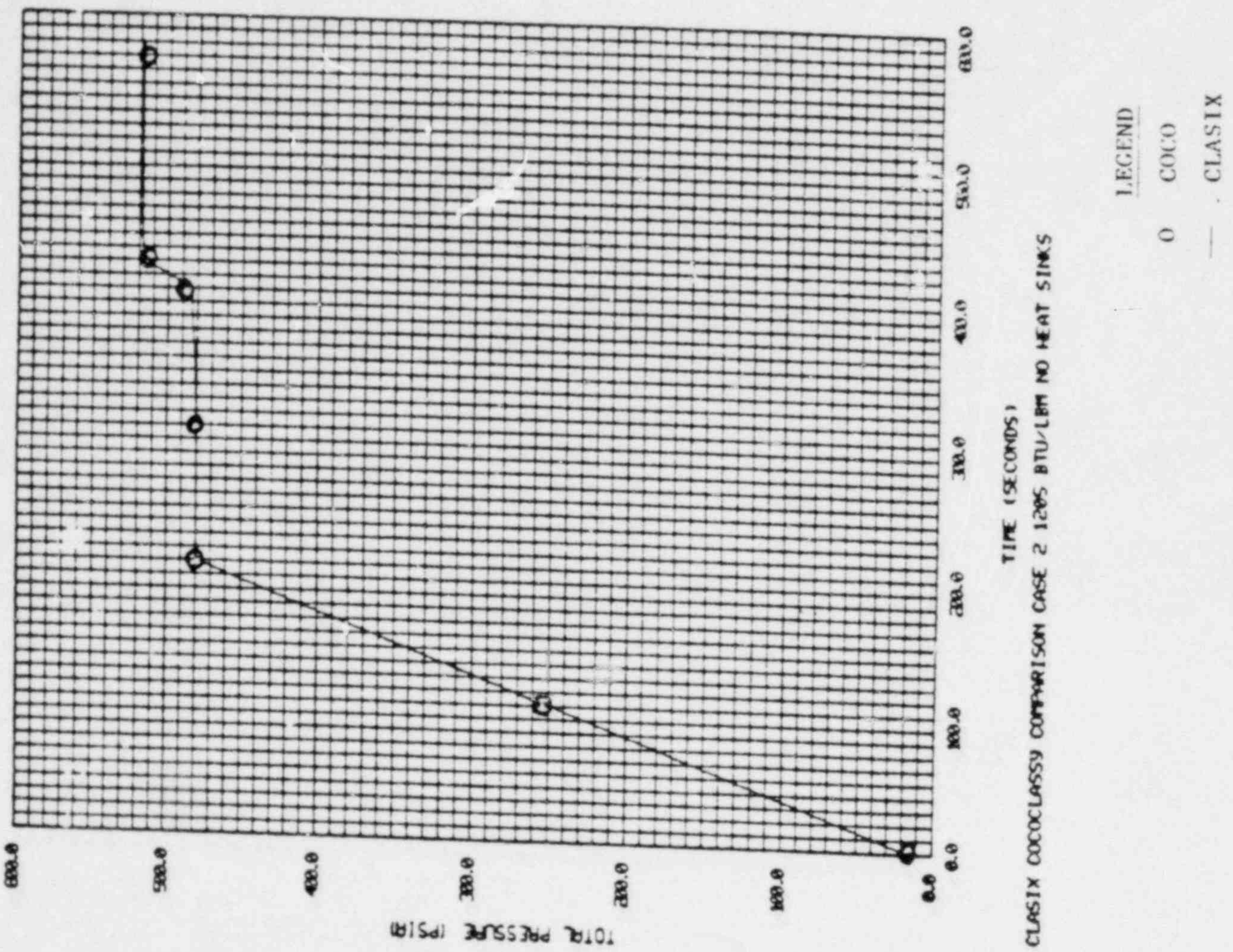
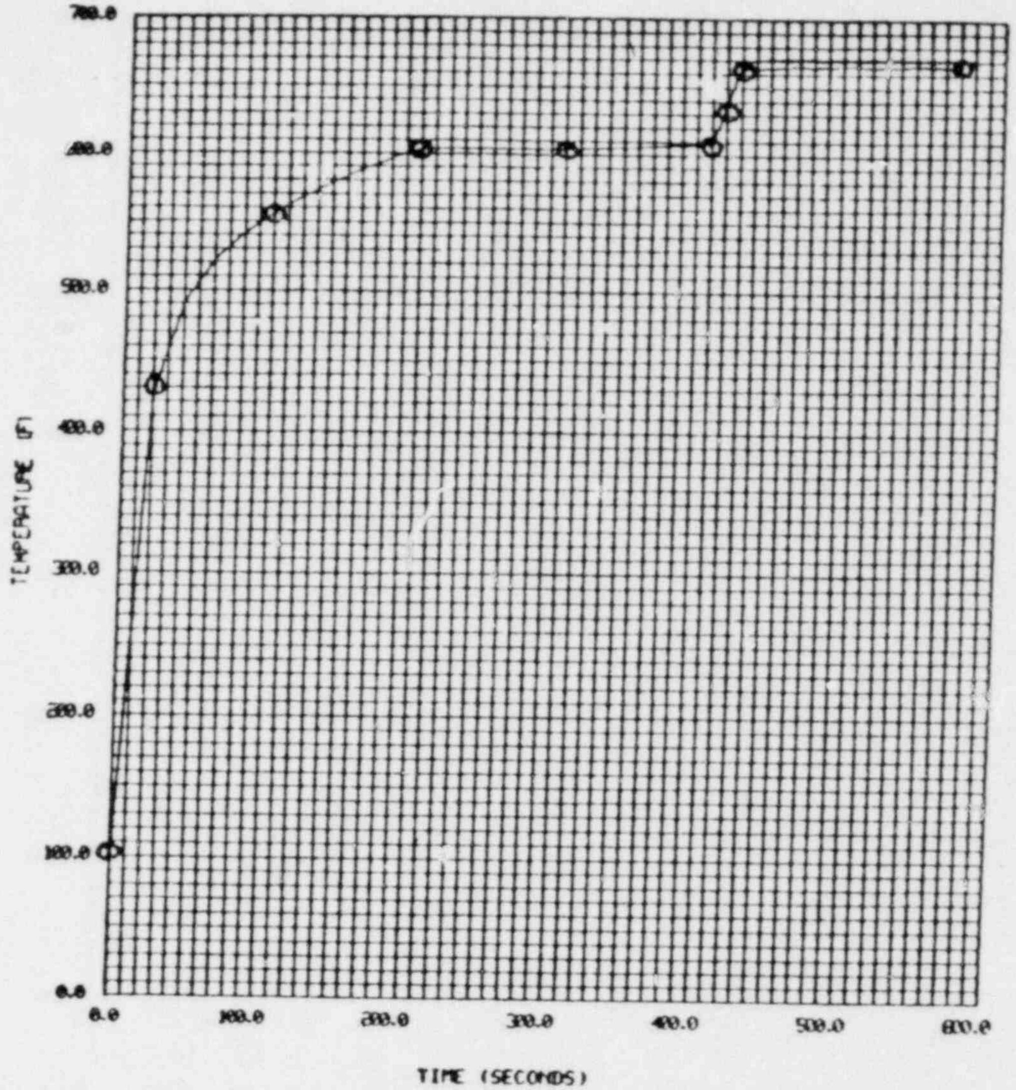

TOTAL PRESSURE (PSIA)
0.0
100.0
200.0
300.0
400.0
500.0
600.0
TIME (SECONDS)
CLASIX COCOCLASS9 COMPARISON CASE 2 120% BTU/LBM NO HEAT SINKS
LEGEND
O COCO
— CLASIX

Figure C-7



CLASIX COCOCLASS9 COMPARISON CASE 2 1205 BTU/LBM NO HEAT SINKS

LEGEND

O COCO

— CLASIX

Figure C-8

Appendix D

Containment Response Analysis

D.1 Introduction

A series of analyses have been performed for the Grand Gulf Nuclear Station using the CLASIX-3 computer program to evaluate the Mark III containment response to hydrogen burn transients. Hydrogen generation was assumed to be the result of a postulated degraded core event arising from a loss of coolant with safety injection failure. Recovery of core cooling was assumed to occur prior to reactor vessel melt-through and in time to prevent hydrogen release from exceeding 75% active fuel cladding/water reaction. Two basic transient types (small break LOCA and stuck open relief valve) were studied. The difference is that releases occur to the drywell volume for a small break LOCA and to the suppression pool for a stuck open safety relief valve case.

Battelle-Memorial Institute of Columbus supplied the results of TPE sequence MARCH computer code run for Grand Gulf from which mass and energy releases (steam, hydrogen, and fission products) were determined. Changes were made (see Input Information) to these results before being used as input to CLASIX-3.

The TPE sequence represents a transient in which a stuck open safety relief valve is coupled with safety injection failure. The MARCH data is summarized in Tables D-1 through D-3. Note that the one set of MARCH data is used for both transient types.

Modeling of Engineered Safeguards Systems interactions and initiations, passive heat sink data, containment geometry and initial conditions are Grand Gulf specific.

D.2 Model

A schematic diagram of the CLASIX-3 Grand Gulf model is given in Figure D-1. The model consists of three compartments (drywell, wetwell, and containment), a suppression pool, containment spray system, upper pool, vacuum breakers, and drywell purge system. (The wetwell is the annular volume outside the drywell above the suppression pool and below the Hydraulic Control Unit floor.) Flow paths between compartments are represented by arrows pointing in the direction of allowed flow.

D.3 Case Description

Four CLASIX-3 runs were made for Grand Gulf. A brief description of each is given below, with a more detailed description of the input data provided in the next section.

Cases 1, 2, and 3 differ only in the burn parameters and transient type. A 10 $^{v}/o$ (volume percent) hydrogen ignition point was used in Cases 1 and 2 with 100% burnup allowed. Case 1 is a small break

LOCA while Case 2 is a stuck open relief valve case. Case 3 is also a stuck open relief valve case, however, the hydrogen ignition volume fraction was reduced to 8 ^{v}/o with only 85% burnup allowed.

Case 4 begins at the end of Case 1 and is intended to evaluate the potential for and consequences of a hydrogen burn in the drywell. Hydrogen, steam, and fission product mass and energy release rates were assumed to fall to zero as a result of coolant injection into the core. A "spray" was added in the drywell to model the water leaving the break.

D.4 Input Information

Data for mass and energy releases were determined from MARCH results. The MARCH results showed a large hydrogen release just prior to reactor vessel melt-through as a result of the core slumping into the water filled lower plenum. In order to be consistent with the assumption of core recovery, it was assumed that a burst of this magnitude would not occur. Instead, beginning at 6358 seconds into the transient, the hydrogen release rate was assumed to increase only to the largest prior value and remain constant thereafter until the cumulative hydrogen release was equivalent to a 75% active fuel cladding/water reaction. MARCH steam and fission product energy releases were modified in a manner corresponding to the hydrogen release. Tables D-1 through D-3 list of the steam, hydrogen and fission product energy releases utilized in these analyses.

Several parameters are used by CLASIX-3 to control when, where, and how much burning occurs. Burns can be ignited in any compartment and they can be allowed to propagate from adjoining compartments through connecting flow paths. Compartment dependent burn parameters are listed below:

1) hydrogen volume fraction (^{v}/F) for ignition

2) hydrogen ^{v}/F for propagation

3) hydrogen fraction burned

4) minimum oxygen ^{v}/F for ignition

5) minimum oxygen ^{v}/F to support combustion

6) burn time

One other burn parameter which is flow path dependent is the propagation delay time, which is the time required for a flame to reach an adjoining compartment.

A complete set of compartment dependent burn parameters is specified for each compartment in the model. Ignition is controlled by parameters (1) and (4) while propagation is controlled by the propagation delay time and parameters (2) and (4). Parameters (3), (5) and (6) are used to control the length of the burn. Values for the hydrogen parameters are variable and depend on the specific case to be analyzed. Oxygen parameters are standard values used in previous CLASIX analyses. Burn times were calculated by determining an average burn length per compartment and assuming a flame speed of 6 feet per second. Burn parameters are summarized in Table D-4.

Parameters for compartment initial conditions are given in Table D-5. Values were specified for compartment net free volumes as well as intial temperatures, pressures, and relative humidities. Initial oxygen, nitrogen, and steam partial pressures were calculated from compartment temperatures, pressures, and relative humidities, assuming the containment atmosphere consisted of a mixture of standard air and steam.

The first 3901 seconds of the stuck open relief valve cases were computed by hand. For these cases the only action taking place before the onset of hydrogen production was the condensation of steam in the suppression pool. Therefore a hand integration was performed for the initial blowdown of steam mass and energy and fission products energy. The results were then added to the initial mass and energy of the suppression pool.

There are two flow paths in the Grand Gulf CLASIX-3 model: wetwell to containment (WW-CONT), and containment to drywell (CONT-DW). Note that the CONT-DW path contains vacuum breakers which were modeled as a check valve in CLASIX-3. (Flow from the drywell to the wetwell is modeled as a part of the suppression pool as discussed below.) Flow loss coefficients and burn propagation delay times for each flow path are given in Tables D-6 and D-7 along with the minimum flow area for the path containing no vacuum breakers. For the path containing vacuum breakers, the maximum opening angle, differential pressure for maximum opening, and maximum flow area are shown. Note that the vacuum breakers open when the drywell pressure falls below the containment pressure.

Parameters for the Drywell Purge System are given in Table D-8. This system (one train) is initiated after the pressure trip setpoint in the drywell (2 psig) is reached and the containment pressure is within 1 psi below the drywell pressure. Compressor head/flow curves were modeled to allow for a variable flow rate depending on the pressure differential between the containment and drywell.

Suppression pool parameters are shown in Table D-9. Included are initial values of density, temperature, mass, and heat capacity for the suppression pool water. Other pool parameters are geometry related. These include pool surface areas in the wetwell and drywell volumes, the number of vents, the flow area and length of each vent, the submergence depth to the bottom of the vent, turning loss coefficient, gas loss coefficient, and additional vent length to account for fluid acceleration. Also included are the drywell holdup volume and surface area which are necessary input to the analysis of reverse flow through the suppression pool. During reverse flow, water from the suppression pool can overflow the weir wall and remain in the drywell.

The containment spray system provides spray to the containment volume. Part of the spray continues through the wetwall as droplets while another fraction of the initial spray falls from ledges into the wetwell as a sheet of water. The remaining fraction of the containment spray cannot enter the wetwell because it collects in the upper pool and is drained directly into the suppression pool. Using a ratio of areas the rates of each flow can be calculated (drain, droplet, sheet). The spray flow entering the wetwell as a sheet will be less effective than the droplet flow but can be expected to have some cooling capability. It was assumed for this analysis that the sheet flow is half as effective as the droplet flow. The drop diameters, spray temperature, and spray flow rate were specified for the containment spray. The film coefficient used in the analysis is the same value used in prior CLASIX analyses. The drop size and flow rate exiting the containment were used as the spray conditions for the wetwell. Only the fall time and the film coefficient for the wetwell spray were specified. The fall times were based on a terminal velocity of 5 feet per second and the average fall height. Initiation of the containment sprays occurs after the first burn in all cases and continues throughout the remainder of each transient.

A "drywell spray" was added in Case 4 to model water spraying from the break as a result of the low pressure coolant injection system. The flow rate was based on the 400 psi pressure drop of the low pressure injection system across an orifice plate with a diameter the size of the break used in MARCH analysis (0.6 ft^2). This "spray" was initiated after the 75% active fuel cladding/water reaction was reached (at the beginning of Case 4). Table D-10 shows the "drywell spray" parameters.

Passive heat sink data for the Grand Gulf analysis are given in Tables D-11 through D-15. Radiant heat transfer beam lenghts were calculated from general geometry considerations and Mark III containment dimensions. Standard textbook values were used for the material emissivities. The last layer of all walls except the containment wall was treated as adiabatic. The number of nodes per layer was calculated from the following criteria:

1) All paint layers have two nodes.

2) All other layers have a minimum of three nodes.

3) Steel walls have a spacing of about 0.02 inch per node for all thicknesses.

4) Concrete walls have spacings of about one inch per node for the first six inches, two inches per node for the next 12 inches, and six inches per node thereafter.

The upper pool parameters are given in Table D-16. The dump flow rate was based on a 5 minute dump time through two lines. Note that initation of the dump occurred 30 minutes after a LOCA signal.

Subsequent to the runs discussed herein, the dump time was changed to 3.75 minutes. A comparison was made and it was found that the results were the same in both cases following completion of the dump.

D.5 Results

Grand Gulf hydrogen transient analysis results are summarized in Table D-17. Individual case results are discussed below.

D.5.1 Case 1

Compartment temperature and pressure plots for Case 1 are shown in Figures D-2 through D-7. Eighteen burns ignited in the wetwell beginning at abount 6726 seconds into the transient at a hydrogen concentration of 10 volume percent (^{v}/o). No burning was experienced in the drywell or the containment by either ignition or propagation. Hydrogen concentrations reached maximum values of 62 ^{v}/o and 7.5 ^{v}/o for these compartments respectively at the end of the transient. The large hydrogen concentration in the drywell was reached without burning due to an oxygen deficit. The initial blowdown pushed all air out of the drywell through the suppression pool vents before the onset of hydrogen release. Therefore only steam and hydrogen remained in the drywell at the end of the transient.

From about 6726 seconds to 7790 seconds into the transient burning occurred at various time intervals ranging from 50 seconds to 100 seconds apart. A total of 711 pounds of hydrogen burned leaving 1135 pounds in the drywell, 33 pounds in the wetwell, and 706 pounds in the containment.

The peak calculated pressure of 15.5 psig occurred in the drywell. Wetwell and containment maximum pressures reached 11.1 psig and 10.7 psig, respectively. In general, each burn resulted in a rapid pressure rise of less than or equal to 1.5 psi and an almost equally rapid return to preburn pressure. (See Figures D-2 through D-4). Between 6726 seconds and 7807, the non-burn pressure envelope slowly rises 5 psi.

The maximum calculated temperature of 1494 F occurred in the wetwell during the first burn. Maximum temperatures in the drywell and containment reached 380 F and 173 F, respectively. Each burn was characterized by rapid temperature rises of up to 1400 F in the wetwell and 50°F in the containment with a rapid return to pre-burn temperature. The drywell temperature rose very slowly during the whole transient due to the steam, hydrogen, and fission product release directly into this compartment. During the burn portion of the transient, the temperature increased more rapidly due to the flow of hot gases through the vacuum breakers (Figures D-5 through D-7). Conditions were never met for the initiation of the Drywell Purge System. The 380 F temperature reached in the drywell during Case 1 is conservatively high due to the MARCH data used in the analysis. Figure D-5 shows a temperature ramp beginning at 310 F and 6350 seconds into the transient and ending at 380 F and 7807 seconds. During this time period, the hydrogen temperature increases sharply to 1800 F, remains constant, and is accompanied by a sharp increase in the steam energy release rate to 6600 BTUs per second. (See Tables D-1 and D-2.) With the assumption of core cooling recovery, the constant high energy release rates of hydrogen and steam are considered to be conservative. The introduction of low temperature water into the core beginning at 6359 seconds into the transient would be expected to reduce the core temperature which in turn would produce an expected decrease in the energy release rates of hydrogen and steam leaving the break. Furthermore, the MARCH data used in the analysis did not include any core cooling recovery.

Since Case 4 is an extension of Case 1, the drywell temperature at the end of Case 1 is the same as at the beginning of Case 4. Figure D-23 shows that the "drywell spray" and passive heat sinks exponentially decrease the drywell temperature to about 300 F in about 200 seconds and to 200 F in about 1200 seconds. The drywell temperature remains above 300 F for about 3000 seconds and above 330 F for about 1300 seconds.

In summary, since the MARCH data used in the analysis of Case 1 did not include the core cooling that is assumed to occur in the transient, it is expected that the energy release rates are conservatively high, and therefore the drywell temperature in Case 1 is expected to be conservatively high. In modifying the MARCH data, the hydrogen temperature was held at 1800 F for over 1000 seconds instead of peaking at 1800 for only a few seconds. The temperature in the drywell peaked at 380 F but remained above 330 F for only 1300 seconds.

Finally, regarding equipment survivability for the period of time that drywell temperature remains above 330 F, preliminary calculations indicate that the inherent thermal inertia of the safety related equipment in the drywell will shelter the vital or limiting component from the resultant adverse temperature environment.

D.5.2 Case 2

Temperature and pressure plots for Case 2 are shown in Figures D-8 through D-13. Forty-three burns ignited in the wetwell at a hydrogen concentration of 10 $^{v}/o$ or greater. At the end of the transient, a total of 1836 pounds of hydrogen burned leaving 46 pounds in the drywell, 75 pounds in the wetwell, and 633 pounds in the containment. Maximum hydrogen concentrations of 2.5 $^{v}/o$ and 8.6 $^{v}/o$ were reached in the drywell and containment compartments respectively at the end of the transient. The small amount of hydrogen in the drywell was admitted by the vacuum breaker and Drywell Purge System. Figures D-8 through D-13 clearly show two sets of burns during the transient. These sets result from the two largest hydrogen release rate peaks. Burning occurred earlier in Case 2 than in Case 1 because hydrogen was introduced directly into the wetwell in which abundant oxygen was present.

The peak calculated pressure of 8.3 psig occurred in the drywell. Maximum pressures in the wetwell and containment reached 7.4 psig and 7.3 psig, respectively. Each burn produced a pressure spike less than or equal to 2.5 psi. Figures 9 and 10 show that the non-burn pressure envelope increased about 3.7 psi from about 5590 seconds to 7000 seconds into the transient. After 7000 seconds the non-burn pressure decreased about 0.7 psi due to the depletion of oxygen during the burns. The drywell pressure increased steadily during the burns due to pressurization by the Drywell Purge System and vacuum breaker (see Figure D-8). The Drywell Purge System was initiated during the first burn.

The maximum calculated temperature of 1471 F is reached in the wetwell during the first burn. Maximum temperatures in the drywell and containment are 137 F and 190 F, respectively. Each burn produced a rapid temperature increase of about 1100 F in the wetwell and 40 F in the containment with a return to approximately pre-burn conditions after the burn (Figures D-12 and D-13). The drywell temperature fluctuated very little since the drywell is essentially isolated from the wetwell where the high temperatures occur.

The upper pool dump added enough water to the suppression pool to allow overflow to occur into the drywell. Some of the burns also created enough of a pressure differential to allow overflow to occur. By the end of the transient, 19,400 cubic feet of water had overflowed into the drywell. This doesn't occur in Case 1 because there is enough steam released in the drywell to offset the pressure differential during burns and to offset the hydrostatic head of the upper pool dump water.

D.5.3 Case 3

Temperature and pressure plots for Case 3 are shown in Figures D-14 through D-19. Burning occurred only in the wetwell beginning at about 4830 seconds into the transient and lasting until 7755 seconds. Each of the 58 burns ignited when the hydrogen concentration reached 8 volume percent or greater. A total of 1915 pounds of hydrogen burned leaving 28 pounds of hydrogen in the drywell, 77 pounds of hydrogen in the wetwell, and 562 pounds of hydrogen in the containment at the end of the transient. Hydrogen concentrations reached maximum values of 1.6 $^{v}/o$, 11 $^{v}/o$, and 7.9 $^{v}/o$ at the end of the transient in the drywell, wetwell, and containment, respectively. Since hydrogen was only introduced into the drywell by vacuum breaker action during burns and by the Drywell Purge System after initiation, the hydrogen concentration increased very slowly in this compartment. The 11 $^{v}/o$ hydrogen was reached in the wetwell at the end due to an oxygen deficit in this compartment. Continued burning depleted the oxygen supply by the end of the transient. Figures D-14 through D-19 clearly show three sets of burns. These three sets result from the three largest hydrogen release rate peaks.

The drywell achieved the highest calculated pressure of 8.1 psig during the transient. Wetwell and containment maximum pressures reached 6.7 psig and 6.6 psig, respectively. Each burn produced a small pressure spike of about 2 psi in the containment and wetwell and about 0.2 psi in the drywell. The non-burn pressure envelope in the wetwell and containment increased during the first two burn sets and partially through the third set. As oxygen depletion became more evident during the third burn set, the non-burn pressure decreases. This can be seen in Figures D-15 and D-16. The drywell non-burn pressure continued to increase at a relatively constant rate after the initial burn due to vacuum breaker action and the Drywell Purge System initiation (Figure D-14). The Drywell Purge System was initiated after the first burn, at 4840 seconds into the transient.

A maximum calculated temperature of 1062 F occurred in the wetwell during the first burn. Drywell and containment maximum temperatures reached 136°F and 183 F, respectively. Each burn produced a rapid temperature rise of approximately 600 F in the wetwell and about 30 F in the containment with a return to approximately pre-burn temperatures (See Figures D-18 and D-19). The drywell temperature fluctuated very little during the transient since the drywell is essentially isolated from the high burn temperatures in the wetwell (Figure D-17).

At the end of the transient a large volume of water remained trapped in the drywell. Due to pressure differentials during burns and to added suppression water from the upper pool dump, 30,240 cubic feet of water sloshed over the weir wall and remained in the drywell.

D.5.4 Case 4

Compartment pressure and temperature plots for Case 4 are shown in Figures D-20 through D-25. Case 4 begins at 7807 seconds into the transient, where Case 1 ends. All mass and energy releases from MARCH were assumed to fall to zero for this part of the transient. The "drywell spray" was initiated at the beginning of this case to model the water from the low pressure injection system spraying from the break. This "spray" cooled the drywell allowing the pressure to fall within 1 psi above the containment pressure at 10500 seconds into the transient at which time the Drywell Purge System was initiated. Due to the low volumetric flow rate of the purge compressors, the oxygen concentration in the drywell was sufficiently pressurized to uncover the first row of vents and allow a hydrogen rich mixture of gases to begin venting into the wetwell. Two burns occurred in the wetwell at about 15850 seconds and 16720 seconds into the transient when a 10 $^{v}/_{o}$ hydrogen concentration was reached. At 17100 seconds a 5 $^{v}/_{o}$ oxygen concentration was reached in the drywell which caused ignition in this compartment to occur. This pressurized the drywell driving hydrogen into the wetwell where it ignited at 10 ^{v}/o. A short burn occurred that forced enough hydrogen into the containment to ignite. As burning continued in the containment, hydrogen and oxygen concentrations again reached an ignitable mixture in the wetwell and burned. From ignition in the drywell, burning continued for approximately 17 seconds and terminated with the containment burn. When all burning subsided, 50010 cubic feet of water remained in the drywell after having sloshed over the weir wall.

The maximum calculated pressure of 42.0 psig was reached in the containment at the end of the containment burn. The wetwell maximum pressure of 41.7 was also reached at the end of the containment burn and the drywell maximum pressure of 34.4 psig was reached during the drywell burn (See Figures D-20 through D-22).

During the fourth burn in the wetwell which occurred during the containment burn, the maximum calculated temperature of 2712 F was reached. This high temperature was reached in the wetwell due to the evaporation of the spray in the containment which eliminated spray carry-over. The maximum drywell temperature reached 1602 F during the drywell burn and the containment maximum temperature reached 1011 F at the end of the containment burn (See Figures D-23 through D-25).

A total of 1548 pounds of hydrogen burned in Case 4. 158 pounds burned in the drywell, 240 pounds burned in the wetwell, and 1149 pounds burned in the containment. At the end, 320 pounds of hydrogen were left in the drywell, 25 pounds were left in the wetwell, and 157 pounds were left in the containment.

GGNS

TABLE D-1

Grand Gulf CLASIX-3 Input

MARCH Reactor Coolant Mass and Energy Release Rates

TPE Sequence

Time (seconds)	Steam Release Rate (lbm/sec)	Energy Release Rate (Btu/sec)
0	220	260000.0
602	183.33	219450.0
902	188.23	226316.67
1204	130.12	157050.82
1789	122.8	148670.43
1803	120.82	146396.67
2707	74.79	93053.33
2994	48.35	62419.85
3601	27.71	38470.73
3631	30.51	42323.33
4201	4.72	6501.99
4504	2.40	3206.05
4541	6.919	10793.33
4858	6.87	12699.55
5158	2.28	3556.80
5458	0.14	202.05
5758	1.08	2015.3
6058	0.10	153.21
6358	2.46	4744.38
*6359	4.25	6601.6
7807.13	4.25	6601.6
**7807.14	0	0

*March output is modified following 6359 sec. See discussion in text.

**Note that 75% of hydrogen has been released by 7807.13 seconds. At this point steam and energy release are reduced to 0.0 for the duration.

TABLE D-2

Grand Gulf CLASIX-3 Input

MARCH Hydrogen Release Rates and Temperatures

TPE Sequence

Time (seconds)	Hydrogen Release Rate (lbm/sec)	Temperature (°F)
0	0	61.24
1803	0	61.24
2707	1.225×10^{-8}	525.36
2995	3.85×10^{-6}	606.09
3295	6.00×10^{-4}	694.34
3601	0.0071	784.66
3631	0.0089	788.80
3901	0.0479	880.29
4201	0.0486	753.07
4541	0.3186	1115.69
4858	1.0415	1693.75
5158	0.4905	1109.04
5458	0.0691	875.86
5758	1.0177	1702.01
6058	0.0556	1039.08
6358	0.8795	1817.42
*6359	1.0415	1808.8
7807.13	1.0415	1808.8
**7807.14	0	61.24

*March output is modified following 6359 sec. See discussion in text.

**Note that 75% of the hydrogen has been released by 7807.13 seconds. At this point the hydrogen release is reduced to 0.0 for the duration.

TABLE D-3

Grand Gulf CLASIX-3 Input

MARCH Fission Product Energy Release Rates

TPE Sequence

Time (seconds)	Energy Release Rate (Btu/sec)
0	0
3631	0
4541	246.47
5458	1097.76
6358	1530.3
*6359	1530.7
7807.13	1530.7
**7807.14	0

*March output is modified following 6359 sec. See discussion in text.

**Note that 75% of the hydrogen has been released by 7807.13 seconds. At this point the fission product energy release is reduced to 0.0 for the duration.

TABLE D-4

Grand Gulf CLASIX-3 Input

Burn Parameters*

	Case 1	Case 2	Case 3	Case 4
H_2 $^V/F$ for ignition	0.1	0.1	0.08	0.1
H_2 $^V/F$ for propagation	0.1	0.1	0.08	0.1
H_2 fraction burned	1	1	0.85	1
Minimum O_2 $^V/F$ for ignition	0.05	0.05	0.05	0.05
Minimum O_2 $^V/F$ to support combusion	0.0	0.0	0.0	0.0
Burn time (sec)**	7.25/1.9/12	7.25/1.9/12	7.25/1.9/12	7.25/1.9/12

*If one number is present, parameters are the same in all compartments; otherwise they are listed by drywell/wetwell/containment.

**Based on flame speed of 6 ft/s.

TABLE D-5

Grand Gulf CLASIX-3 Input

Compartment Initial Conditions

	Drywell	Wetwell	Containment
Volume (ft^3)	270,128	151,644	1,248,588
Temperature (^oF)	135	80	80
O_2 Pressure (psia)	2.8	3.01	3.01
N_2 Pressure (psia)	10.59	11.38	11.38
H_2C Pressure (psia)	1.3	0.3	0.3

TABLE D-6

Grand Gulf CLASIX-3 Input

Flow Path Parameters

	WW-CONT	CONT-DW
Maximum Flow Area (ft^2)	1500	See Tables D-7 & D-8
Flow Loss Coefficient	5	" "
Burn Propagation Delay Time (sec)*	1.0	" "

*Based on flame speed of 6 ft/sec.

TABLE D-7

Grand Gulf CLASIX-3 Input

Vacuum Breaker Parameters

Quantity	6
Total Maximum Flow Area (Ft^2)	3.27
Differential Pressure for Maximum Opening (PSI)	3.9
Maximum Opening Angle (Degrees)	89.9
Flow Direction	Cont to DW
Flow Loss Coefficient	1.19
Burn Propagation Delay Time (sec)*	12.0
Initiation**	..

*Based on flame speed of 6 ft/sec.
**Initiation when drywell pressure falls below containment pressure.

TABLE D-8

Grand Gulf CLASIX-3 Input

Drywell Purge System Parameters

Suction Compartment	Containment
Sink Compartment	Drywell
Initiation*	
Flow Rate	

Head (inches of H_2O)	Flow Rate (CFM)
234	1175
350	1090
421	960
453	850
467	700

*Initiation after LOCA signal and after drywell pressure comes within 1 psi above containment pressure.

TABLE D-9

Grand Gulf CLASIX-3 Input

Supression Pool Parameters

Pool surface area in drywell (ft^2)	553
Pool surface area in wetwell (ft^2)	6667
Weir height above water level (ft)	5.75
Pool Water Density (lbm/ft^3)	62.17
Mass (lbm)	8.52×10^6
Temperature (^oF)	85
Heat Capacity (Btu/lb-^oF)	1.0

	Row 1	Row 2	Row 3
Number of vents	45	45	45
Flow area per vent (ft^2)	4.28	4.28	4.28
Vent length (ft)	5.0	5.0	5.0
Depth of vent bottom (ft)	8.42	12.58	16.75
Additional vent length (ft)*	2.87	2.87	2.87
Turning loss coefficient	1.3	2.9	8.6
Gas loss coefficient	3.0	3.0	3.0

Drywell Holdup Volume (ft^3)**	50010
Drywell Holdup Surface Area (ft^2)	3145

*Accounts for acceleration of fluid.

**Net free volume in drywell, inside and below the top of the weir wall.

TABLE D-10

Grand Gulf CLASIX-3 Input

Spray System Parameters

	Cont/Wetwell	Drywell***
Flow rate (GPM)	11300	14518
Temperature (^oF)	135	185
Drop diameter (microns)	230	6350
Fall time (seconds)	13.1/3.1	20.0
Heat transfer coefficient ($BTU/HR - Ft^2\ ^oF$)	20.0	10.0
Containment to Wetwell Carry Over Fraction	0.4314	
Initiation	*	**

*Initiation occurs after first burn.

**Initiation occurs after hydrogen release stops.

***Break Flow

TABLE D-11

Grand Gulf CLASIX-3 Input

Compartment Dependent Passive Heat Sink Parameters

Parameter	Compartment	Value
Temperature	Drywell	135°F
	Wetwell	80°F
	Containment	80°F
Radiant Heat Transfer Beam Length	Drywell	48.67 ft
	Wetwell	13.67 ft
	Containment	82.67 ft

TABLE D-12

Grand Gulf CLASIX-3 Input

Material Dependent Passive Heat Sink Parameters

Parameter	Material	Value
Emissivity	Concrete	0.9
	Steel	0.2
	Coating	0.7
Thermal Conductivity (Btu/hr ft °F)	Coating on Steel	0.21
	Concrete	1.2
	Steel (drywell)	27.73
	Steel (wetwell, cont.)	30.05
Volumetric Heat Capacity (Btu/ft^3 °F)	Coating on Steel	29.8
	Concrete	6.24
	Steel	54.31
Exit Heat Transfer Coefficient ($Btu/hr\ ft^2$ °F)	Coating to Steel	10^4
	Concrete to Concrete	10^8
	Steel to Concrete	10
	Concrete to Steel	10
	Last Layer Adiabatic Wall	0

TABLE D-13

Grand Gulf CLASIX-3 Input

Drywell Passive Heat Sinks

Description	Surface Area (ft^2)	Layer Number	Layer Material	Layer Thickness (ft)
Reactor Pedestal mat	2530	1	Concrete	0.5
		2	Concrete	1.0
		3	Concrete	1.5
Weir Wall	8610	1	Concrete	0.5
		2	Concrete	0.75
Drywell Grating	25370	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0074
Miscellaneous Steel	21000	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0245
Reactor Shield Wall	5007	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0417
		3	Concrete	0.5
		4	Concrete	0.48
Reactor Shield Wall	3296	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0625
		3	Concrete	0.5
		4	Concrete	0.48
Reactor Shield Wall	1260	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.125
		3	Concrete	0.5
		4	Concrete	0.48
Drywell Wall and Top	17675	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0208
		3	Concrete	0.5
		4	Concrete	1.0
		5	Concrete	1.5

TABLE D-14

Grand Gulf CLASIX-3 Input

Wetwell Passive Heat Sinks

Description	Surface Area (ft^2)	Layer Number	Layer Material	Layer Thickness (ft)
Wetwell Inner Wall	6330	1	Concrete	0.5
		2	Concrete	1.0
		3	Concrete	1.0
Wetwell Outer Wall	8726	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0208
		3	Concrete	0.5
		4	Concrete	1.0
		5	Concrete	1.5

TABLE D-15

Grand Gulf CLASIX-3 Input

Containment Passive Heat Sinks

Description	Surface Area (ft^2)	Layer Number	Layer Material	Layer Thickness (ft)
Containment Wall and Dome	61947	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0208
		3	Concrete	0.5
		4	Concrete	1.0
		5	Concrete	1.5
Containment Grating	57231	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0073
Miscellaneous Floor Steel	47400	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.0245
Miscellaneous Floor	2341	1	Concrete	0.5
		2	Steel	0.1004
RWCU Compartment and Floor	5653	1	Concrete	0.5
		2	Concrete	0.174
TIP Removal Area and Assorted Walls	9733	1	Concrete	0.5
		2	Concrete	0.5052
Filter Demineralizer Room Regenerative Heat Room Pipe Tunnel	23298	1	Concrete	0.5
		2	Concrete	1.0
		3	Concrete	0.3302
Upper Containment Pool	11252	1	Concrete	0.5
		2	Concrete	1.0
		3	Concrete	1.5
Polar Crane	12788	1	Coating	1.3×10^{-5}
		2	Carbon Steel	0.7062
Drywell Wall	13170	1	Concrete	0.5
		2	Concrete	1.0
		3	Concrete	1.0

TABLE D-16

Grand Gulf CLASIX-3 Input

Upper Pool and Related Parameters

Location	Containment
Volume Dumped (ft^3)	36380
Temperature (^oF)	125
Dump Flow Rate (ft^3/min)	7276
Initiation	*

*Initiation occurs at 30 minutes after LOCA signal.

TABLE D-17

GRAND GULF CLASIX-3 RESULTS

		CASE 1	CASE 2	CASE 3	CASE 4
Number of burns	DW*	0	0	0	1
	WW	18	43	58	4
	CT	0	0	0	1
Total H_2 Burned (lbm)	DW	0	0	0	158
	WW	711	1836	1914	240
	CT	0	0	0	1149
H_2 Remaining (lbm)	DW	1135	46	28	320
	WW	33	75	77	25
	CT	706	633	562	157
Peak Temp. (^{O}F)	DW	380	137	136	1602
	WW	1494	1471	1062	2712
	CT	173	190	183	1011
Peak Pressure (psig)	DW	15.5	8.3	8.1	34.4
	WW	11.1	7.4	6.7	41.7
	CT	10.7	7.3	6.6	42.0

*Drywell, wetwell, and containment are abbreviated as DW, WW, and CT.

GRAND GULF CLASIX-3 MODEL

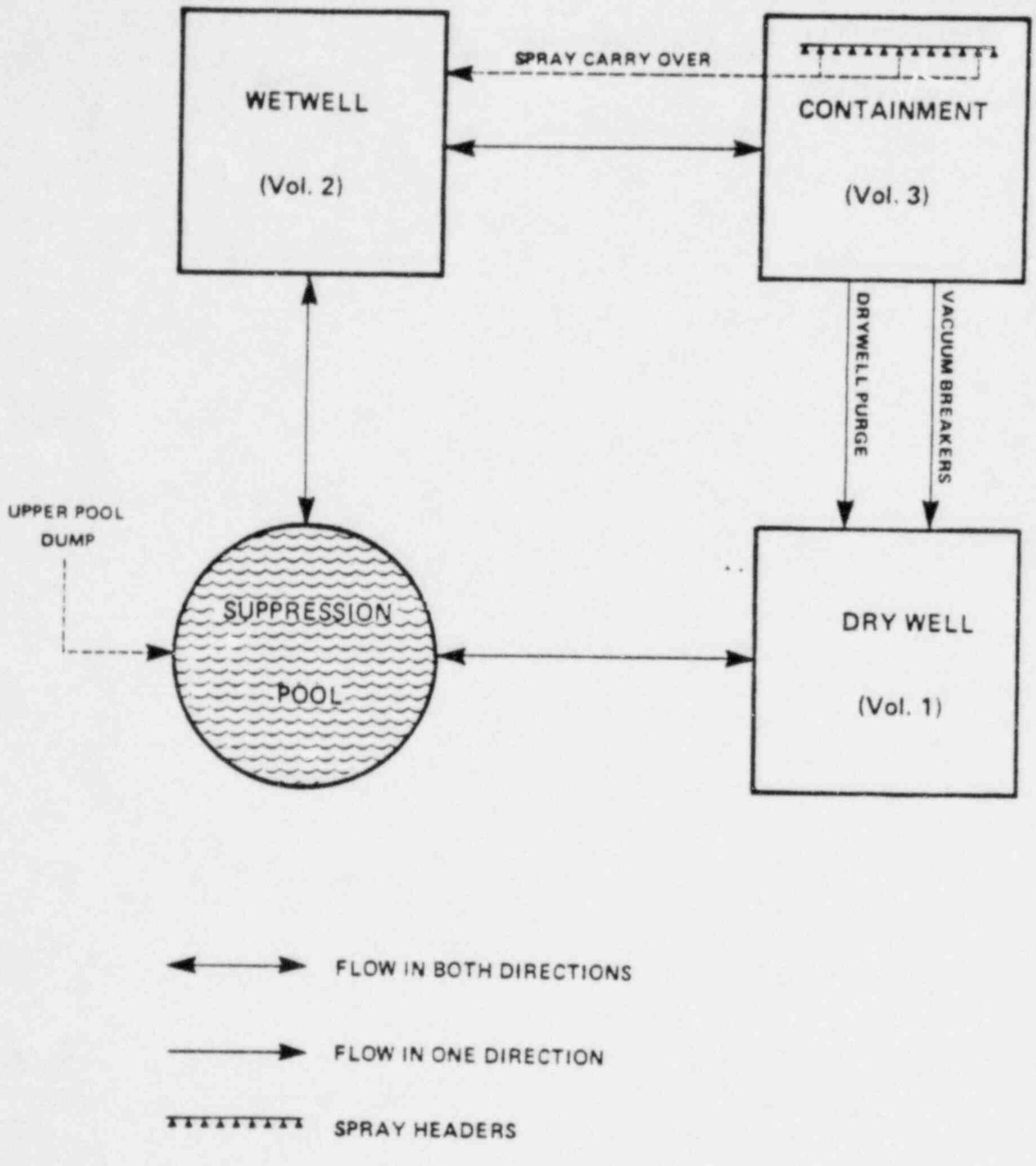


Figure D-1

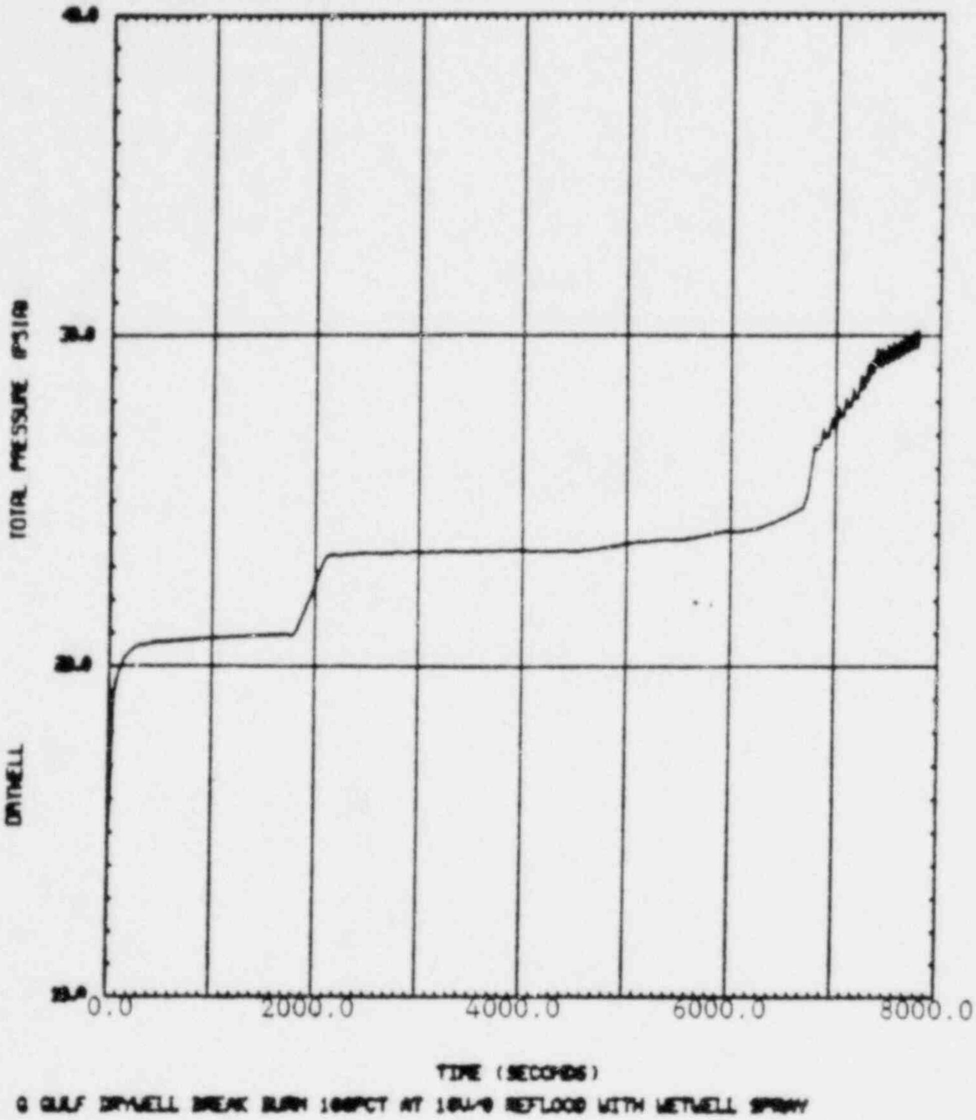

DRYWELL TOTAL PRESSURE (PSIA)
0.0
2000.0
4000.0
6000.0
8000.0
TIME (SECONDS)
G GULF DRYWELL BREAK BURN 100PCT AT 10V/O REFLOOD WITH WETWELL SPRAY

Figure D-2

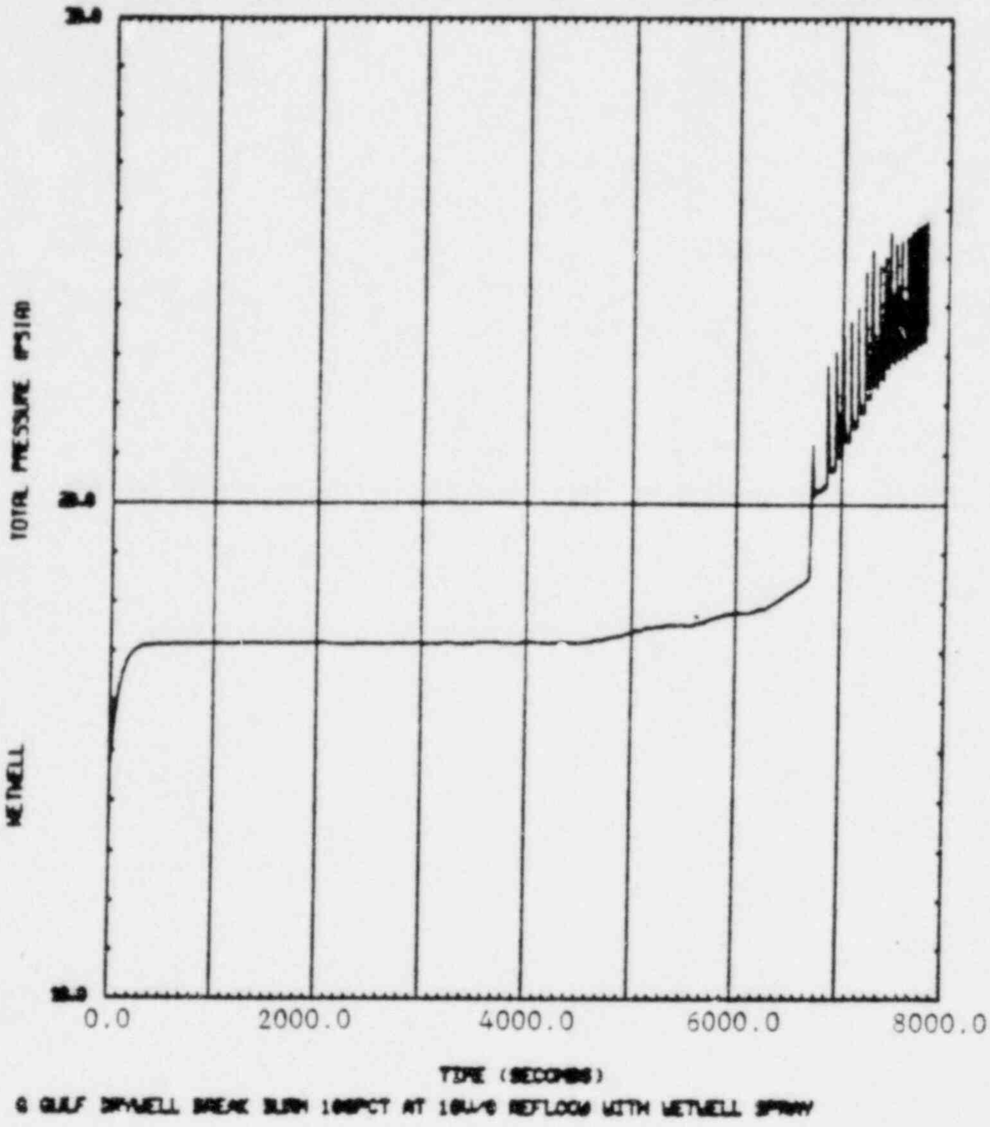


Figure D-3

POOR ORIGINAL

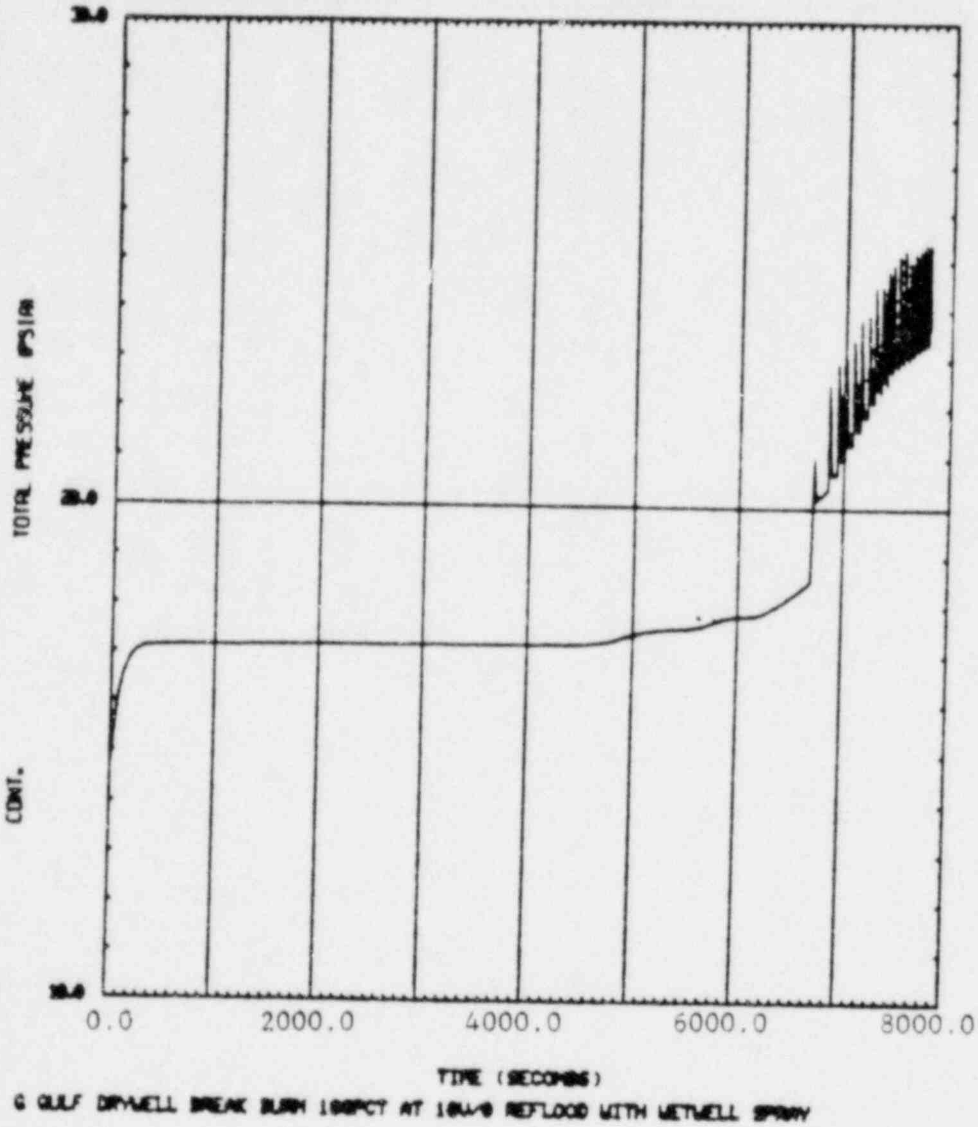

30.0
20.0
10.0
CONT. TOTAL PRESSURE PSIA
0.0
2000.0
4000.0
6000.0
8000.0
TIME (SECONDS)
G GULF DRYWELL BREAK BURN 100PCT AT 10V/O REFLOOD WITH WETWELL SPRAY

Figure D-4

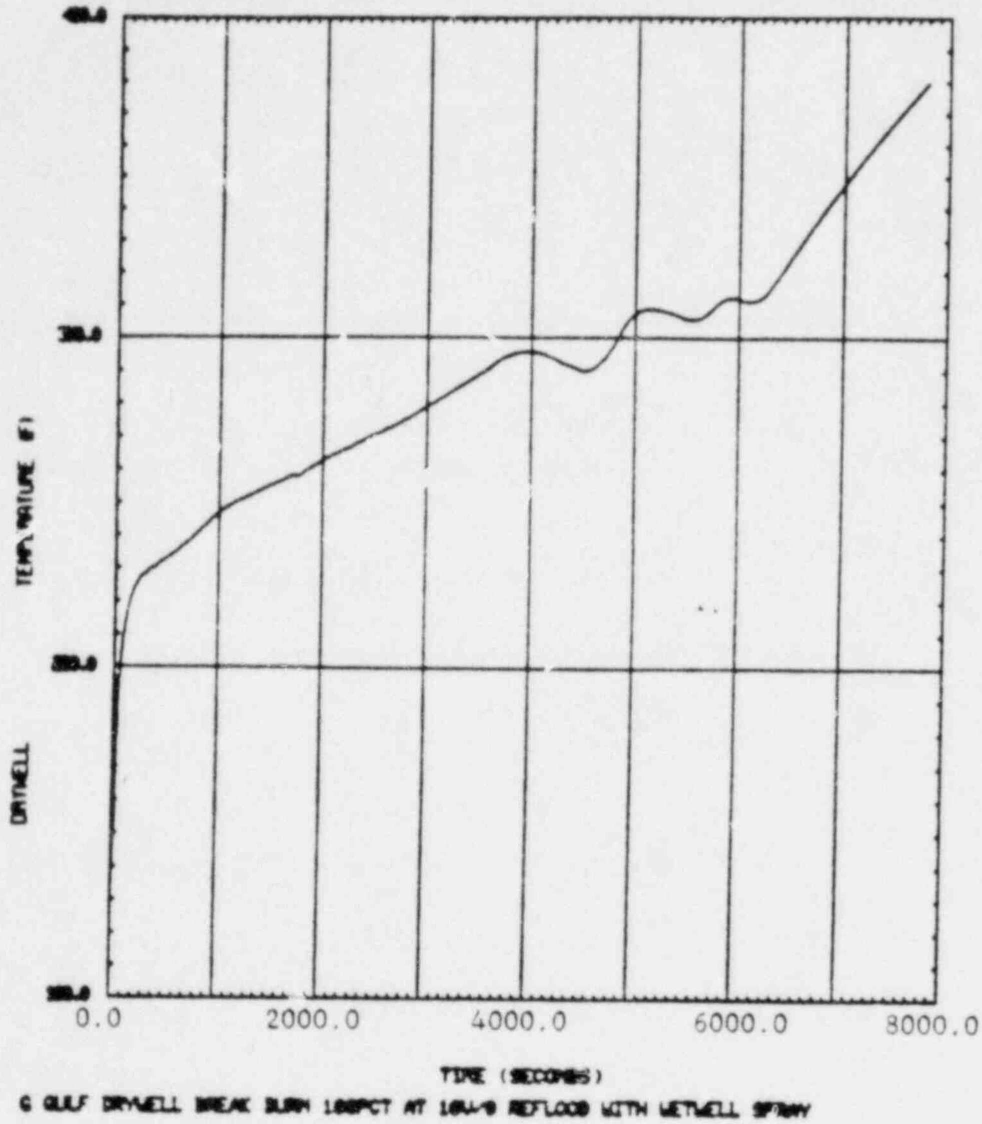


Figure D-5

POOR ORIGINAL

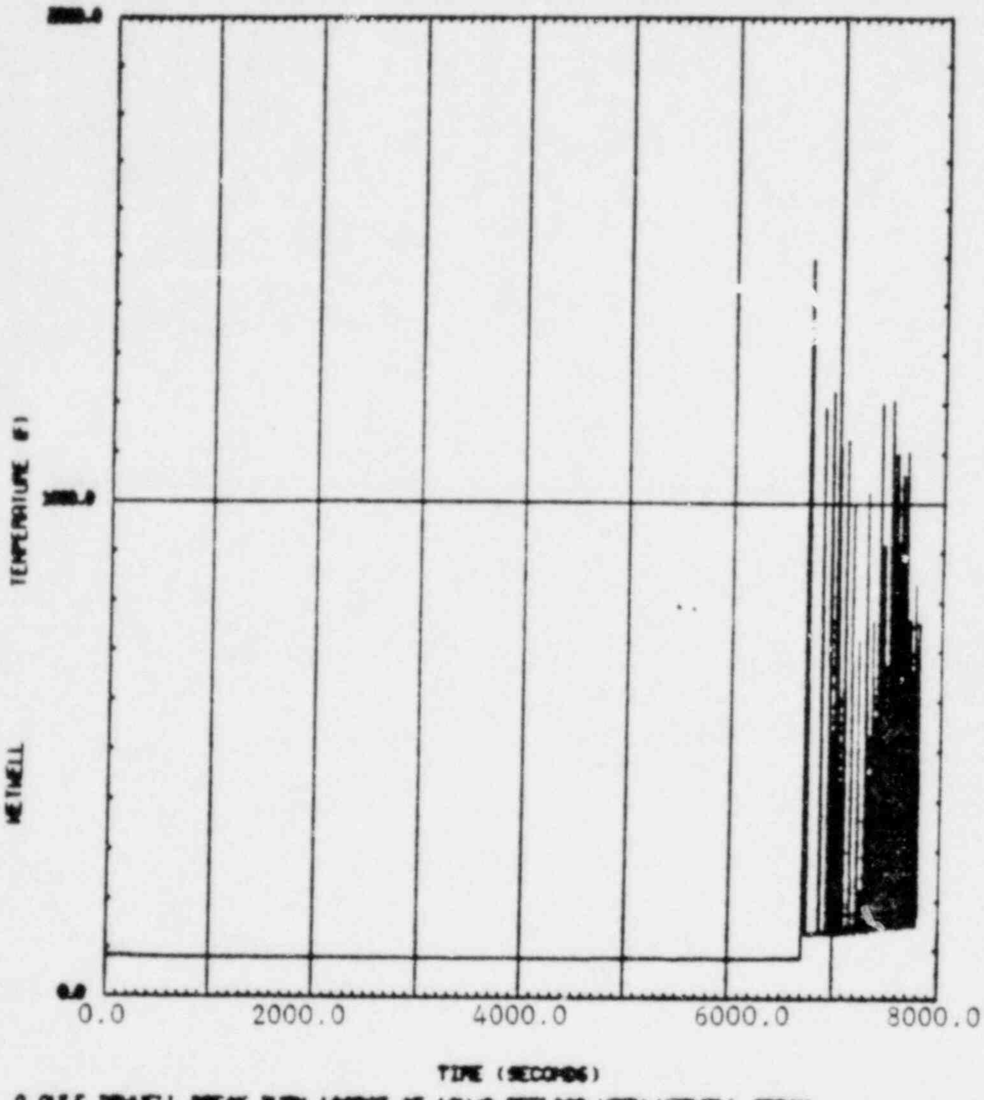

2000.0
1000.0
0.0
WETWELL TEMPERATURE (F)
0.0
2000.0
4000.0
6000.0
8000.0
TIME (SECONDS)
G GULF DRYWELL BREAK BURN 100PCT AT 10V/O REFLOOD WITH WETWELL SPRAY

Figure D-6

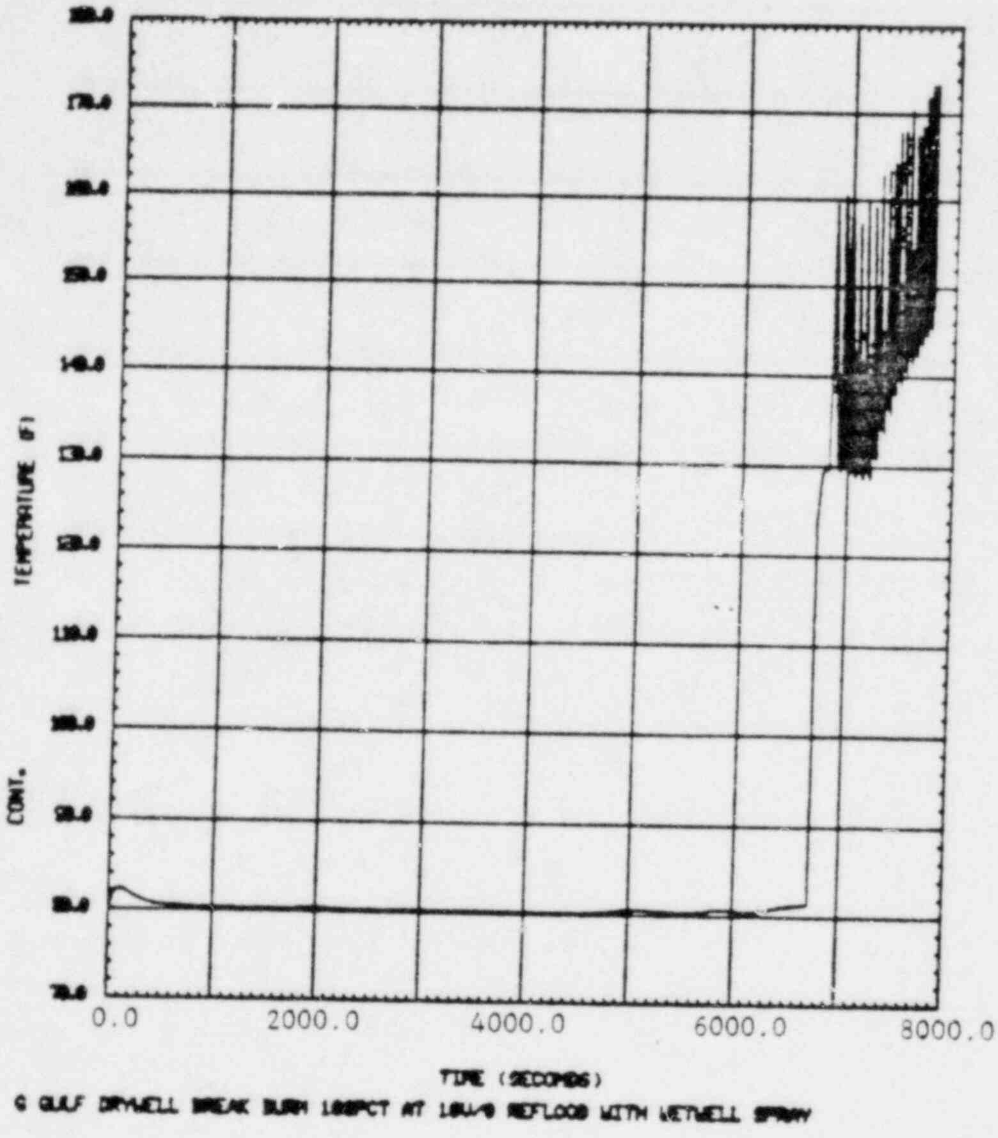


Figure D-7

POOR ORIGINAL

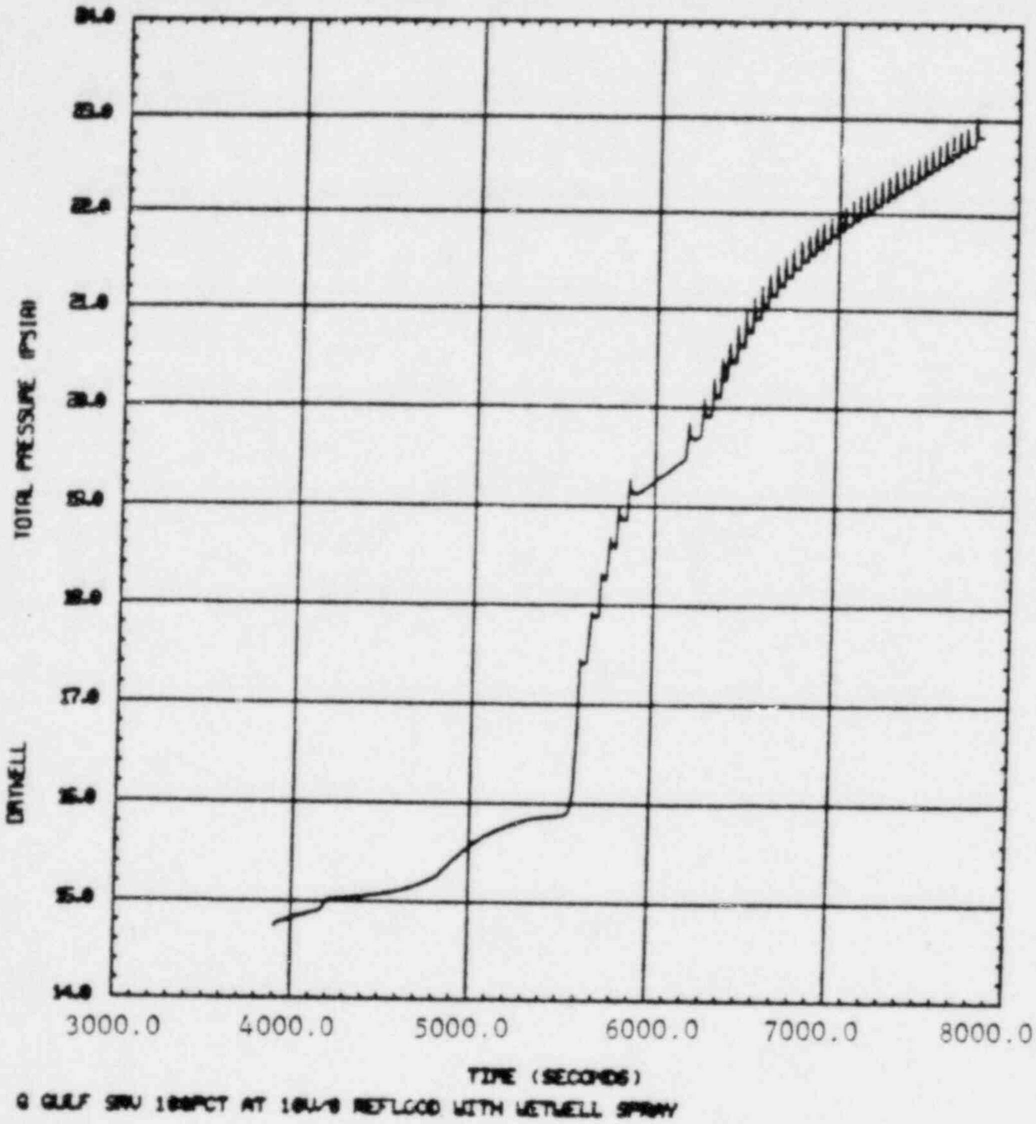


Figure D-8

POOR ORIGINAL

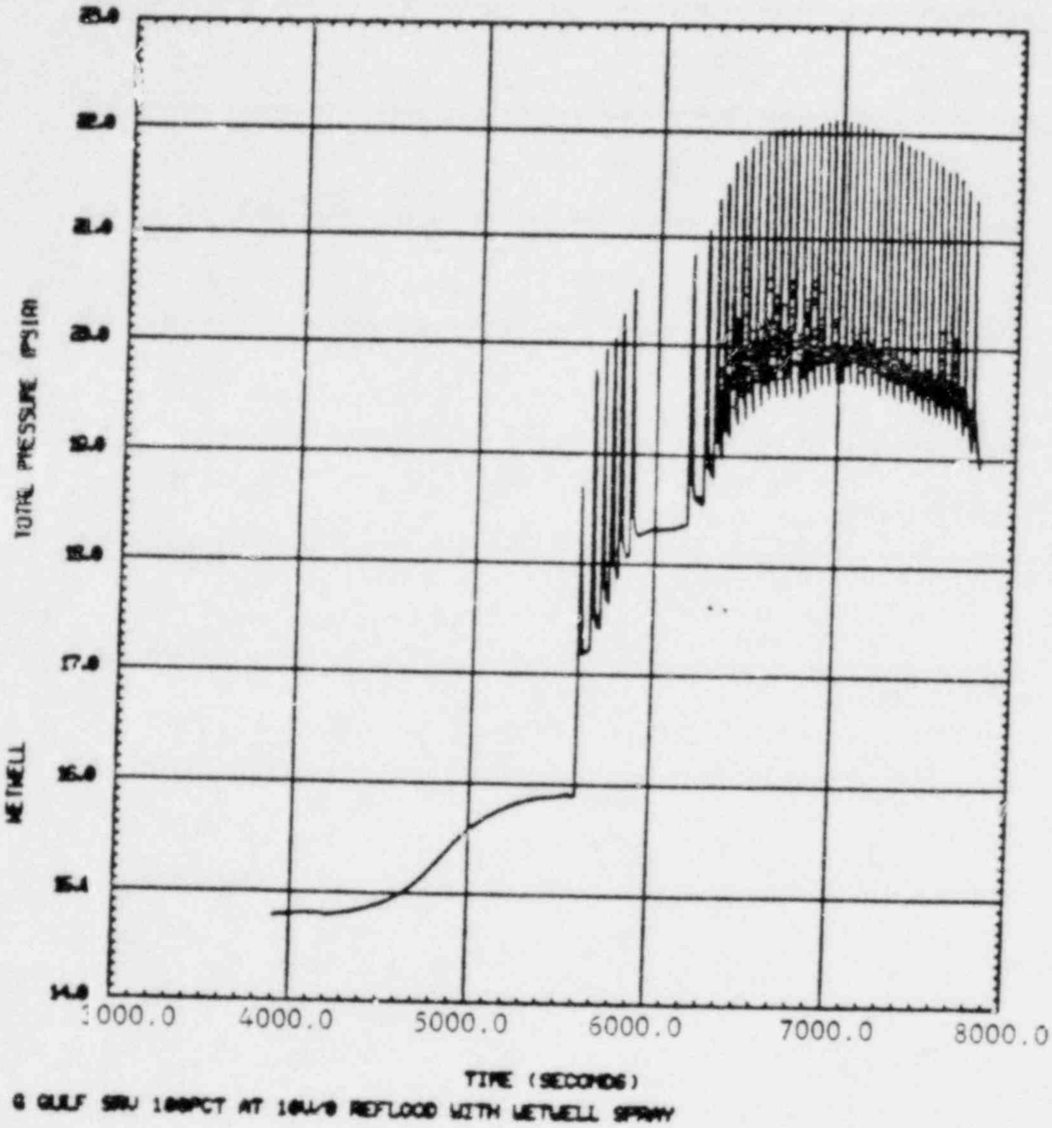

WETWELL TOTAL PRESSURE (PSIA)
14.0
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)
G GULF SRV 100PCT AT 10W/0 REFLOOD WITH WETWELL SPRAY

Figure D-9

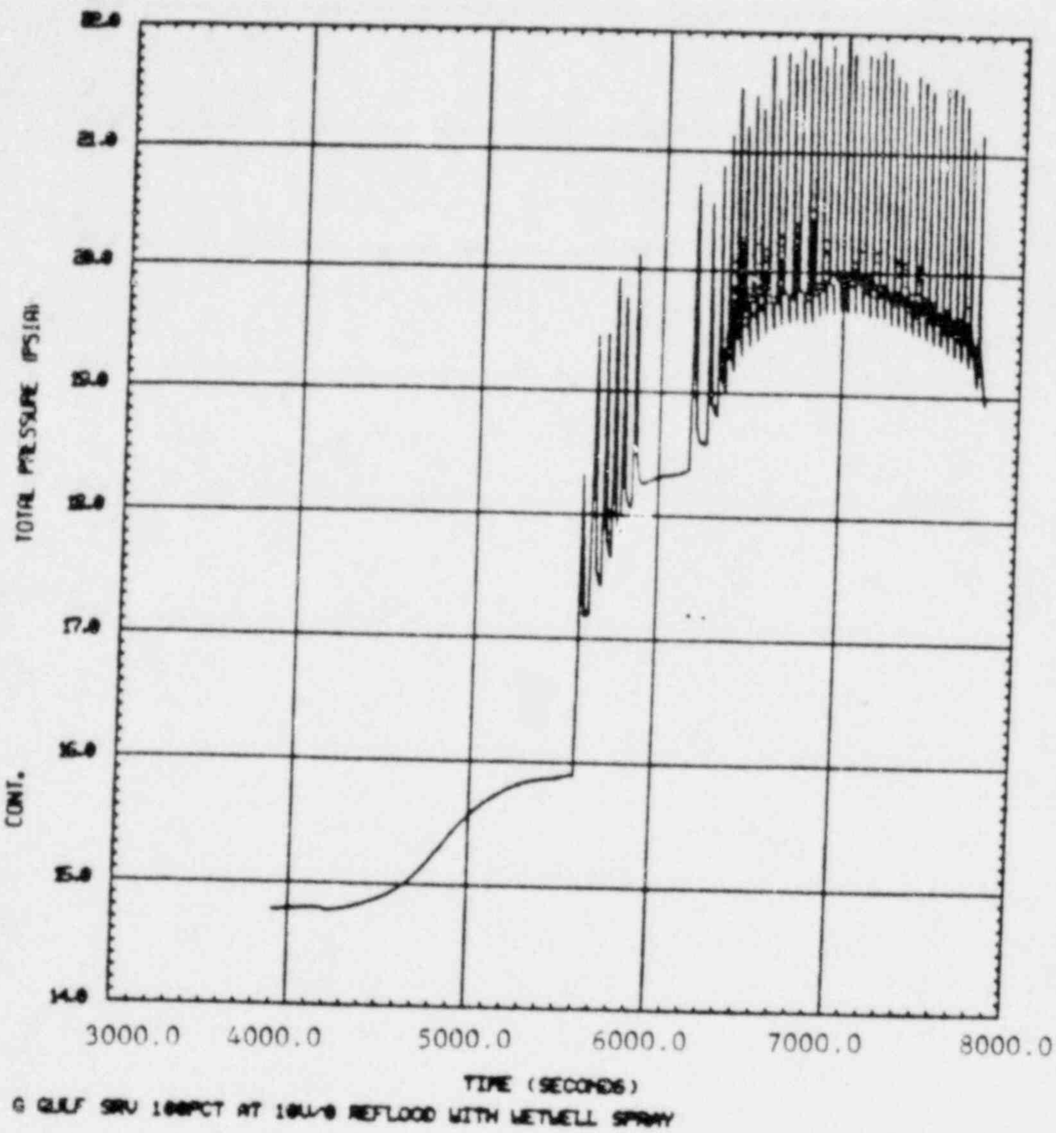
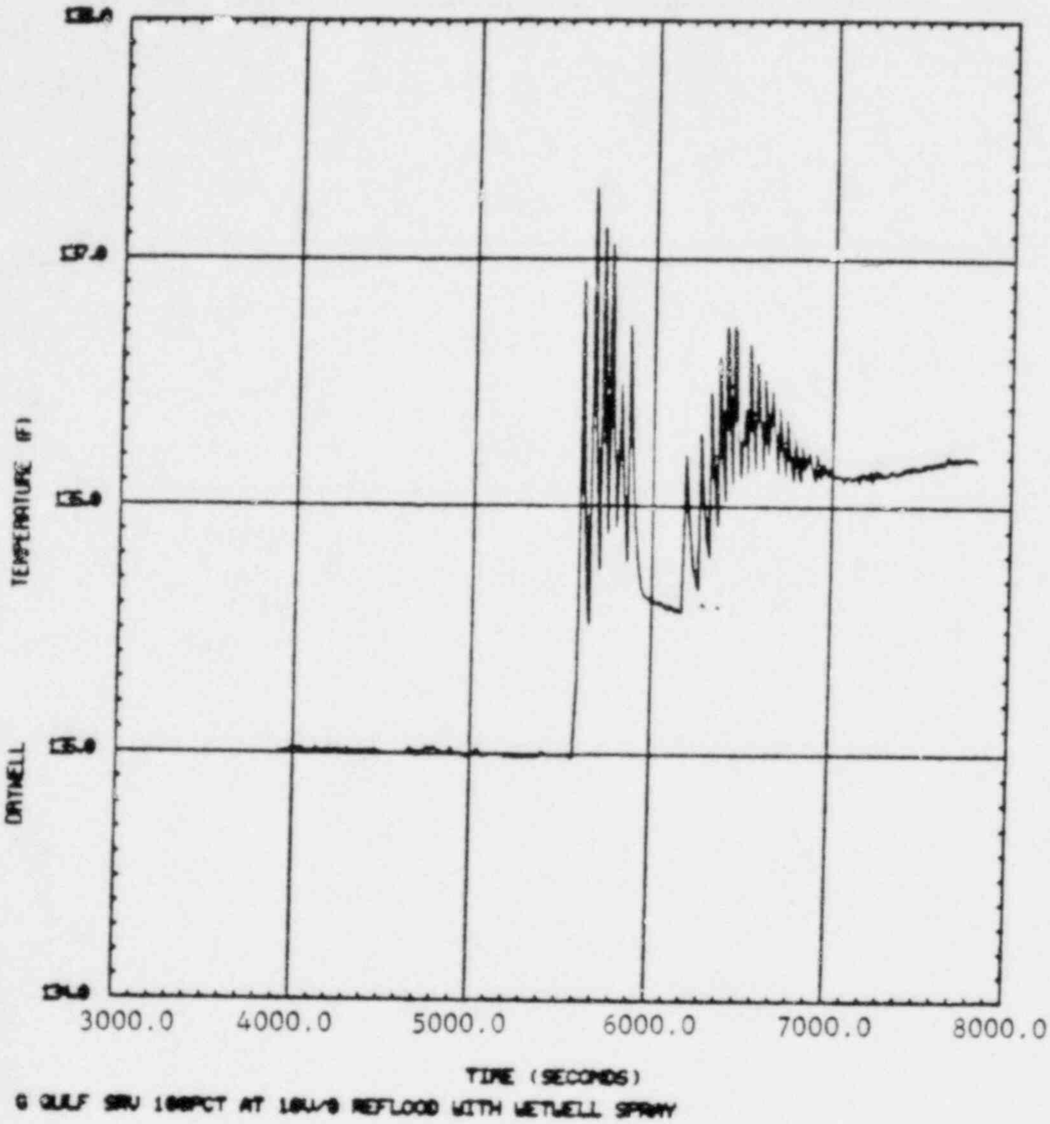

CONT. TOTAL PRESSURE (PSIA)
17.0
16.0
15.0
14.0
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)
G GULF SRV 100PCT AT 10W/0 REFLOOD WITH WETWELL SPRAY

Figure D-10



138.0
137.0
136.0
135.0
134.0
DRYWELL TEMPERATURE (F)
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)
G GULF SRV 100PCT AT 10LV/8 REFLOOD WITH WETWELL SPRAY

Figure D-11

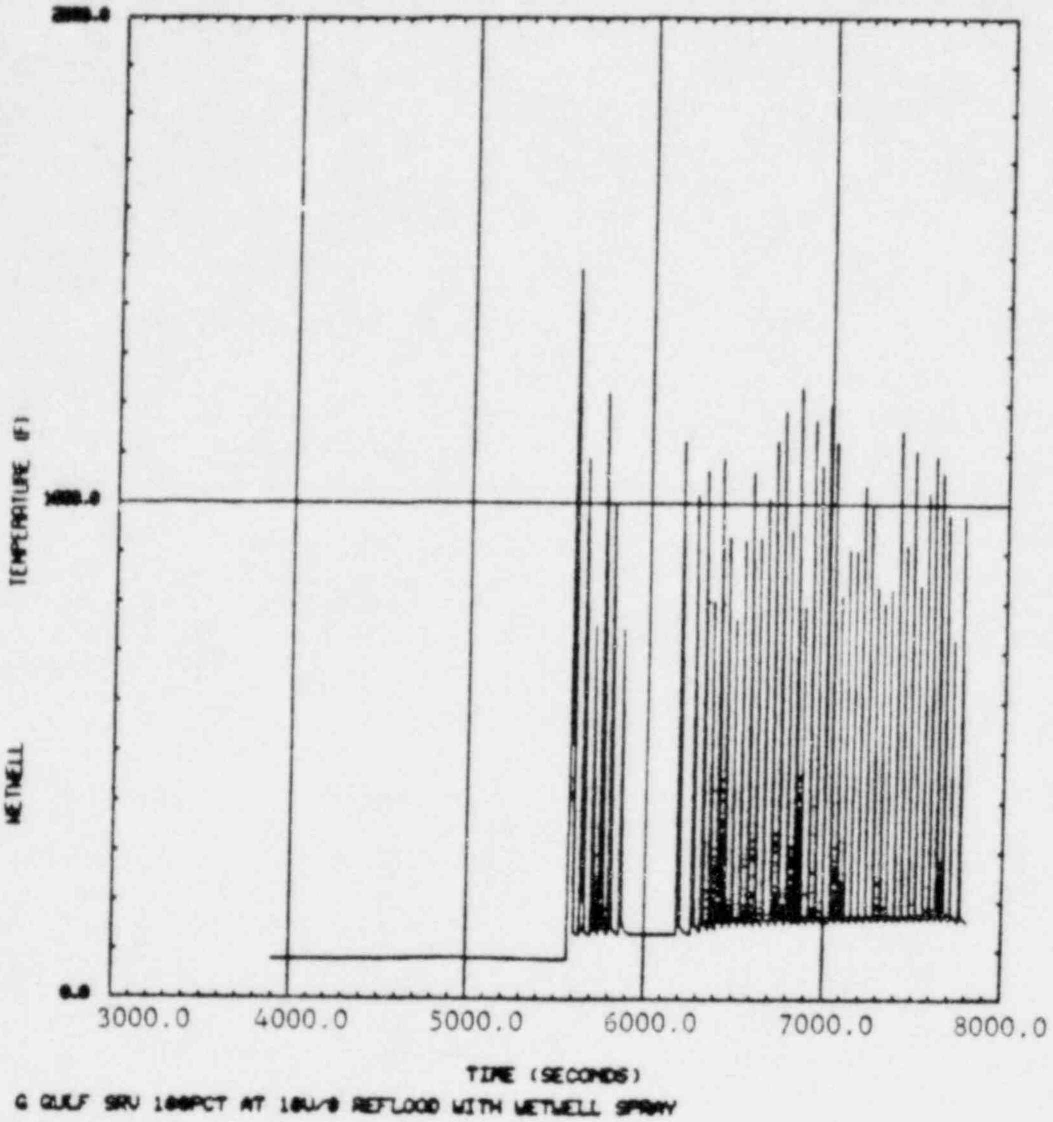


Figure D-12

POOR ORIGINAL

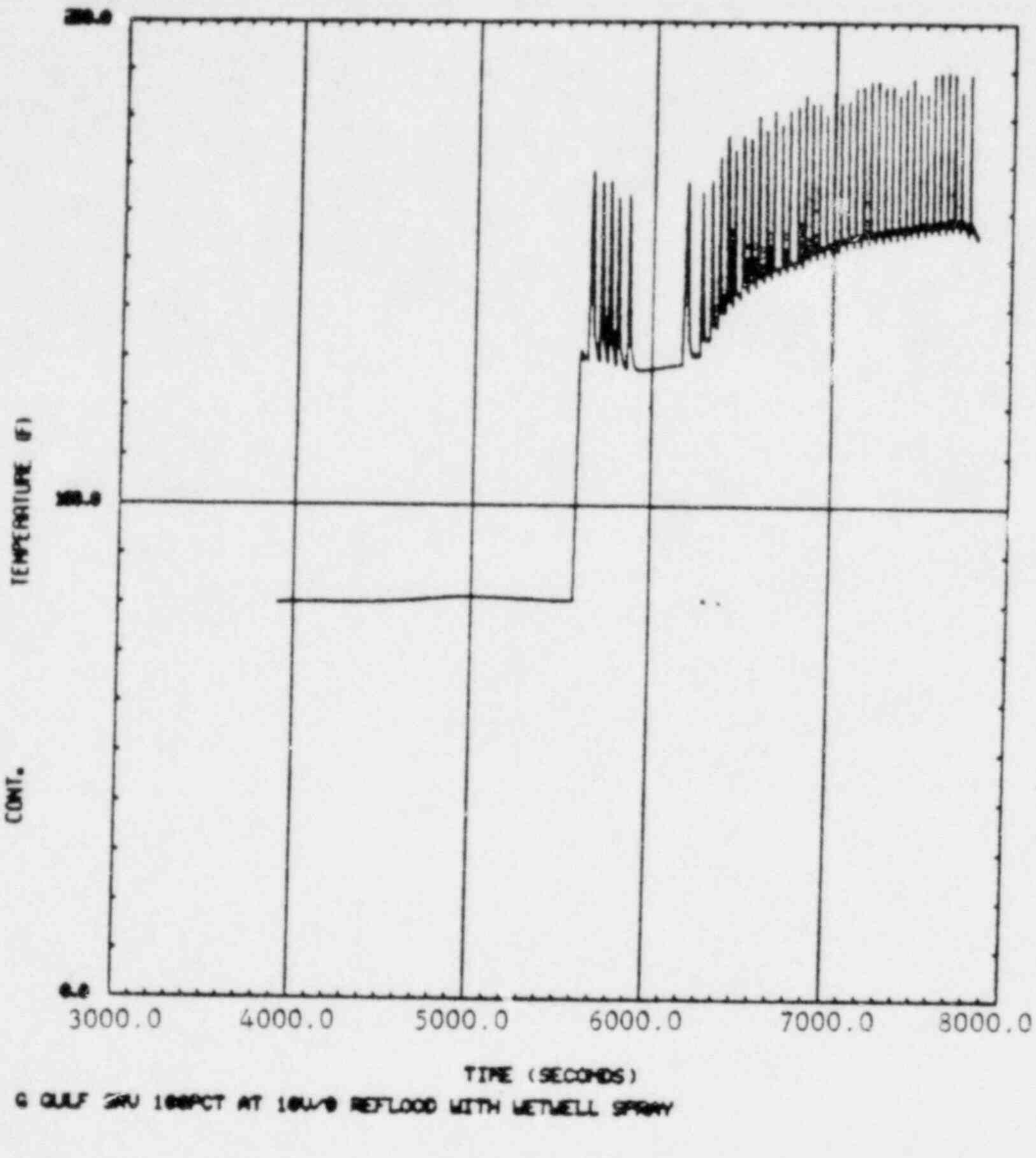

TEMPERATURE (F)
CONT.
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)
G GULF SRV 100PCT AT REFLOOD WITH WETWELL SPRAY

Figure D-13

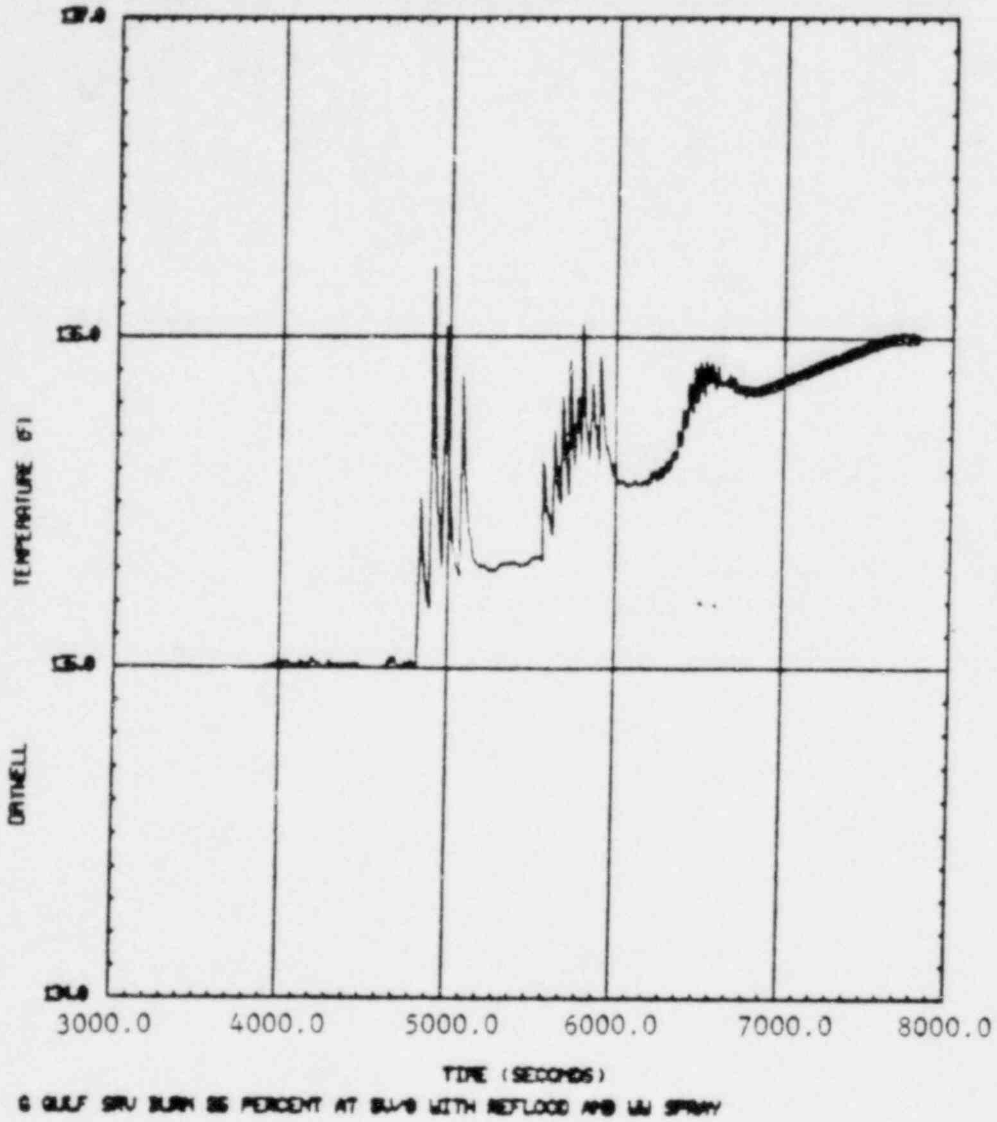

DRYWELL TEMPERATURE (F)
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)

Figure D-14

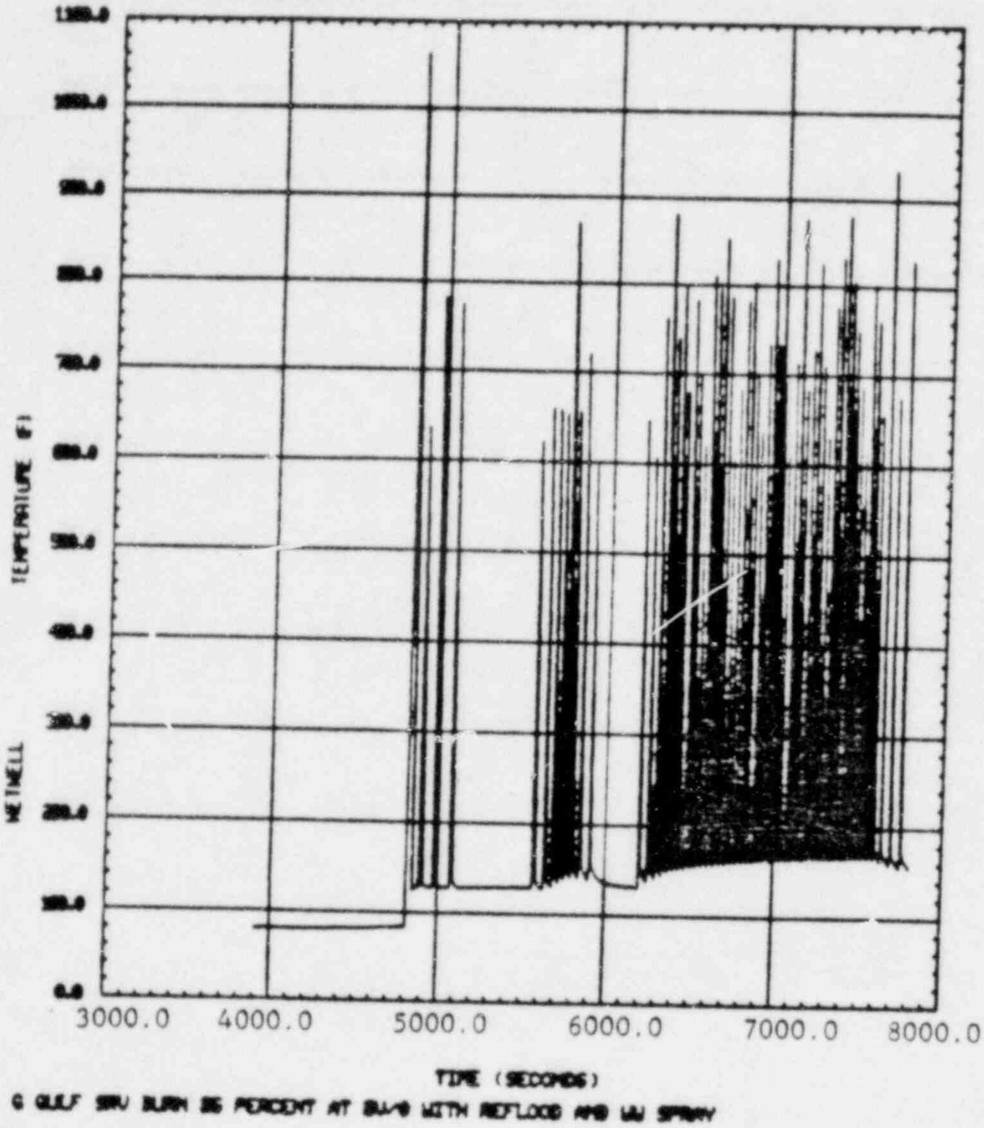
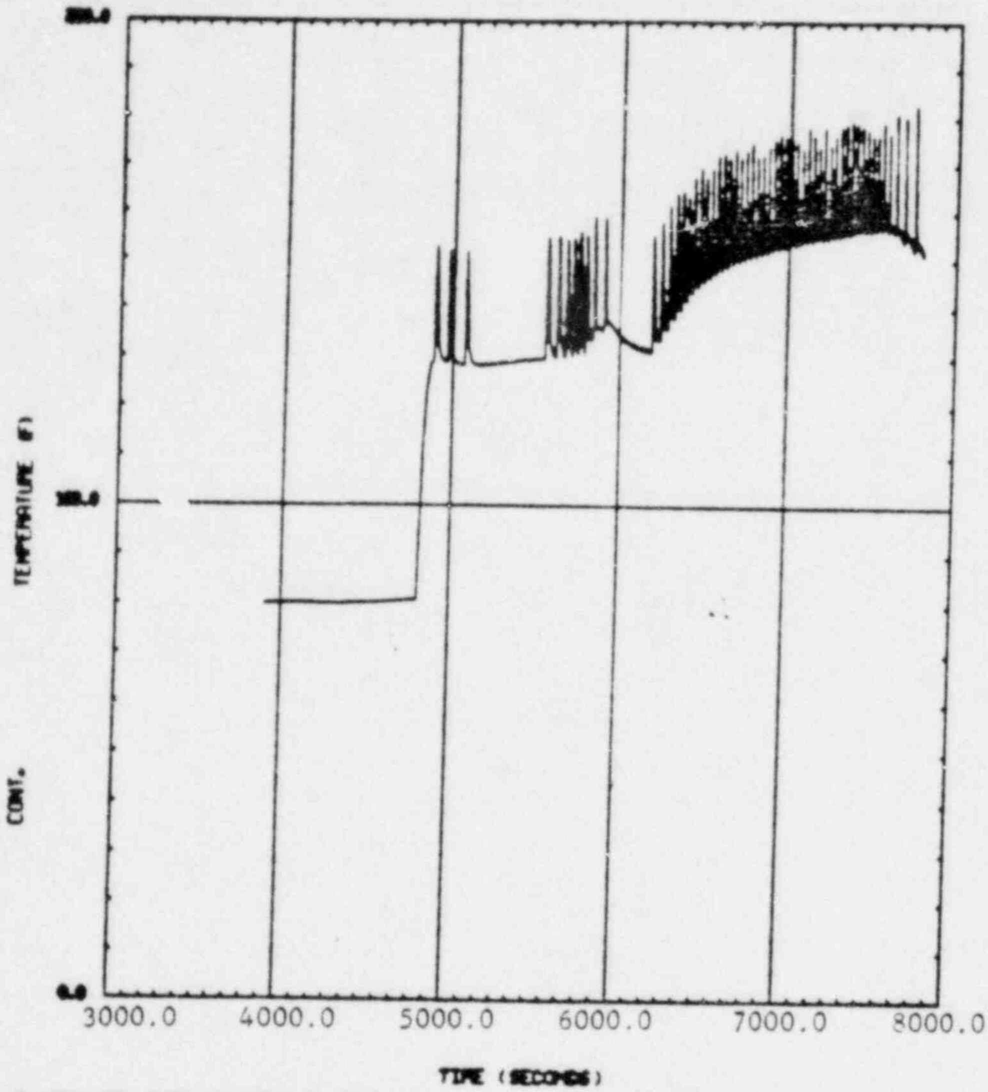
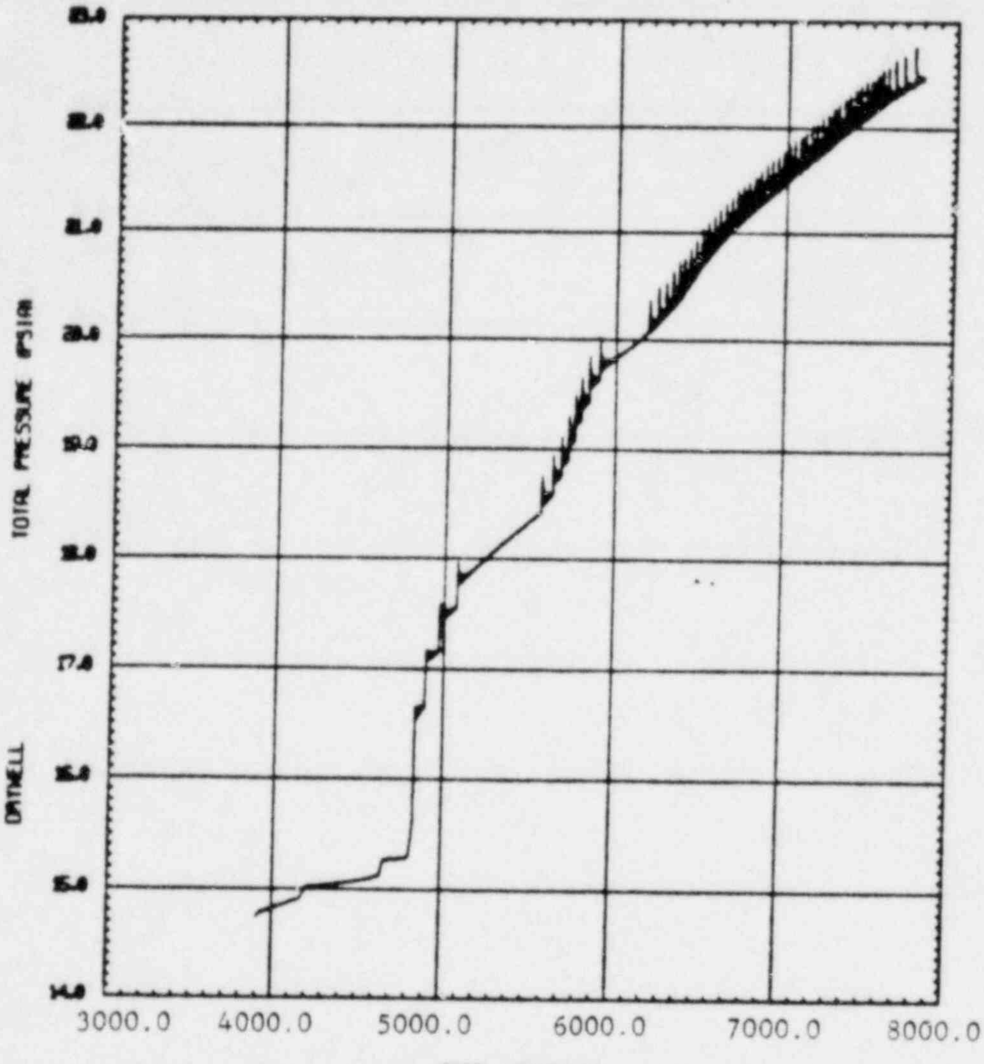

WETWELL TEMPERATURE (F)
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)

Figure D-15



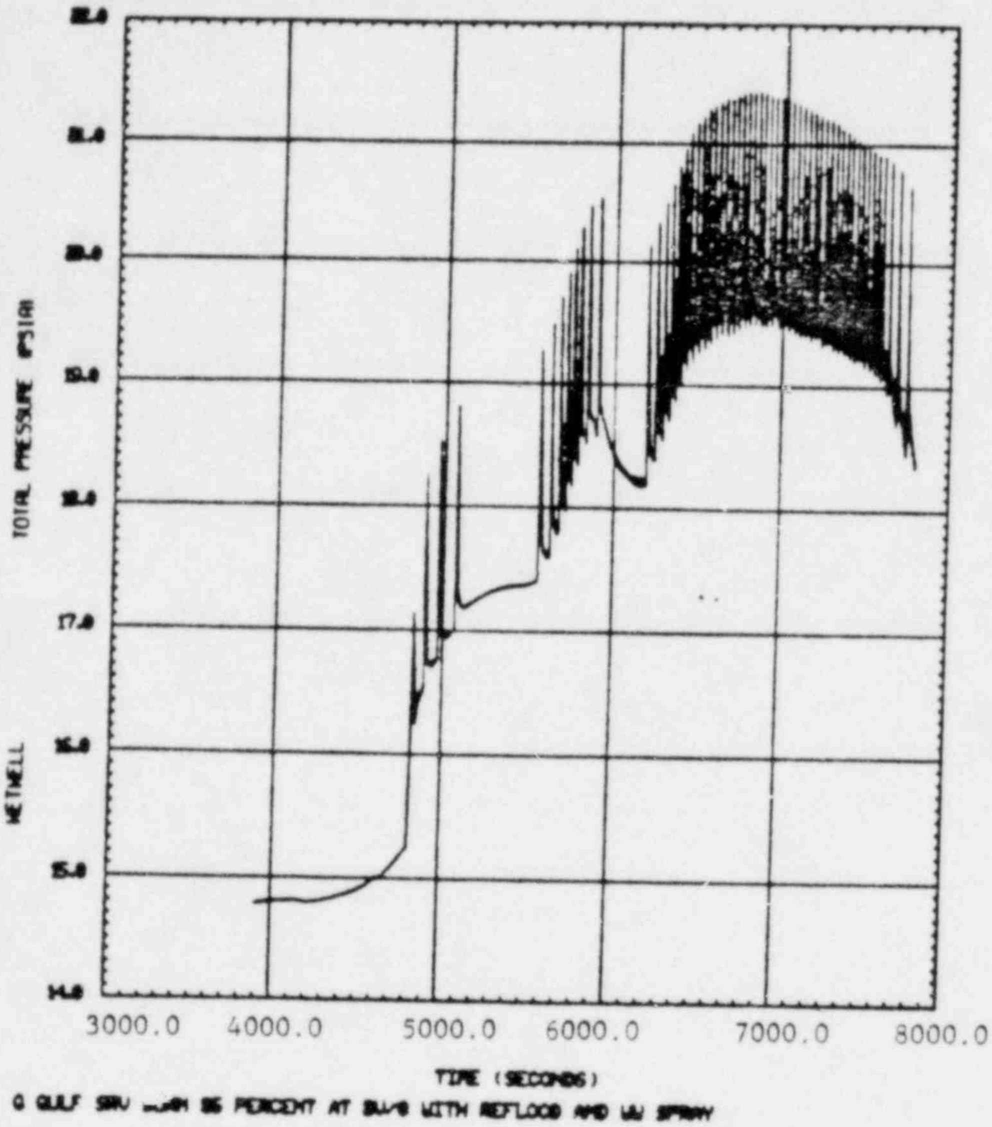
TEMPERATURE (F)
CONT.
0.0
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)

Figure D-16



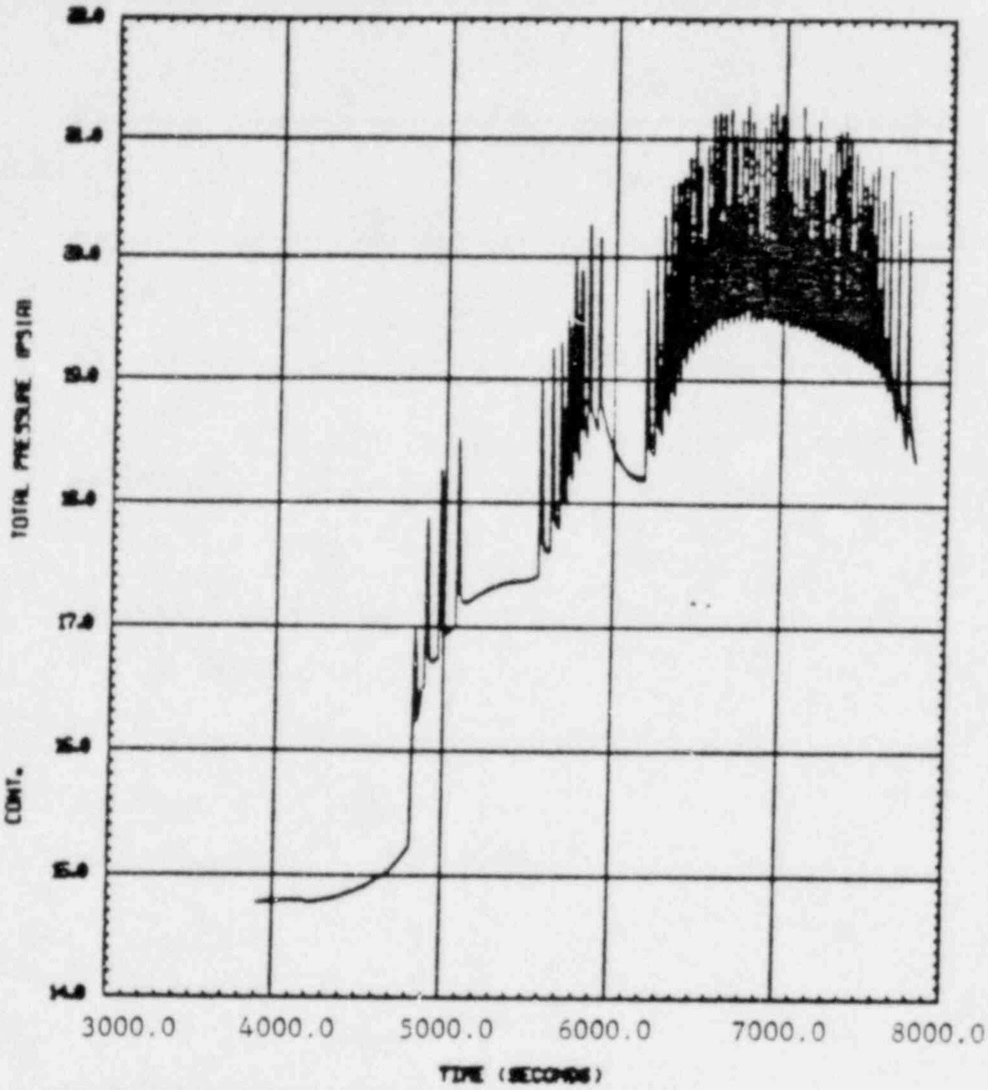
G GULF SRV BURN 85 PERCENT AT 8V/0 WITH REFLOOD AND WW SPRAY

Figure D-17



WETWELL
TOTAL PRESSURE (PSIA)
17.0
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)

Figure D-18



CONT.
TOTAL PRESSURE (PSIA)
17.0
19.0
14.0
3000.0
4000.0
5000.0
6000.0
7000.0
8000.0
TIME (SECONDS)

Figure D-19

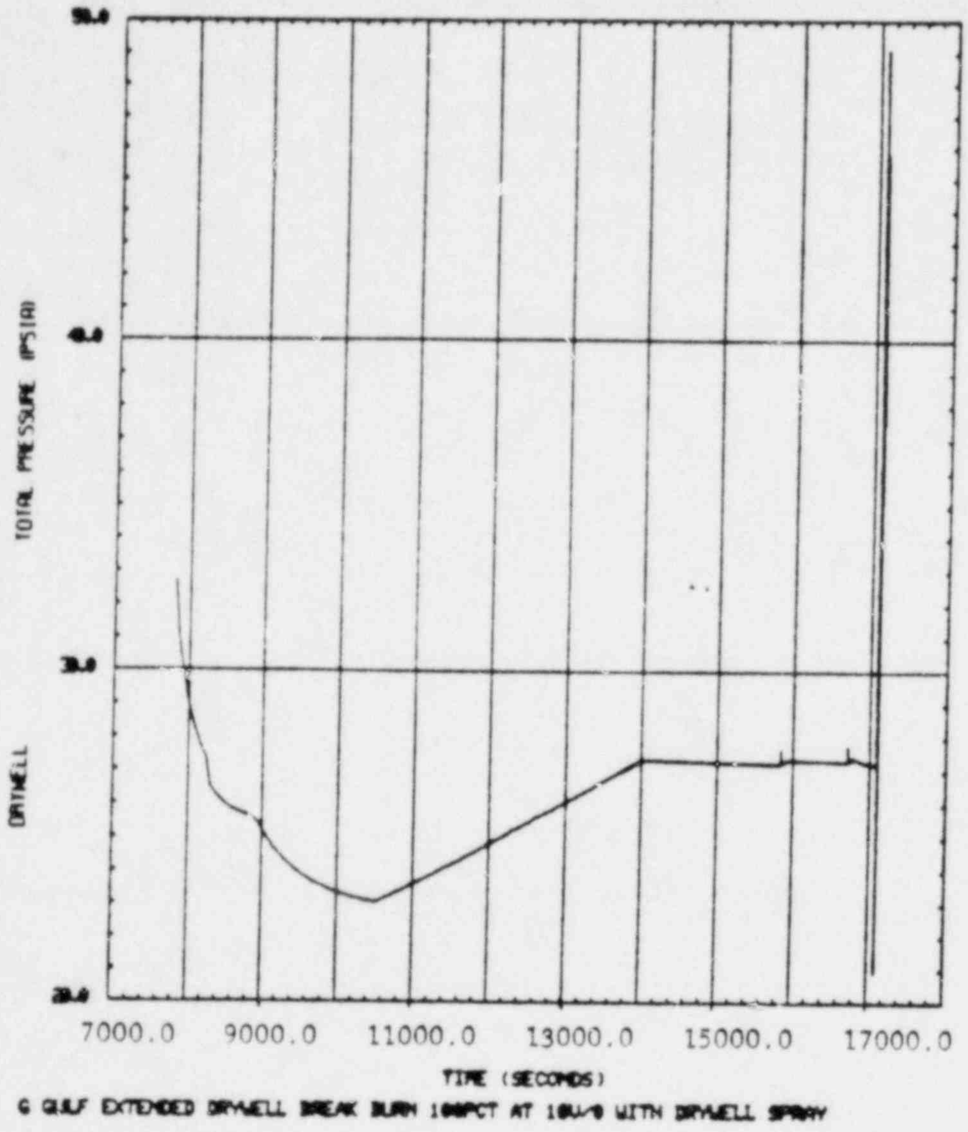

50.0
40.0
30.0
20.0
DRYWELL TOTAL PRESSURE (PSIA)
7000.0
9000.0
11000.0
13000.0
15000.0
17000.0
TIME (SECONDS)
G GULF EXTENDED DRYWELL BREAK BURN 100PCT AT 10V/0 WITH DRYWELL SPRAY

Figure D-20

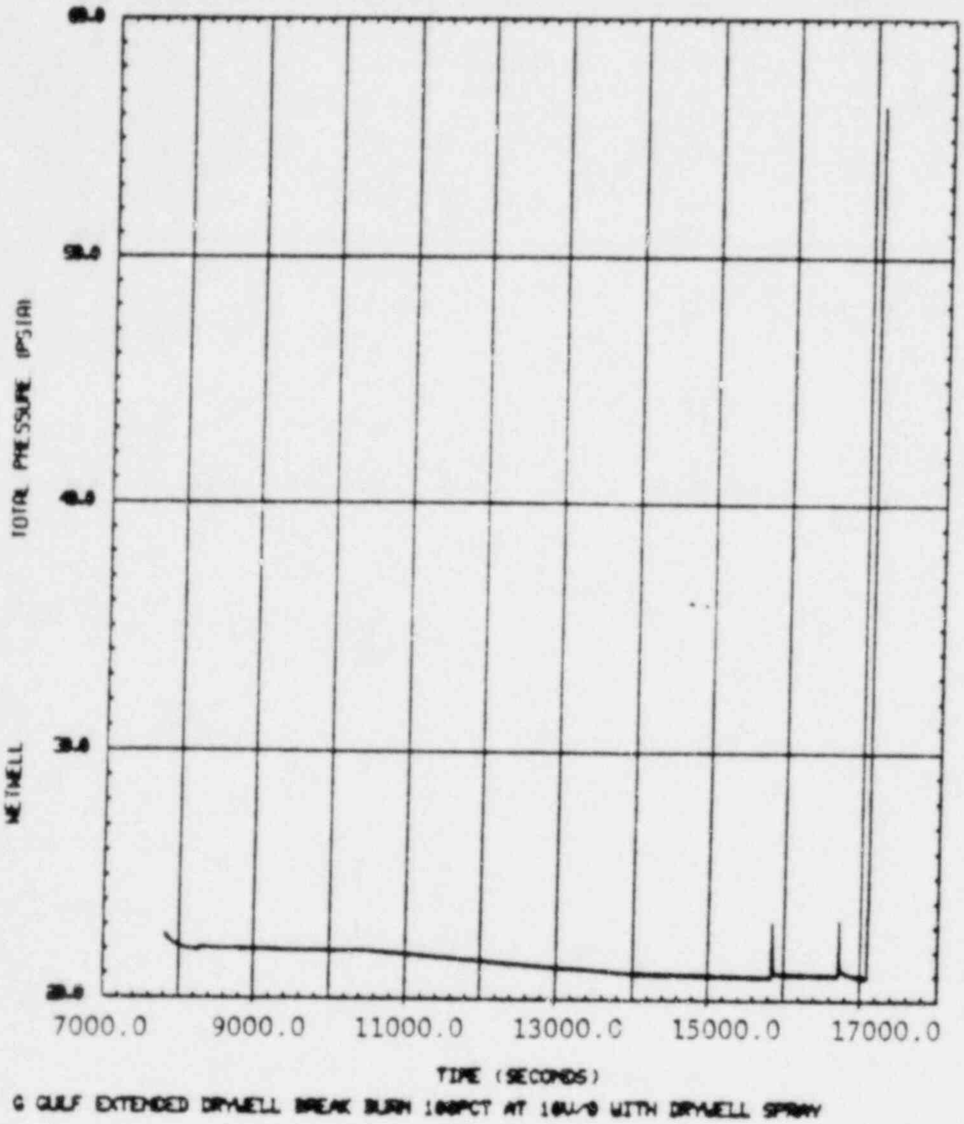
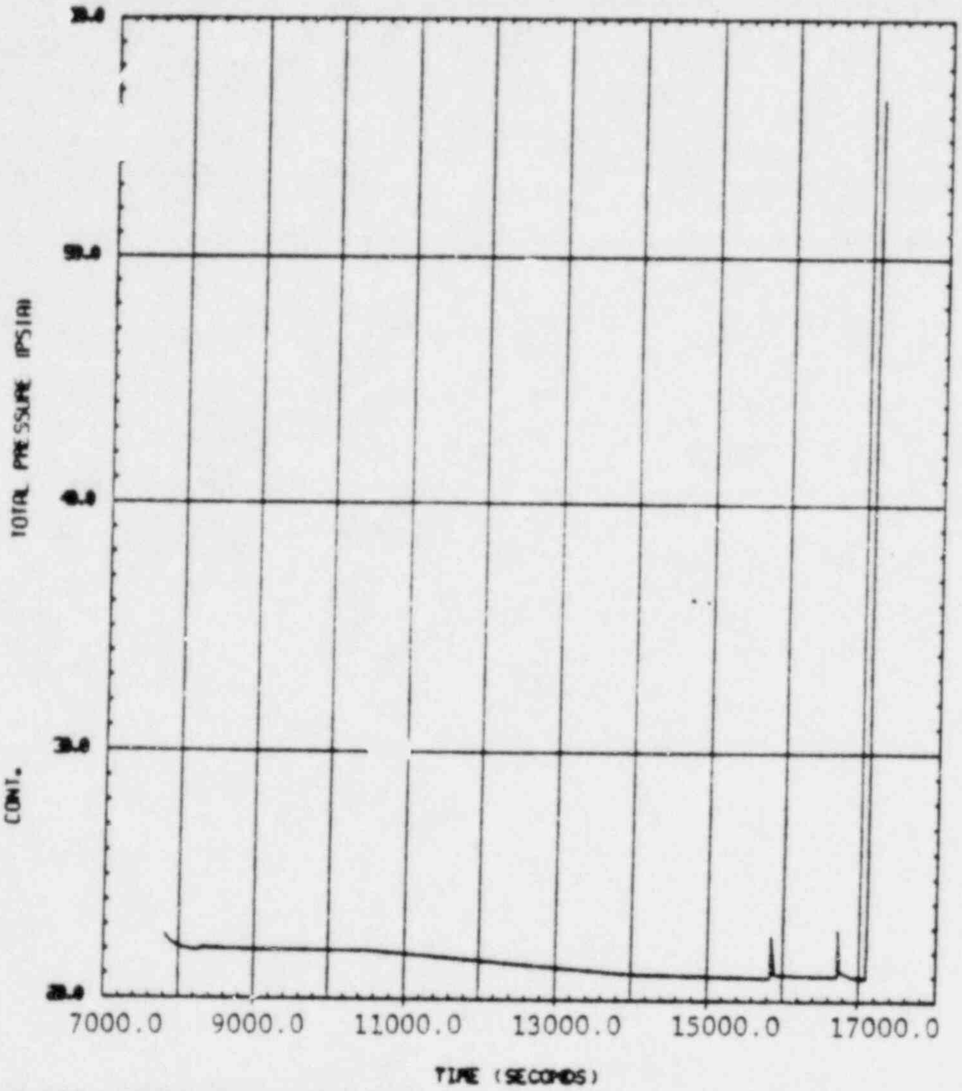


Figure D-21

POOR ORIGINAL



G GULF EXTENDED DRYWELL BREAK BURN 100PCT AT 10V/O WITH DRYWELL SPRAY

Figure D-22

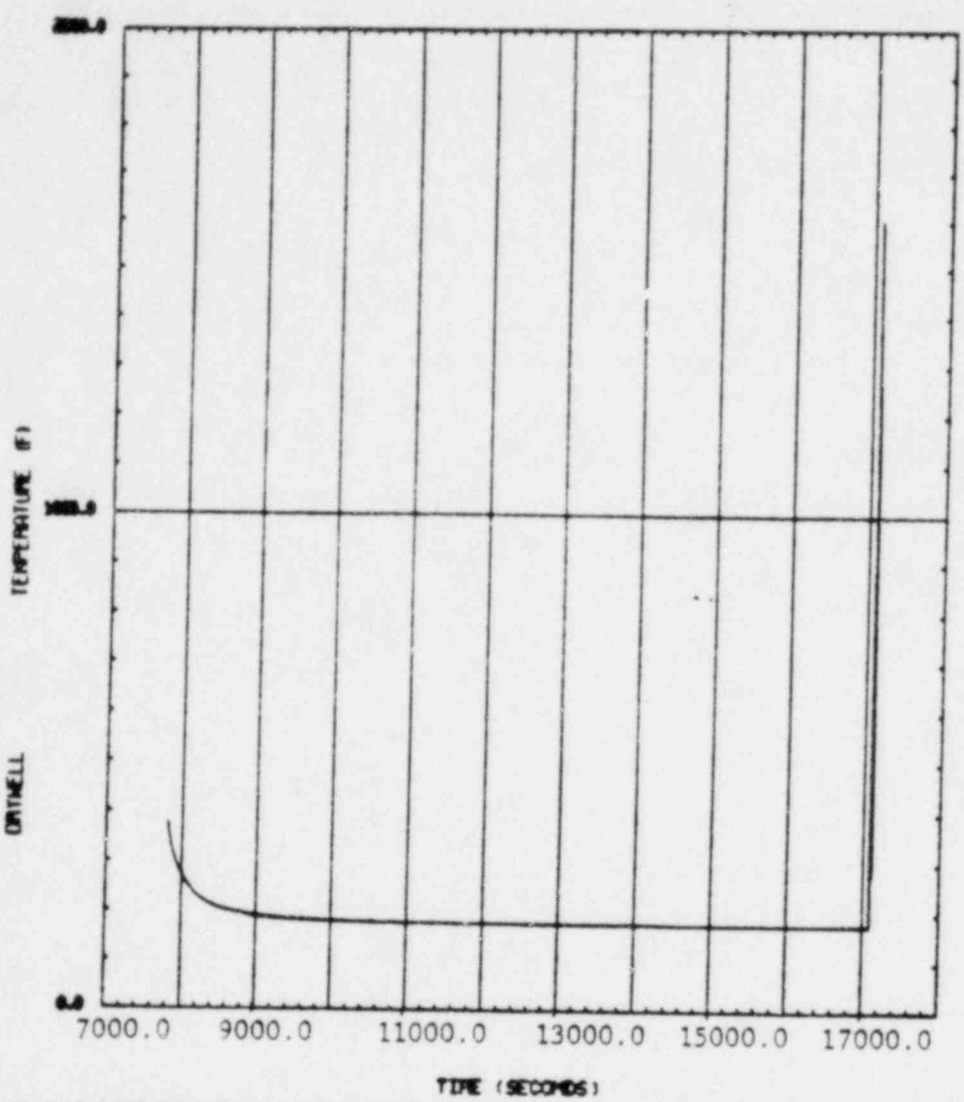

DRYWELL TEMPERATURE (F)
2000.0
1000.0
0.0
7000.0
9000.0
11000.0
13000.0
15000.0
17000.0
TIME (SECONDS)

Figure D-23

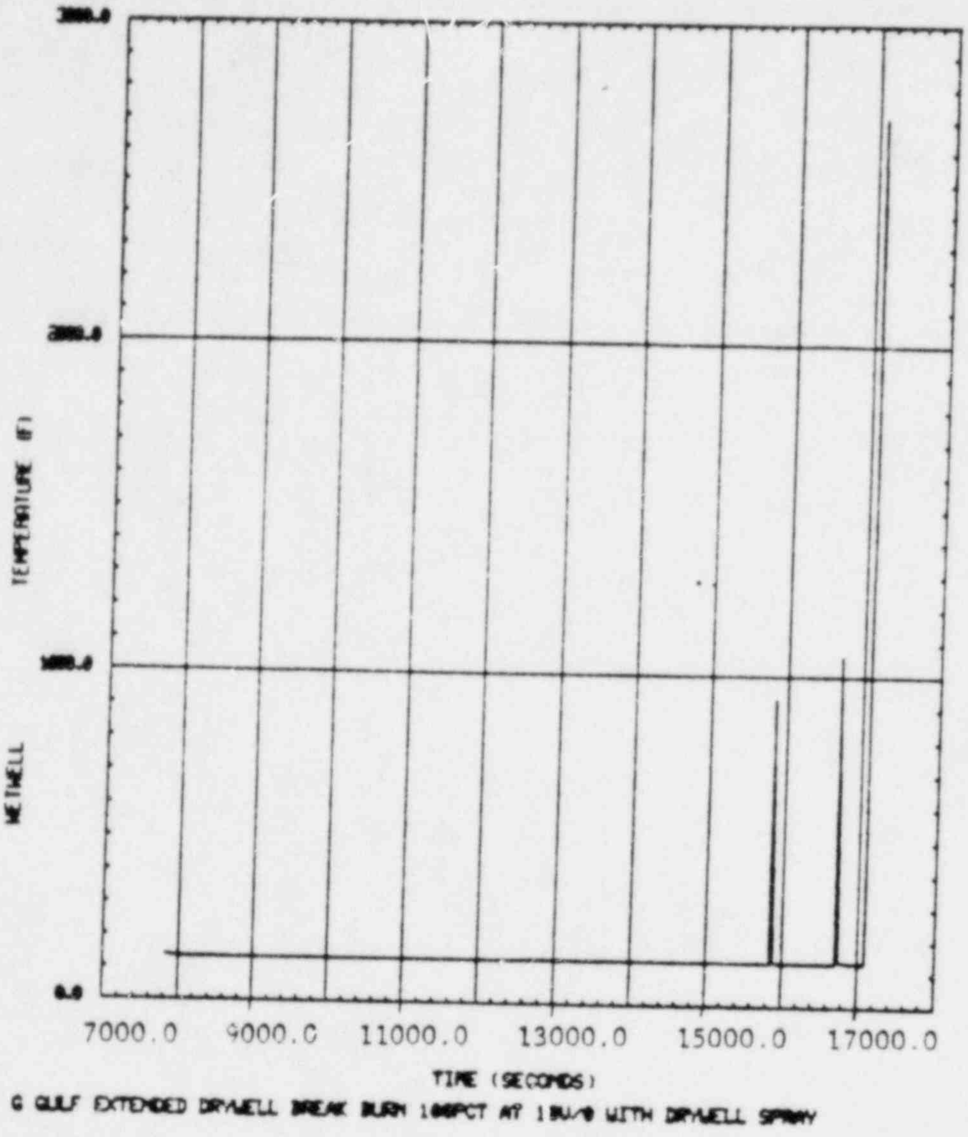

WETWELL TEMPERATURE (F)
7000.0
9000.0
11000.0
13000.0
15000.0
17000.0
TIME (SECONDS)
G GULF EXTENDED DRYWELL BREAK BURN 100PCT AT 1 BU/9 WITH DRYWELL SPRAY

Figure D-24

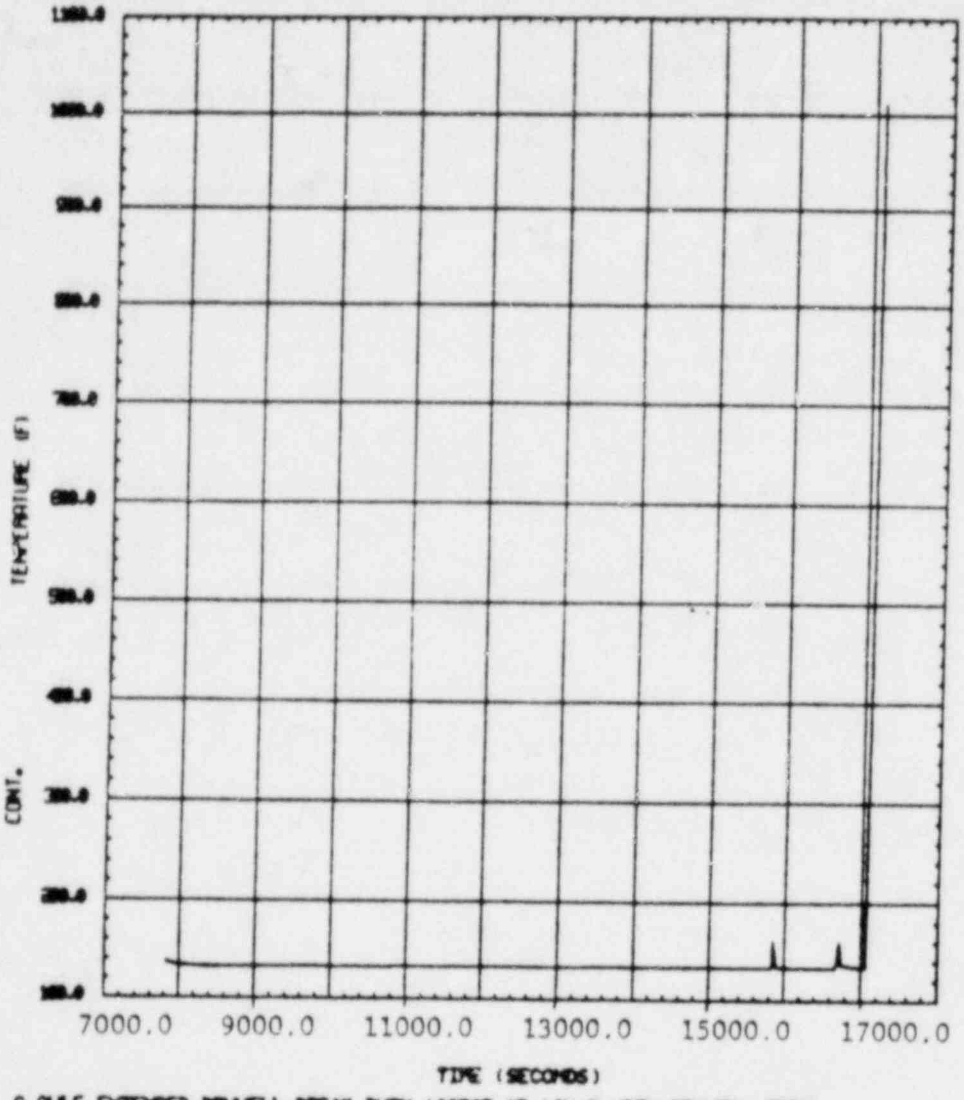

CONT. TEMPERATURE (F)
7000.0
9000.0
11000.0
13000.0
15000.0
17000.0
TIME (SECONDS)
G GULF EXTENDED DRYWELL BREAK BURN 100PCT AT 10W/0 WITH DRYWELL SPRAY

Figure D-25