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THE HARTFORD ELECTRIC LIGHT COMPANY
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HOLYOKE WATER POWER COMPANY
NORTHEAST UTILITIES SERVICE COMPANY
NORTHEAST NUCLEAR ENERGY COMPANY

General Offices ● Selden Street, Berlin, Connecticut

P.O. BOX 270
HARTFORD, CONNECTICUT 06101
(203) 666-6911

April 13, 1982

Docket No. 50-245
B10485

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Director of Nuclear Reactor Regulation
Attn: Mr. Dennis M. Crutchfield, Chief
Operating Reactors Branch #5
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

References: (1) D. G. Eisenhut letter to All SEP Licensees, dated July 7, 1981.
(2) W. G. Counsil letter to D. G. Eisenhut, dated July 29, 1981.

Gentlemen:

Millstone Nuclear Power Station, Unit No. 1
SEP Topic III-5.A, High Energy Pipe
Break Inside Containment

Reference (1) requested the SEP licensees to commit additional resources devoted to completion of the SEP. In Reference (2), Northeast Nuclear Energy Company (NNECO) committed to develop Safety Assessment Reports (SARs) for certain SEP topics which would be submitted for Staff review. In accordance with this commitment, NNECO hereby provides the Safety Assessment Report for SEP Topic III-5.A, which is included as Attachment 1.

We trust the Staff will appropriately use this information to develop a Safety Evaluation Report for this SEP topic.

Very truly yours,

NORTHEAST NUCLEAR ENERGY COMPANY

W. G. Counsil

W. G. Counsil
Senior Vice President

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Docket No. 50-245

Attachment 1

Safety Assessment Report

SEP Topic III-5.A, High Energy Pipe Break Inside Containment

April, 1982

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APPENDICES

1.0 INTRODUCTION

The safety objective of SEP Topic III-5.A, High Energy Pipe Break Inside Containment, is to assure that pipe breaks would not cause the loss of needed functions of safety related systems, structures, and components, and to assure that the plant can be safely shut down in the event of such breaks. The needed functions of safety related system are those functions required to mitigate the effects of the pipe break and safely shutdown the reactor plant.

The study includes the following.

1. Definition of the criteria and assumptions used in the study.
2. Identification of the high energy piping systems inside the drywell.
3. A discussion of the independent methods of placing the plant in safe shutdown condition including the systems and components required to do so. Not all of these methods are necessarily available in the case of pipe break event.
4. A discussion of the effects of postulated ruptures in each of the high energy systems.
5. An evaluation of the ability to place the reactor in a safe shutdown condition following each postulated pipe break event.
6. A discussion of the approaches, under considering, that will help mitigate the consequences of pipe breaks and place the plant in safe shutdown condition.

2.0 CRITERIA

The criteria and assumptions used in this study are based on NRC Standard Review Plans 3.6.1 and 3.6.2 with attached Branch Technical Positions, Regulatory Guide 1.46, and the lead plant assessment of the Oyster Creek Plant. The letter from D. K. Davis to KMC, Inc., outlining the desired approach to be used in evaluating Topic III-5.A was also employed in this study.

2.1 DETERMINATION OF HIGH ENERGY PIPING SYSTEMS

A high energy piping system is one which meets either or both of the following conditions.

2.1.1 Design temperature is 200°F or greater.

2.1.2 Design pressure is 275 psig or greater.

Systems which are designed for the above conditions solely due to accident scenarios are not considered to be high energy for all intents and purposes of this study.

This is the case due to the fact that a pipe rupture coincident with a LOCA is not considered to be credible.

2.2 DETERMINATION OF PIPE BREAK LOCATIONS

Three acceptable methods of postulating pipe break locations are as follows.

2.2.1 Mechanistic Approach (essentially complies with Regulatory Guide 1.46, BTP MEB 3-1, SRP 3.6.2).

2.2.2 Effects Oriented Approach (essentially derived from BTP ASB 3-1).

2.2.3 Simplified Mechanistic Approach (from SRP 3.6.2).

The study is based on the Simplified Mechanistic Approach which basically assumes a pipe rupture at the terminal ends and at each intermediate weld in the system.

The study utilizes the Mechanistic Approach in certain cases where detailed stress analysis information is available. This is done in accordance with the Reference 1 NRC criteria.

2.3 TYPES OF BREAKS

The NRC's criteria outlined in Reference 1 for postulating size and type of pipe breaks is utilizied in the HEPB study as follows.

2.3.1 Circumferential breaks are postulated to occur in runs of greater than one inch (1") nominal pipe size at each location in accordance with the simplified mechanistic approach.

2.3.2 Longitudinal breaks are postulated to occur in runs of greater than four inch (4") nominal pipe size at each location in accordance with the simplified mechanistic approach.

2.4 SIZE AND ORIENTATION OF BREAKS

The NRC's criteria outlined in Reference 1 requires postulating circumferential breaks resulting in complete severance and separation; i.e., guillotine break. This same approach is utilized in the HEPB study.

Longitudinal breaks for the purposes of this HEPB study are defined in a manner consistent with the Reference 1 NRC criteria as being orientated parallel to the pipe axis at any point around the pipe circumference using an effect orientated approach having a break area equal to the cross sectional flow area of the pipe.

2.5 EFFECTS OF BREAKS

The HEPB study incorporates the current NRC requirements that pipe whip, jet impingement, compartment pressurization, and related environmental effects (including flooding) be addressed for all postulated pipe ruptures.

In addition to the pipe whip and jet impingement addressed later in Section 7.0 of this study, the effects of changes in pressure, temperature, humidity and wetted spray have been addressed as part of the SEP Environmental Qualification of Electrical Equipment.

2.6 SINGLE ACTIVE FAILURE

Current NRC criteria require the assumption of a single failure in an active component of a required safety related system coincident with the postulated pipe break. These guidelines are adhered to in the HEPB study.

2.7 OFF-SITE POWER

The HEPB study is consistent with NRC guidelines in assuming the loss of off-site power when a turbine trip is the direct consequence of a pipe rupture.

2.8 OTHER ASSUMPTIONS

2.8.1 Safe shutdown of the reactor is defined as a cold shutdown.

2.8.2 Operating conditions prior to pipe rupture are considered normal steady state.

2.8.3 Other passive failures in addition to the postulated pipe break are not assumed credible.

2.8.4 Only those high energy systems that are in service during normal operation are assumed to rupture.

3.0 HIGH ENERGY PIPING SYSTEMS

All piping systems inside the drywell that have a design temperature of 200°F or greater and/or design pressure of 275 psig or greater during normal operation are considered high energy systems.

System	Nominal Size (in.)	Min. Wall Thickness (in.)	Design Temperature (°F)	Design Pressure (psig)
Isolation Condenser	14	0.750	575	1250
	10	0.594	575	1250
Core Spray*	10	0.594	575	1250
Main Steam	20	1.031	575	1250
Cleanup Water	8	0.500	575	1250
Shutdown Cooling*	14	0.750	350	1250
Feedwater	18	1.562	375	2300
	12	0.844	375	1250
Recirculation	28	1.317	575	1250
	22	1.048	575	1250
	12	0.566	575	1250
Containment Cooling (LPCI)*	18	0.938	575	1250
Reactor Vent*	2	0.218	575	1250
Reactor Head Cooling*	2	0.218	575	1250
Standby Liquid Control*	1.5	0.200	575	1250
Control Rod Drive	1	0.179	150	1900

*System is considered to be high energy between its energy reservoir and the check valve or valve which is closed during normal operation. All other systems are evaluated up to the penetration anchor.

4.0 PLANT SHUTDOWN METHODS

Four (4) independent methods of plant shutdown are available to bring the plant to a safe shutdown condition. None require that the control room be available for functional activities. These methods are as follows.

- Isolation condenser only.
- Normal shutdown (steam dump to main condenser).
- Auto pressure relief (APR) and control rod drive (CRD).
- Emergency core cooling (APR and core spray/LPCI).

It should be noted, however, that these plant shutdown methods may not be all available in the event of a high energy pipe break, or may not be capable of handling such an event.

In each postulated break event, as will be discussed later, the specific available safe shutdown method will be outlined.

4.1 ISOLATION CONDENSER ONLY

If the inventory of water in the vessel is maintained, assurance of fuel integrity is maintained. Threfore, with the reactor scram used and the vessel isolated, use of the isolation condenser retains the inventory of water by condensing the steam and returning the condensate to the vessel with no losses. Temperatures can be reduced to and maintained at approximately 200°F for the duration of decay heat production.

4.2 NORMAL SHUTDOWN (STEAM DUMP TO MAIN CONDENSER)

With the reactor scrammed and not isolated, a safe shutdown may proceed by using the main condenser as a heat sink for pressure reduction and control, with the condensate/feedwater systems supplying makeup water to the vessel for level control.

4.3 AUTO PRESSURE RELIEF (APR) AND CONTROL ROD DRIVE (CRD) SYSTEM

With the reactor scrammed and the vessel isolated, a safe shutdown may be made by using one auto pressure relief valve for pressure reduction and control, with the control rod drive system supplying water to the vessel for level control. The control rod drive pumps (two) can supply more than 160 gpm at 1600 psig for this shutdown method.

4.4 EMERGENCY CORE COOLING SYSTEM (APR AND CORE SPRAY/LPCI)

With the reactor scrammed and the vessel isolated, a safe shutdown may proceed, with one core spray or LPCI (low pressure coolant injection) pump for makeup water to the vessel for level control.

4.5 IMPACT OF HEPB CRITERIA ON SHUTDOWN METHODS

The shutdown methods outlined above are discussed here with respect to the single active failure and loss of off-site power criteria.

4.5.1 Normal shutdown outlined above in Section 4.2 is affected in the following manner. After the loss of off-site power, emergency power may be generated by either the gas turbine or diesel generator. Assuming the most limiting single active failure, inability to start the gas turbine, leaves only the diesel generator to supply emergency power. The diesel generator cannot supply sufficient power to operate the FWCI system; therefore, this shutdown method is essentially eliminated due to the assumptions stated above. However, the diesel generator is still available to power all other safety systems.

4.5.2 The most limiting single active failure for the isolation condenser shutdown method is the loss of function of the motor operator on valve IC-3. This valve must be opened to initiate flow by natural circulation through the isolation condenser. However, credit for the isolation condenser system may still be taken since the valve may be manually operated and is accessible in the reactor building.

4.5.3 The remaining shutdown methods are unaffected by the assumptions outlined above due to the redundancy inherent in each system. They are designed with redundant trains, backup pumps, and emergency power supplies so that they are essentially immune to the loss of off-site power and single active failure assumptions.

5.0 PIPE BREAK EFFECTS ON STRUCTURES

5.1 BIOLOGICAL SHIELD WALL

Included in this study as Appendix D is an analysis prepared by Jersey Central Power and Light Company, entitled "Evaluation of Structural Integrity of the Biological Shield Wall Under Pipe Whip Loadings". The results of the analyses which are applicable to Millstone Unit No. 1, indicate that no gross structural damage will occur under "worst case" impact loadings, and that the shield wall is capable of withstanding the full spectrum of postulated breaks without incurring significant loss of load carrying capability. Damage to the shield wall will be restricted to the local region of impact and will not significantly affect overall structural capability.

5.2 DRYWELL LINER

Containment integrity must be shown for pipe whip interaction with the drywell liner. The drywell consists of a one and three-quarter inch air gap between a five-eighth inch inner liner plate and an outer concrete containment. Appendix E contains a study performed by Chicago Bridge and Iron Company, pertinent to the Millstone Unit No. 1 drywell liner, which indicates that a circular area of at least 14" diameter impacting the one-quarter inch liner plate will deform it without failure to the point where the plate comes in contact with the concrete. Assuming that the impact area of the pipe is equal to its cross sectional area, a whipping pipe with nominal diameter 14" or greater cannot rupture the drywell liner.

For impacting pipes less than 14" nominal size, in Appendix F, calculations show that the smaller diameter pipes do not have sufficient energy to penetrate the drywell liner. These calculations are based on the General Electric report entitled, "The Design of Barricades for Hazardous Pressure Systems". Therefore, in combining the above sources, containment integrity is proven.

6.0 BREAKS AT PENETRATION ASSEMBLIES

The penetration assemblies are assumed to withstand and transmit pipe rupture forces to support structures without plastic deformation. Additionally, the effects of jet impingement are not analyzed for breaks postulated to occur between the penetration assembly and the first isolation valve outside containment, since they were previously evaluated as part of another assessment.

7.0 INTERACTION ANALYSIS

The purpose of this section of the report is to describe the effects of pipe whip and jet impingement resulting from postulated pipe breaks. Circumferential and longitudinal breaks are considered to be non-simultaneous occurrences and the effects of these breaks are, therefore, analyzed independently.

7.1 ASSUMPTIONS

The criteria of Section 2.0 along with the following assumptions form the basis for the interaction analysis.

7.1.1 Pipe whip is assumed to occur as a result of a circumferential rupture in a high energy system provided there is a significant reservoir of energy. Table 7-1 of this report lists these systems and their attendent energy reservoirs.

7.1.2 For circumferential breaks, the free end of a moving pipe is assumed to move in only one direction parallel to its reactor force. This type of pipe break event does not cause dynamic instability (large amplitude oscillations) since the critical length required for this phenomenon is substantially greater than any major pipes in the drywell of BWR plants.

7.1.3 Impacted active equipment (e.g., valves and instruments) is considered unable to perform its intended function.

7.1.4 Pipe anchors and whip restraints are considered to be capable of continuing to perform their intended functions.

7.1.5 Valves which are normally closed and are not signaled to open, are not assumed to fail open. Valves normally open shall remain open during and after loss of power or impact.

7.1.6 Plastic hinge formation due to pipe rupture is assumed to occur at system anchors or at other intermediate locations as dictated by the complexity of the particular system configuration. The hinges can form in either bending or torsion mode depending on the configuration.

7.1.7 Longitudinal breaks are assumed to cause a jet in the form of a cone with a 20° angle of divergence.

7.2 INTERACTION CONSEQUENCES

The basis for evaluating the consequences of interactions between the high energy source system and the selected targets are as follows.

7.2.1 A whipping pipe is considered to have sufficient energy to cause damage to:

7.2.1.1 Pipes of smaller nominal size and lighter wall thickness.

7.2.1.2 Electric motor operators.

7.2.1.3 Electric conduit and cable trays.

7.2.2 A steam jet is considered to have sufficient energy to cause damage to:

7.2.2.1 Electric cable trays.

7.2.2.2 Electric motor operators.

Reports deemed applicable to Millstone Unit No. 1, prepared by MPR Associates, Inc. (Report No. MPR-285, dated May 7, 1971) and Burns and Roe, Inc. (Penetration Analysis for Jet Impingement Due to Pipe Rupture, dated April 24, 1968) demonstrate the ability of the steel containment vessel to withstand the effects of jet impingement.

7.3 INTERACTION MATRICES

The results of the analysis are shown on matrices in Appendix B. The isometric drawings used to develop these interaction matrices are included in Appendix A. All postulated break points on the high energy piping are shown and numbered on these drawings.

The matrices are prepared on a system basis showing the potential interactions between the source, for each postulated break point, and the selected target. Interactions are defined as follows.

7.3.1 (A) Acceptable: Interaction causes no damage.

7.3.2 (N) No Interaction: Interaction physically not possible.

7.3.3 (D) Damage Possible: Further evaluation required.

It should be noted that interactions falling within the last category, (D), does not mean that the occuring damage will impair the safety function of the target. Each interaction falling within this category is evaluated individually, in Appendix C, to assure that such possible damage does not prevent the safe shutdown of the reactor or that the damage does not impair the safety function of the target (if any).

Table 7-2 gives a summary of the interactions between piping, structures, and components, within the drywell for each high energy piping system.

The single failure criteria are considered in preparing the interaction scenarios and evaluation presented in Appendix C.

7.4 DISCUSSION

The following sections discuss the results of the interaction matrices and other factors involved in the consequences of the postulated pipe ruptures.

7.4.1 Instrumentation

The essential instrumentation inside the drywell consists of reactor pressure and level indication taps and associated tubing. This instrumentation is made up of two redundant systems located on opposite sides of the drywell protected by the reactor vessel itself. Therefore, a pipe whip or jet impingement which interacts with one system can in no way impact the other due to their physical separation. Also within each system there exists redundancy in the pressure gauges and level indicators so that a single active failure concurrent with a detrimental interaction cannot result in total loss of indicators.

7.4.2 Electrical Equipment

The only necessary electrical equipment (motor operators, cabling, etc.) located inside the drywell is associated with the ADS valves (Automatic Depressurization System) located on the main steam lines. As stated in Reference 2, for a pipe rupture of 8" nominal size or greater, reactor depressurization can occur through the break without the use of the ADS valves. The critical factor involved here is the amount of inventory lost during the time it takes for the reactor to depressurize to the point where core spray and LPCI may be initiated. This takes no credit for any high pressure makeup capabilities; i.e., FWCI and CRD pumps. Therefore, the ADS valves and cables were evaluated only for pipe ruptures of less than 8" nominal pipe diameter. High energy systems in this category include the reactor head cooling, reactor vent, and standby liquid control systems. It is evident in the evaluation of interactions that these systems are physically separated from the ADS valves and cabling from the standpoint of pipe whip and need not be evaluated for jet impingement due to their small diameter (less than 4").

The remaining motor operators and electrical cables associated with safety related systems need not be addressed in this study due to the valve line-ups. All the shutdown systems may be initiated without changing the position of any valve on each particular system.

7.4.3 Recirculation Loop Interaction

Since the recirculation loops are equipped with pipe whip restraints, it is assumed that a break resulting in pipe whip cannot interact with any other system. Jet impingement may interact with other systems but can have no detrimental effects on shutdown capabilities as shown in Section 7.4.2, above.

The system is vulnerable as a target only as far as the 12" risers are concerned. The 22" headers and 28" discharge and suction lines are not included in the interaction matrices as targets due to the fact that any other pipe impacting them is smaller in size, thus resulting in acceptable consequences.

7.4.4 Control Rod Drive (CRD) Piping Interaction

The only interaction resulting in the inability to bring the reactor to a cold shutdown condition involves the CRD piping. It is postulated that circumferential breaks in the main steam lines "B" and "C" result in a pipe whip which impacts one of the four CRD insert and withdraw line banks. Each pair of insert and withdraw lines represents one control rod. If a withdraw line is crimped but not severed, the control rod may not scram when signaled due to the flow restriction.

In examining the main steam piping stress analysis, the detrimental break locations are eliminated by using a mechanistic approach. As shown in Appendix G, the break locations which interact with the CRD lines have stress values which are below those specified by the criteria under the mechanistic approach. Also, the standby liquid control system may be used to bring the reactor subcritical when the CRD system is not available.

7.4.5 Small Bore Piping Interactions

The small bore piping (reactor vent, reactor head cooling, and standby liquid control) are not included in the interaction matrices as sources. The only damage due to pipe whip which these systems may inflict is on electrical and instrumentation, which has already been addressed, and on themselves. Since the damage possible is so limited, it is not practical to include them in the interaction matrices. However, as stated in Appendix C, a rupture of any of these pipes poses no threat to a safe shutdown. The CRD piping is not considered a source due to the fact that its largest pipe is only one inch nominal diameter, and therefore is below the size criteria for postulating pipe ruptures.

7.4.6 Reactor Vessel Interaction

The only interaction concerning the reactor vessel itself is with the isolation condenser above the top of the biological shield wall. This interaction is not considered to be detrimental to the reactor vessel and in no way affects the capability to reach a safe shutdown.

TABLE 7-1

PIPING SYSTEMS AND ENERGY RESERVOIRS

System	Energy Reservoir
Isolation Condenser	Reactor Vessel
Core Spray	Reactor Vessel
Reactor Cleanup	Reactor Vessel
Shutdown Cooling	Reactor Vessel
Reactor Recirculation Loop	Reactor Vessel
LPCI	Reactor Vessel
Main Steam	Reactor Vessel and Main Steam System Outside Drywell
Feedwater	Reactor Vessel and Feedwater System Outside Containment
Reactor Head Cooling	Reactor Vessel
Reactor Vent	Reactor Vessel
Standby Liquid Control	Reactor Vessel

TABLE 7-2

SUMMARY OF INTERACTION MATRICES

Source		Target Piping	Drywell Liner	Biological Shield
Isolation Condenser	A	D	A	A
	B	D	D	A
Core Spray	A	A	N	N
	B	A	N	N
Main Steam	A	D	A	A
	B	D	A	A
	C	D	A	A
	D	D	A	A
Cleanup Water	A	A	N	A
	B	A	D	A
Shutdown Cooling		D	N	A
Feedwater	A	D	D	A
	B	D	D	A
LPCI	A	D	N	N
	B	N	N	N
Reactor Vent		D	D	A
Reactor Head Cooling		A	D	N
Standby Liquid Control		A	N	A

A = Acceptable Interaction (Causes no damage)

N = No Interaction (Interaction physically not possible)

D = Damage Possible (Further evaluation required)

8.0 CONCLUSIONS

The combination of the interaction matrices, evaluations, and analyses performed with regard to postulated ruptures of high energy piping systems inside the drywell of Millstone Unit No. 1 leads to the following conclusions.

8.1 For all postulated break locations, acceptable safe shutdown methods are available as shown in Appendix C.

8.2 Structural stability inside the drywell and containment integrity are maintained for all postulated pipe ruptures.

8.3 The environmental effects of pipe breaks do not impair the ability to arrive at a safe shutdown of the reactor plant.

9.0 REFERENCES

9.1 D. K. Davis letter to KMC, Inc., dated July 20, 1978; re: Assessment of Postulated Pipe Breaks Inside Containment.

9.2 SEP Topic III-5.A, Lead Plant Evaluation of Oyster Creek.

9.3 Ebasco Main Steam Stress Analysis per I&E Bulletin 79-14, Reanalysis Program, Calculation No. 262.

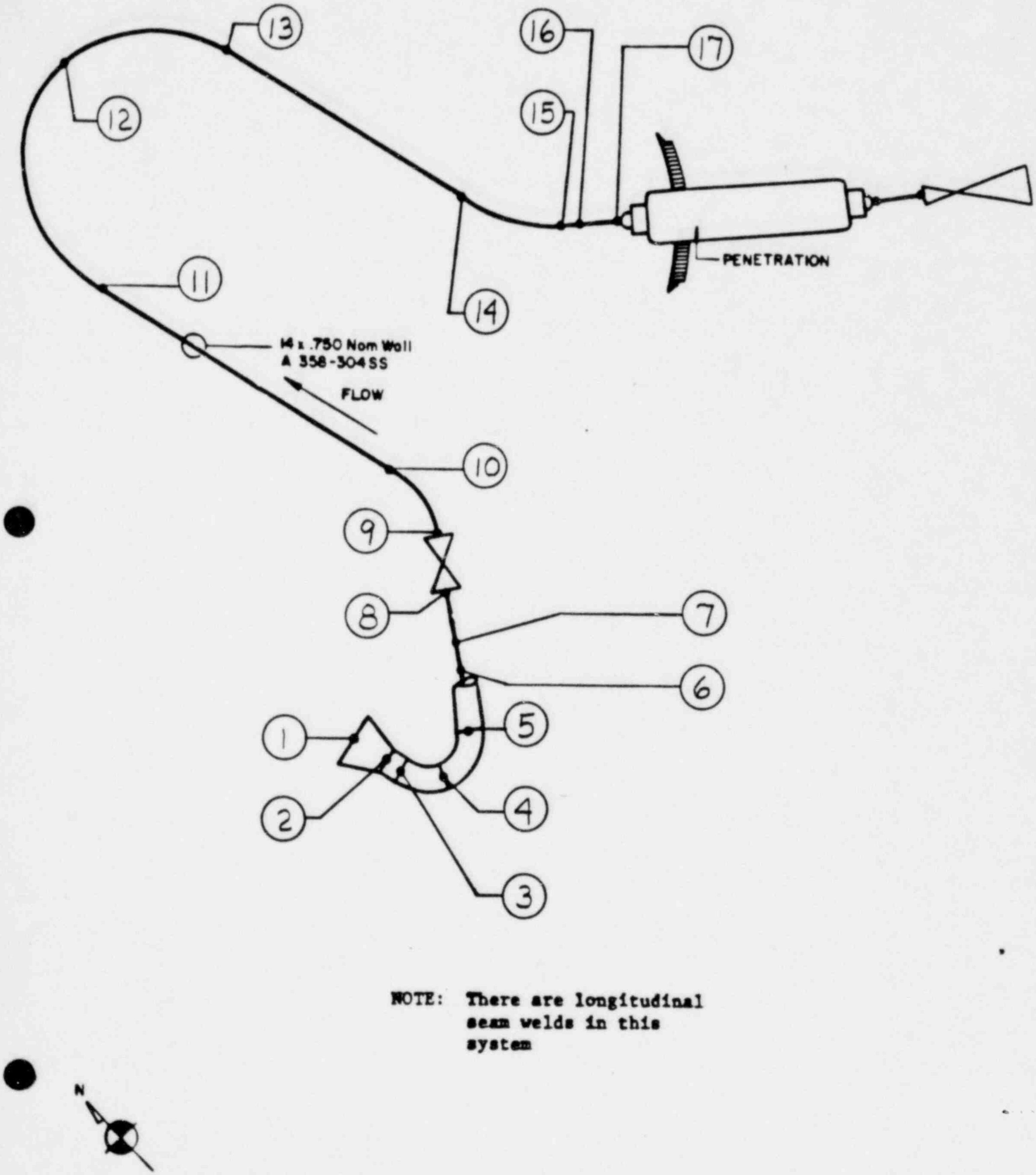
Appendix A

Isometric Drawings

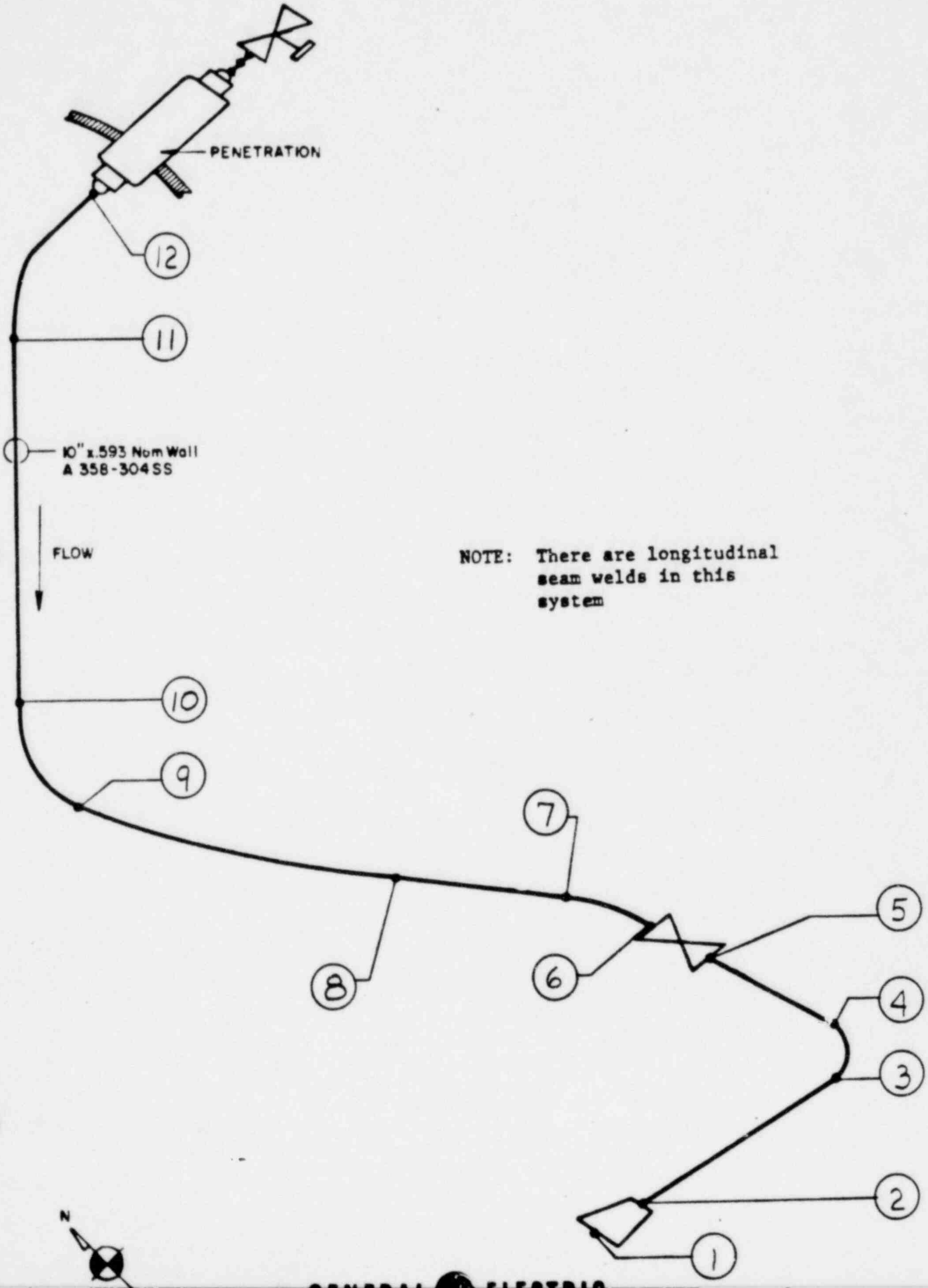
Postulated break point locations are numbered on the isometric drawings listed below.

List of Drawings

System	Drawing Number
Isolation Condenser A	BMR072-IC15
Isolation Condenser B	BMR072-IC16
Core Spray A	BMR072-IC11
Core Spray B	BMR072-IC12
Main Steam A	BMR072-IC10
Main Steam B	BMR072-IC9
Main Steam C	BMR072-IC8
Main Steam D	BMR072-IC7
Cleanup Water A	BMR072-IC17
Cleanup Water B	BMR072-IC19
Shutdown Piping A	BMR072-IC13
Feedwater A	BMR072-IC6
Feedwater B	BMR072-IC5
LPCI A	BMR072-IC1
LPCI B	BMR072-IC3



NOTE: There are longitudinal seam welds in this system

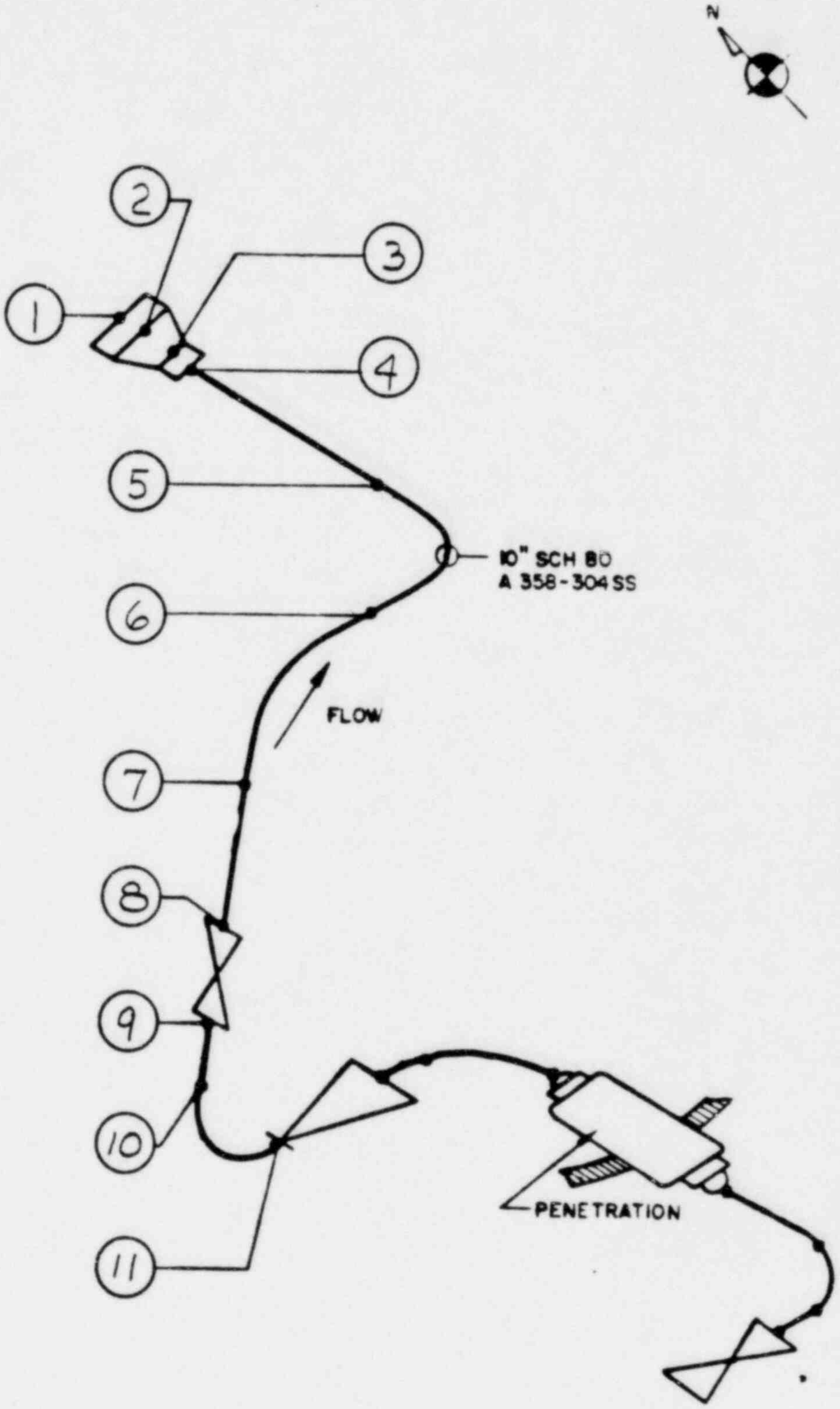


NOTE: There are longitudinal seam welds in this system

CORE SPRAY A

BMR072-IC11

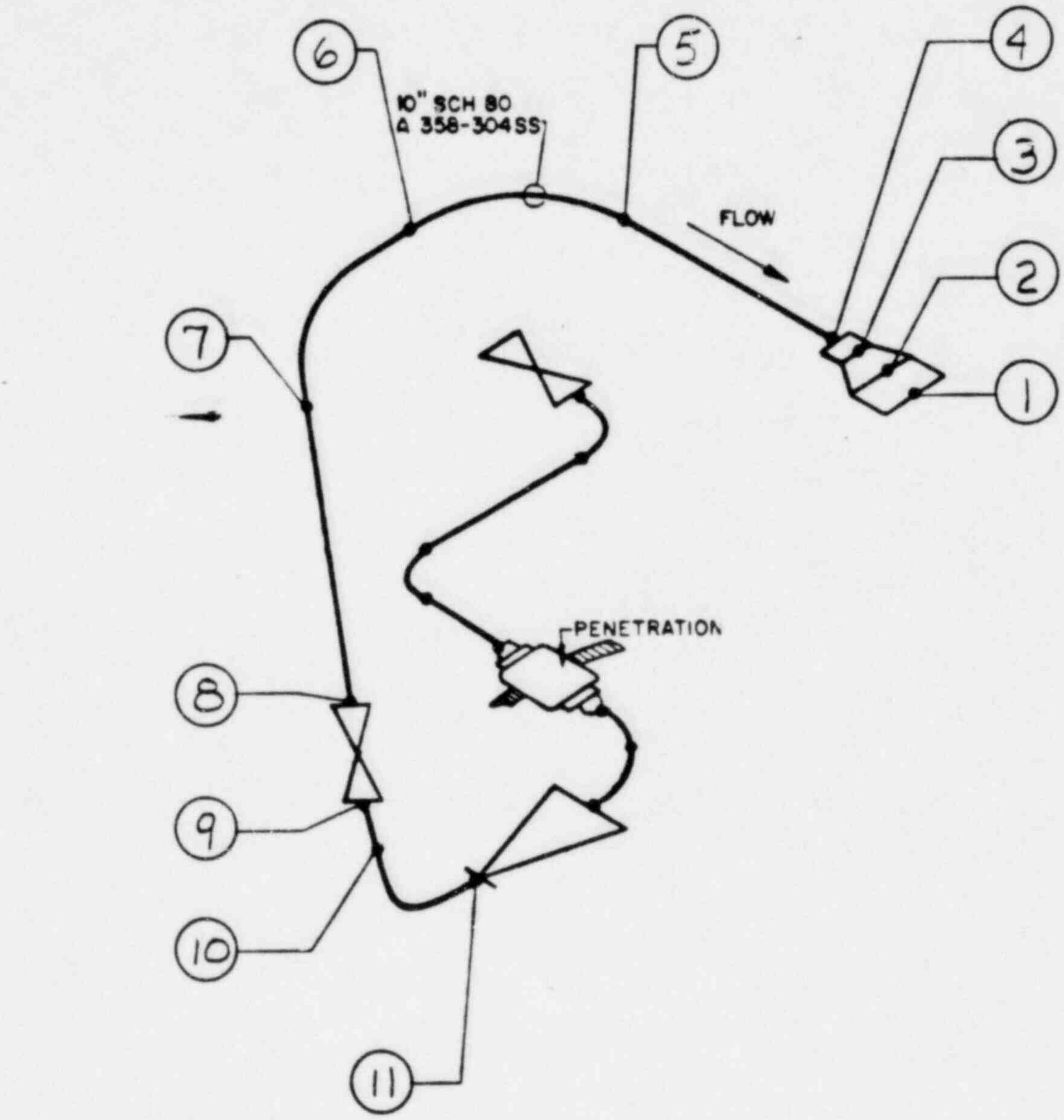
REV. 1 – 6/1/77



CORE SPRAY B

BMR072-IC12

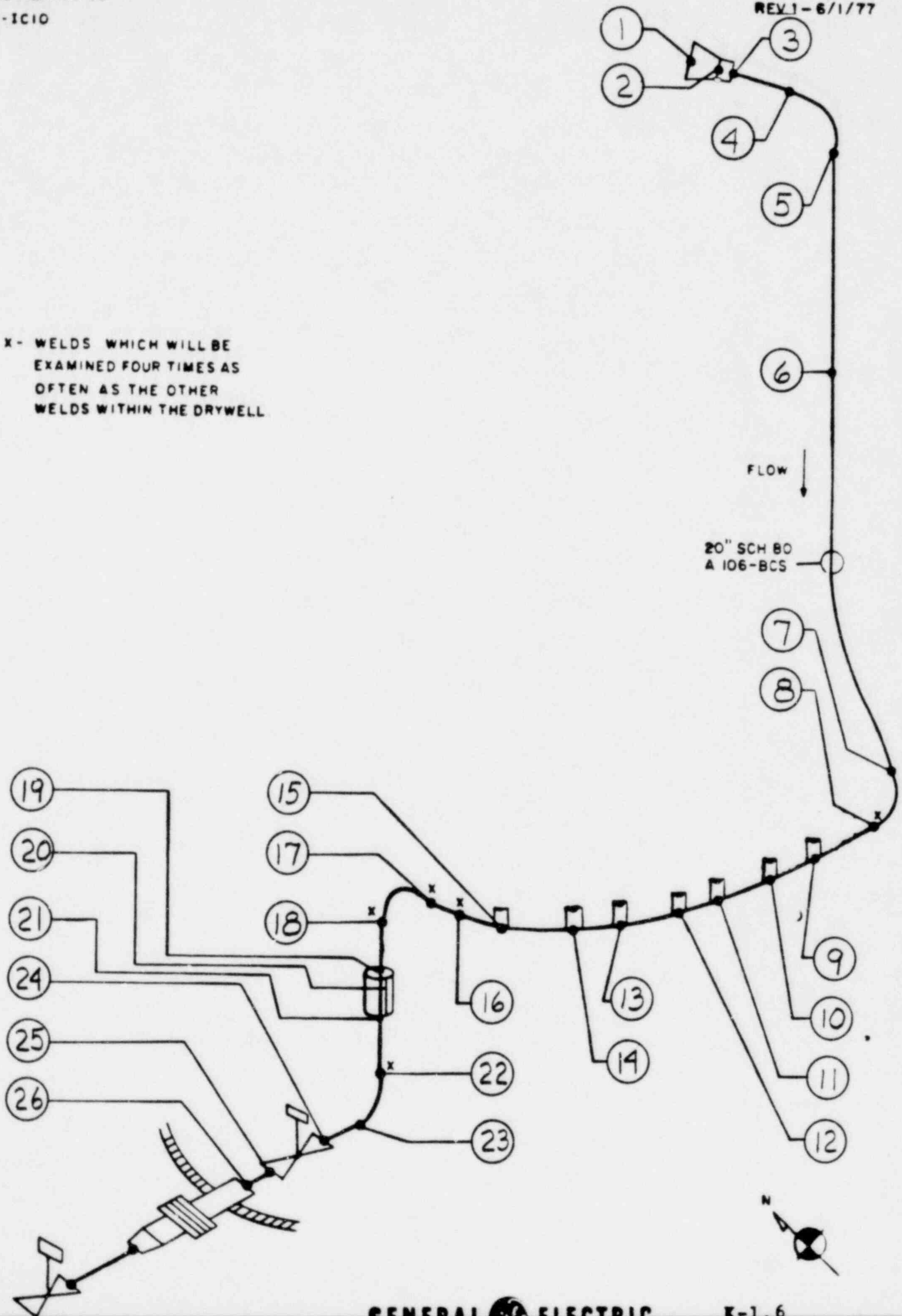
REV. 1 – 6/1/77



MAIN STEAM A

BMR072-IC10

REV 1 - 6/1/77



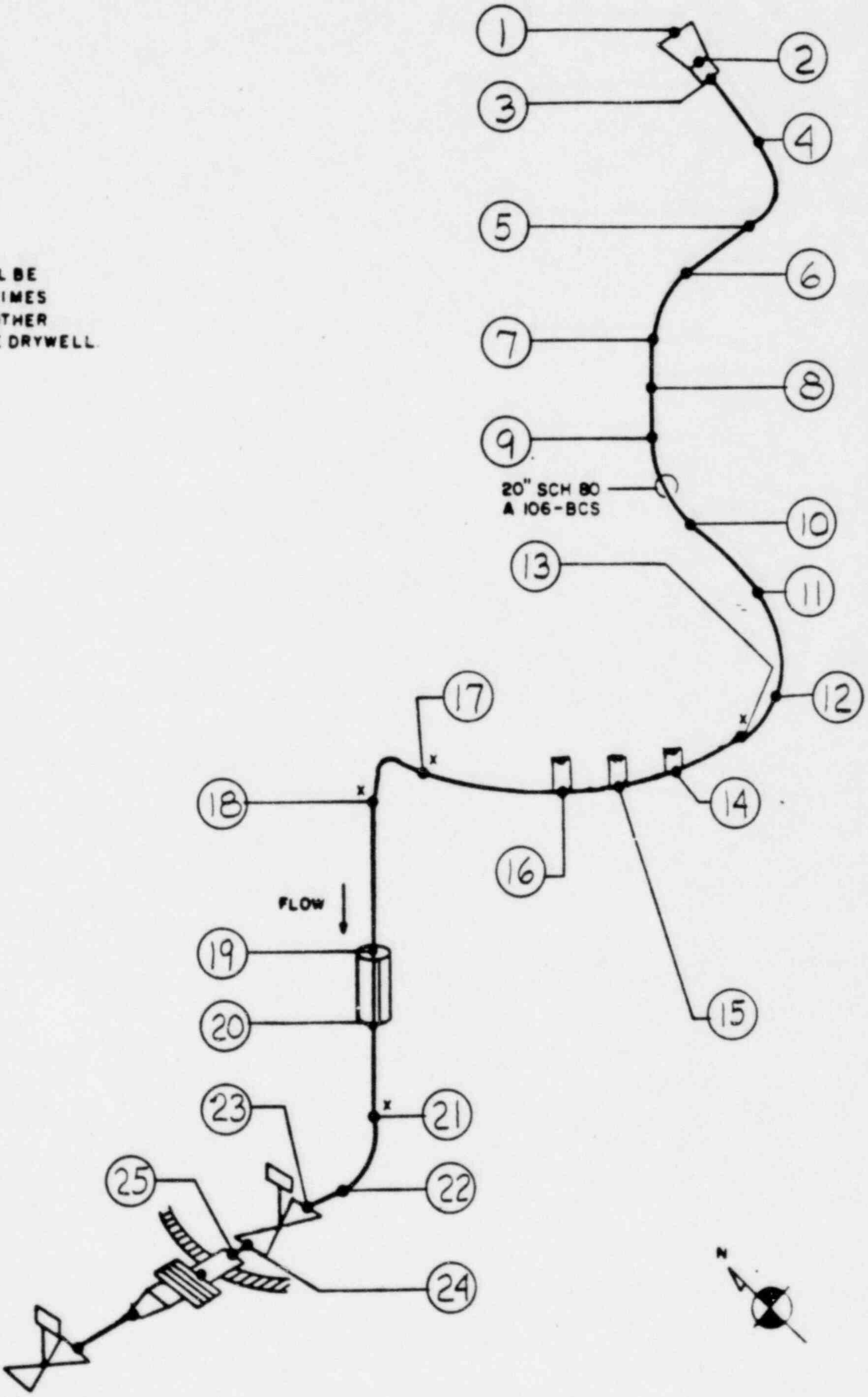
X- WELDS WHICH WILL BE EXAMINED FOUR TIMES AS OFTEN AS THE OTHER WELDS WITHIN THE DRYWELL

MAIN STEAM B

BMR072-IC9

REV. 1 – 6/1/77

X - WELDS WHICH WILL BE
EXAMINED FOUR TIMES
AS OFTEN AS THE OTHER
WELDS WITHIN THE DRYWELL.

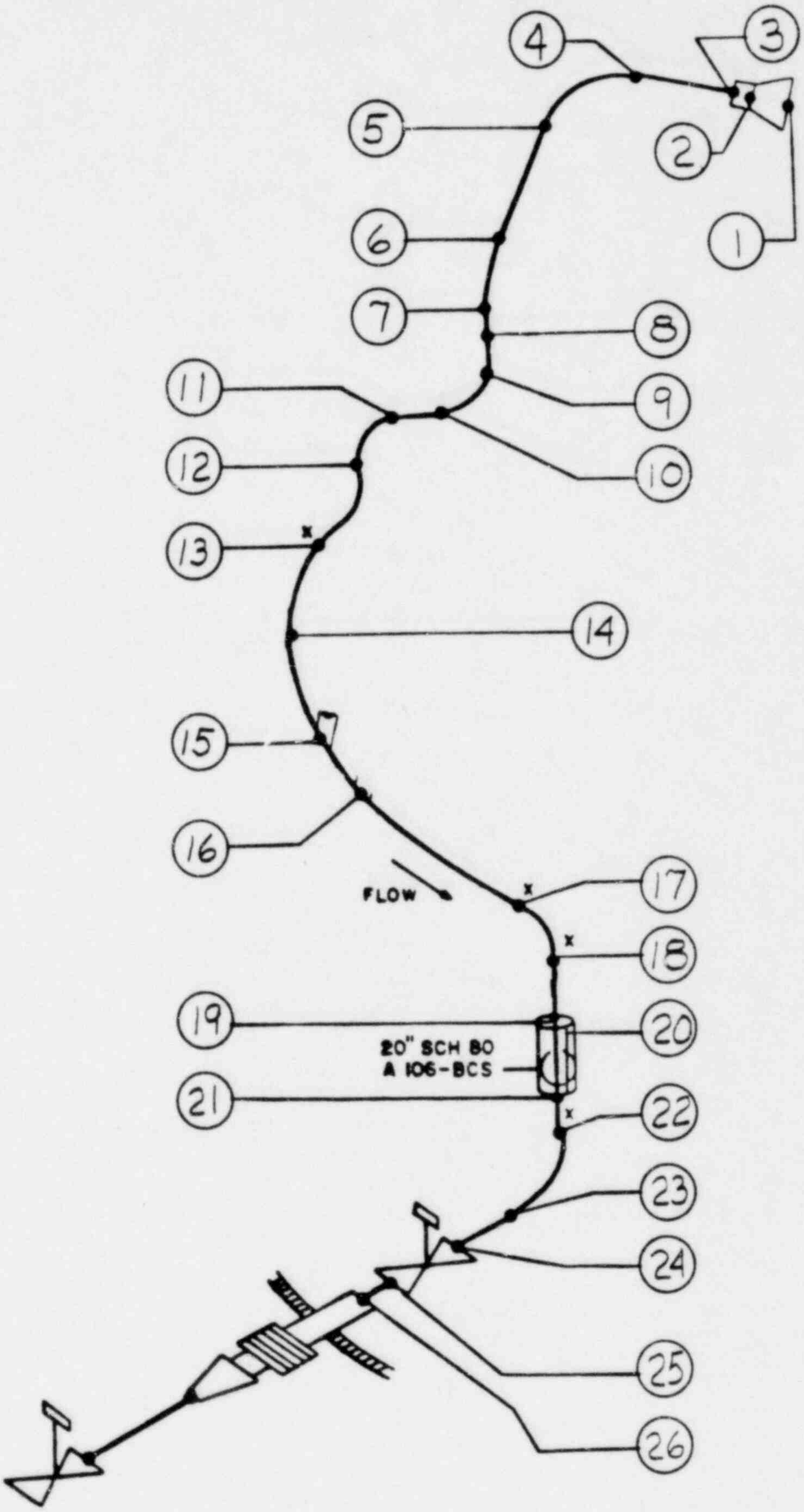


MAIN STEAM C

BMR072-IC8

REV 1-6/1/77

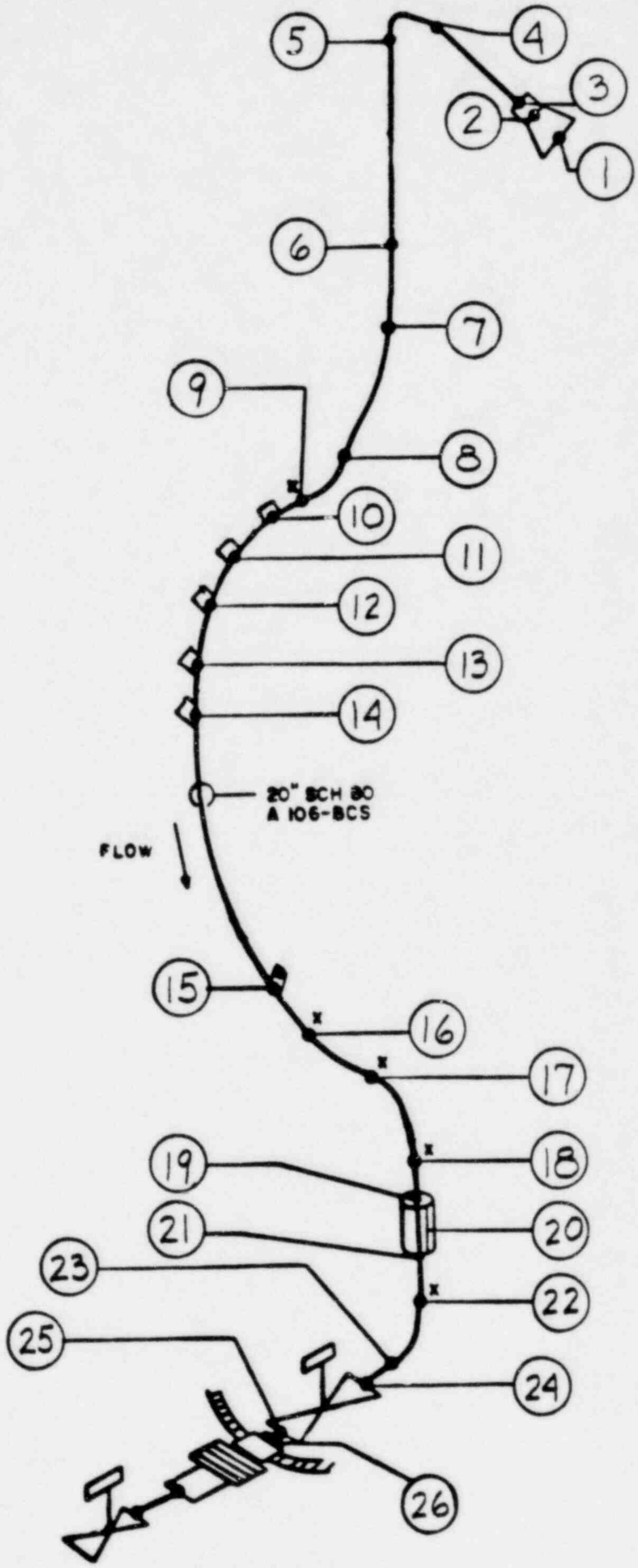
X- WELDS WHICH WILL BE EXAMINED FOUR TIMES AS OFTEN AS THE OTHER WELDS WITHIN THE DRYWELL.



MAIN STEAM D
BMRO72-IC7

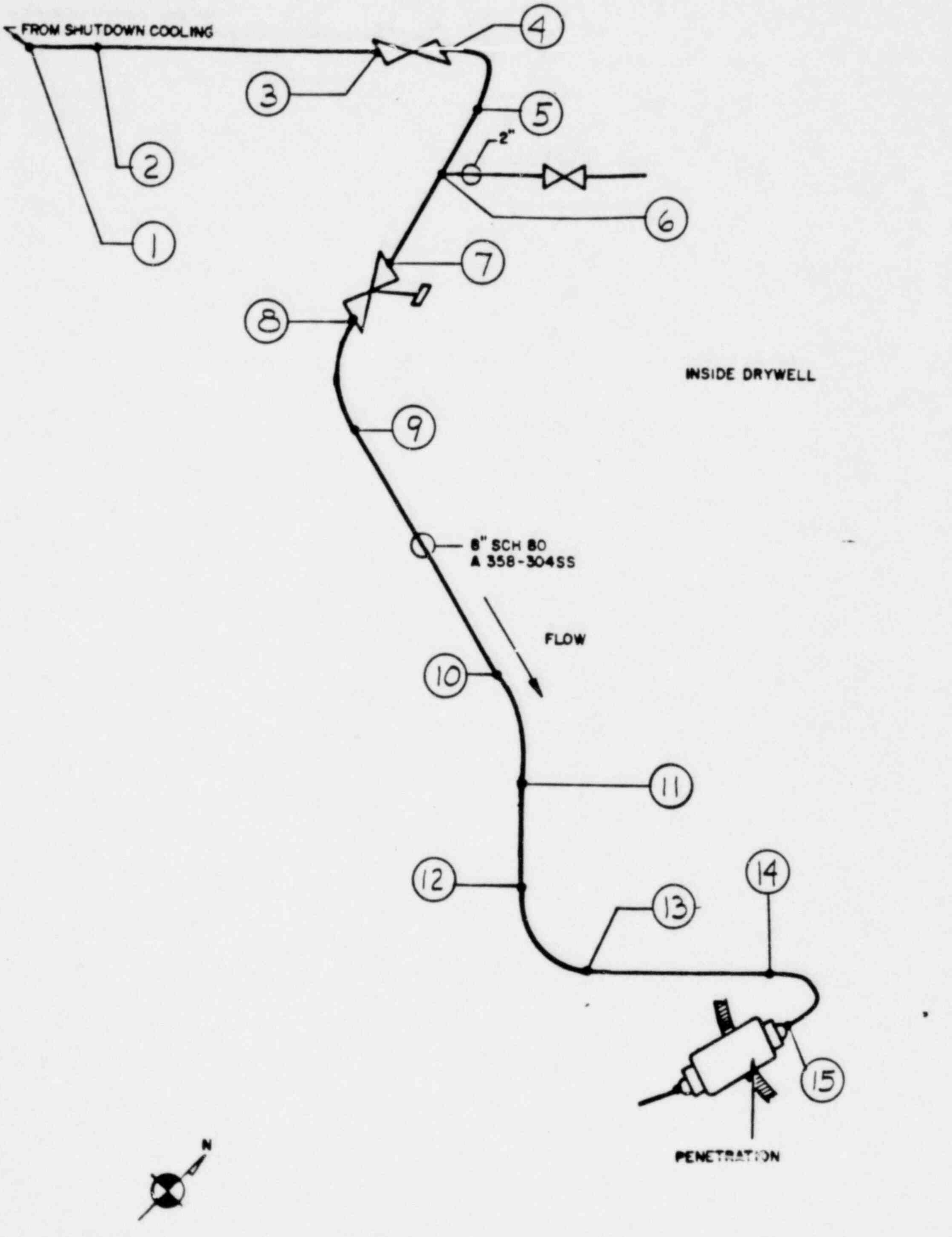
REV 1-6/1/77

X- WELDS WHICH WILL BE
EXAMINED FOUR TIMES
AS OFTEN AS THE OTHER
WELDS WITHIN THE DRYWELL



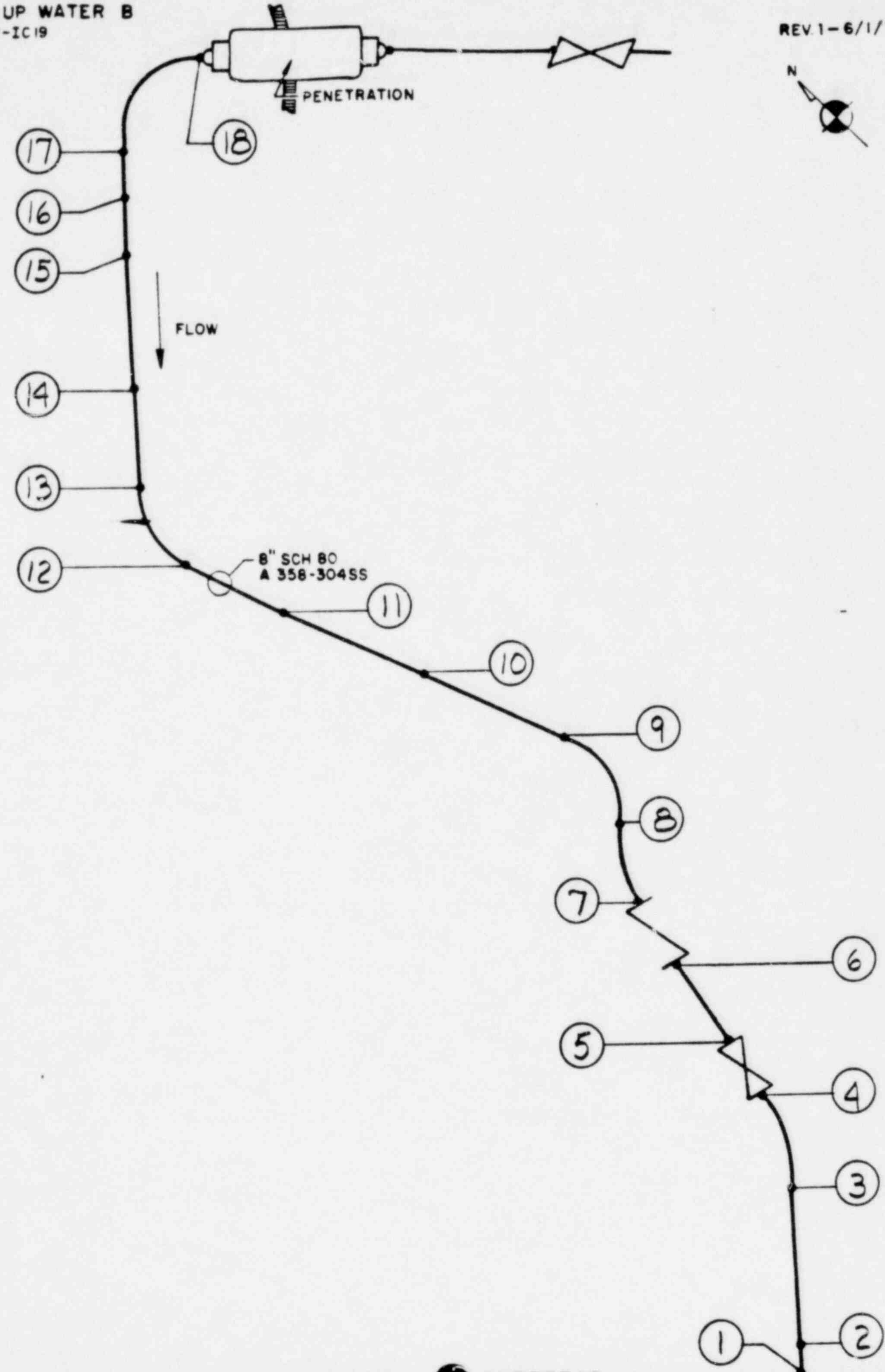
CLEAN UP WATER A
BMR072-IC17

REV. 1 – 6/1/77



CLEAN UP WATER B
BMRO72-IC19

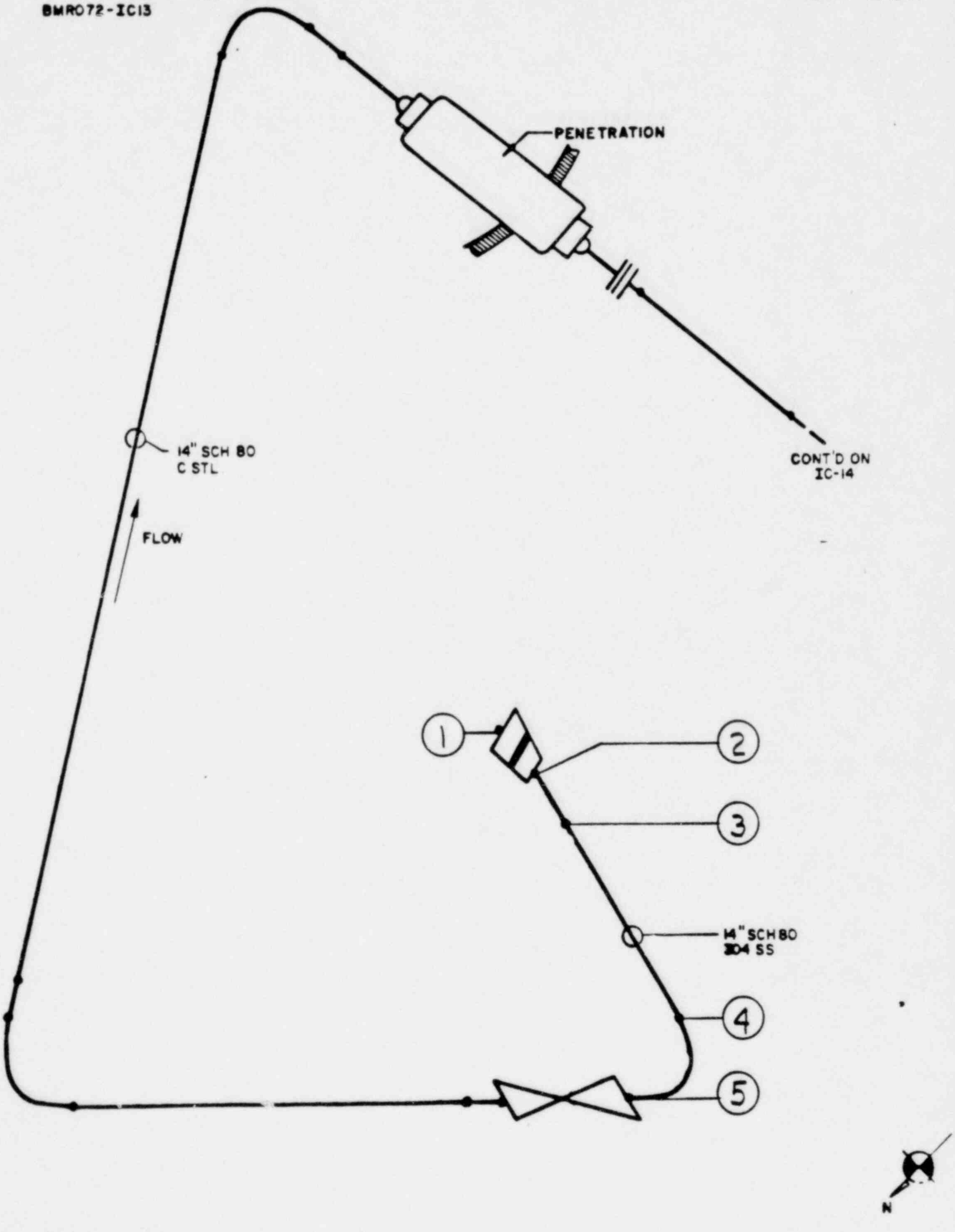
REV 1-6/1/77



SHUT DOWN PIPING A

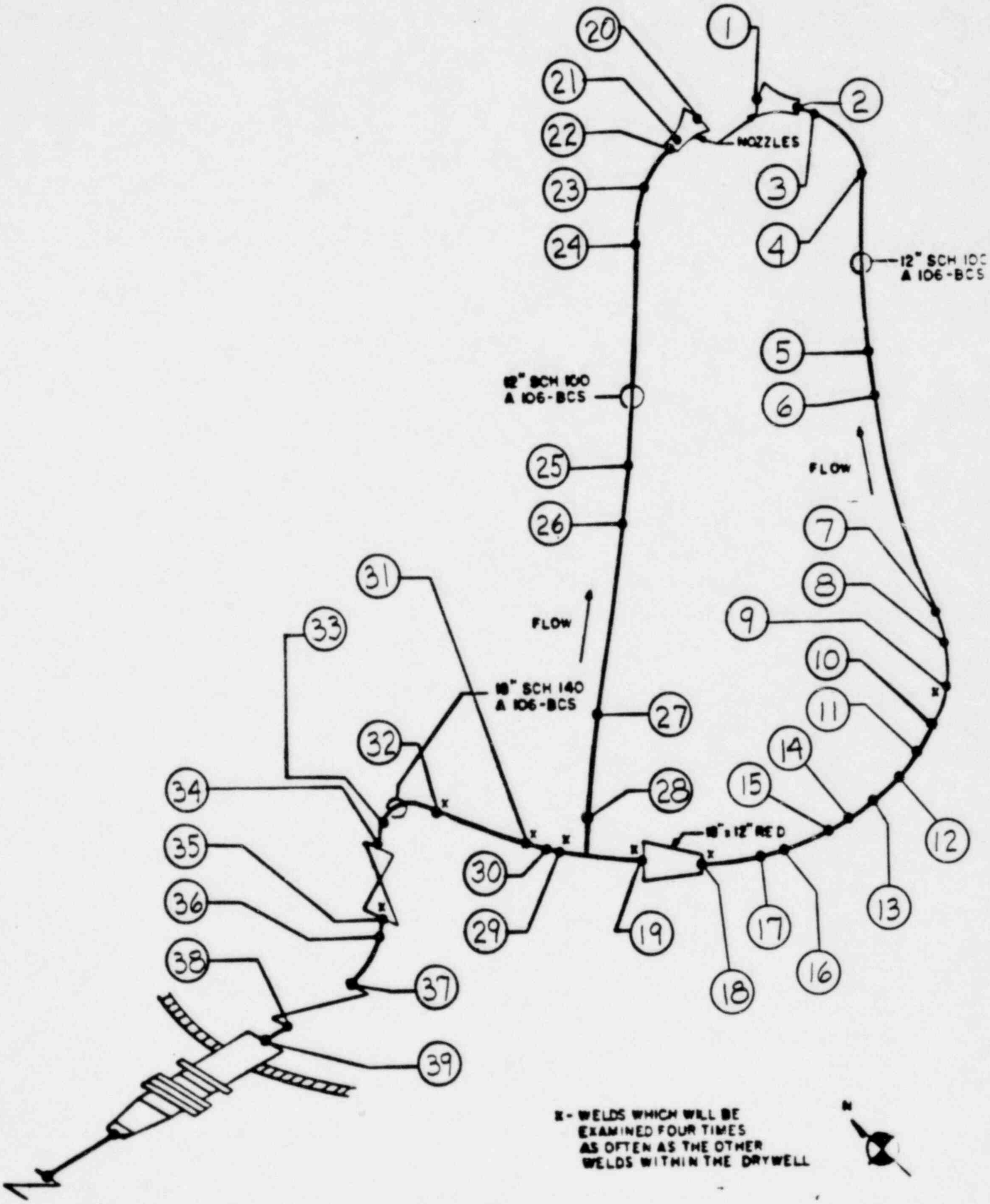
BMR072-IC13

REV 1-6/1/77



FEEDWATER A
BMR072-1C6

REV.1-6/1/77

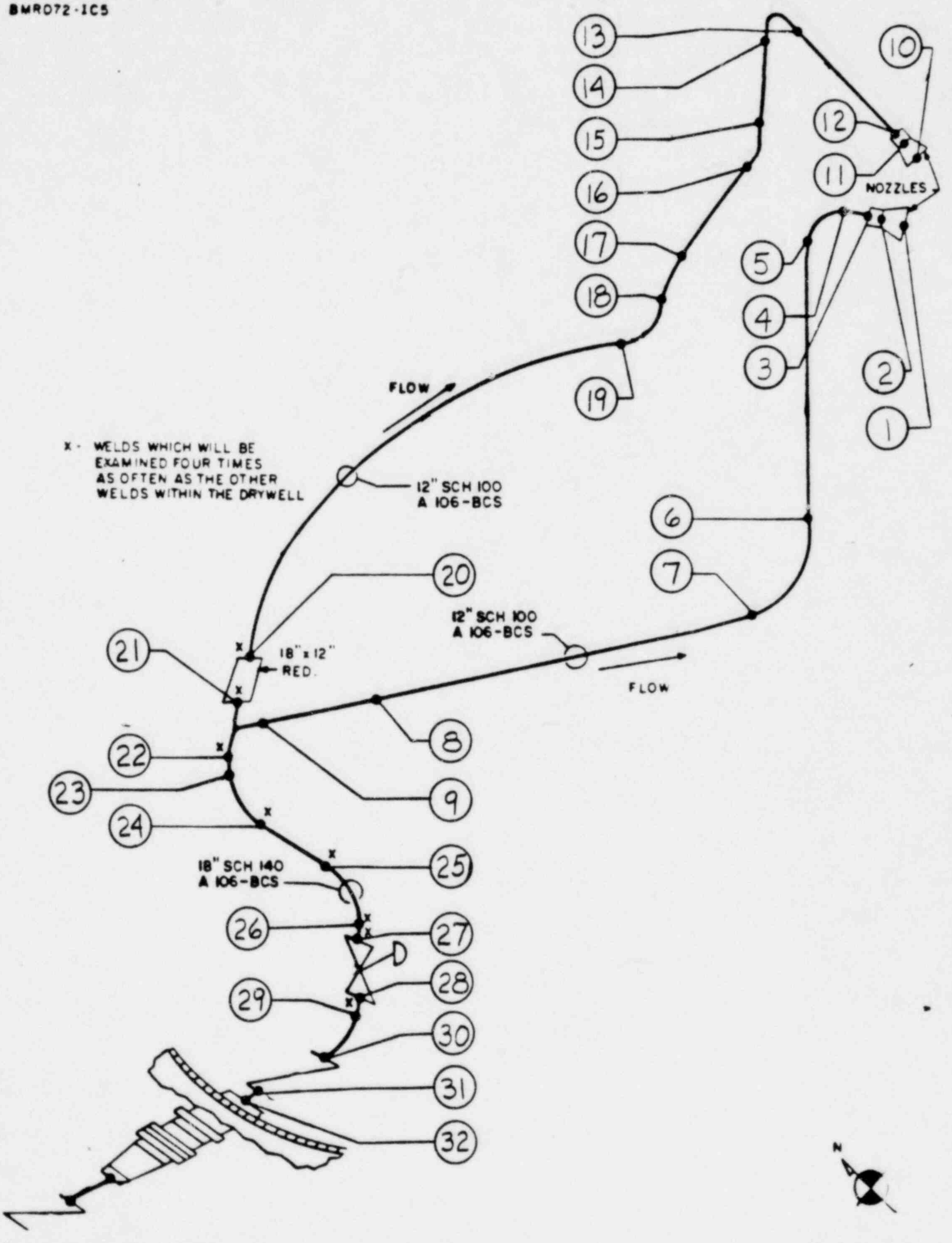


x - WELDS WHICH WILL BE EXAMINED FOUR TIMES AS OFTEN AS THE OTHER WELDS WITHIN THE DRYWELL

FEEDWATER B

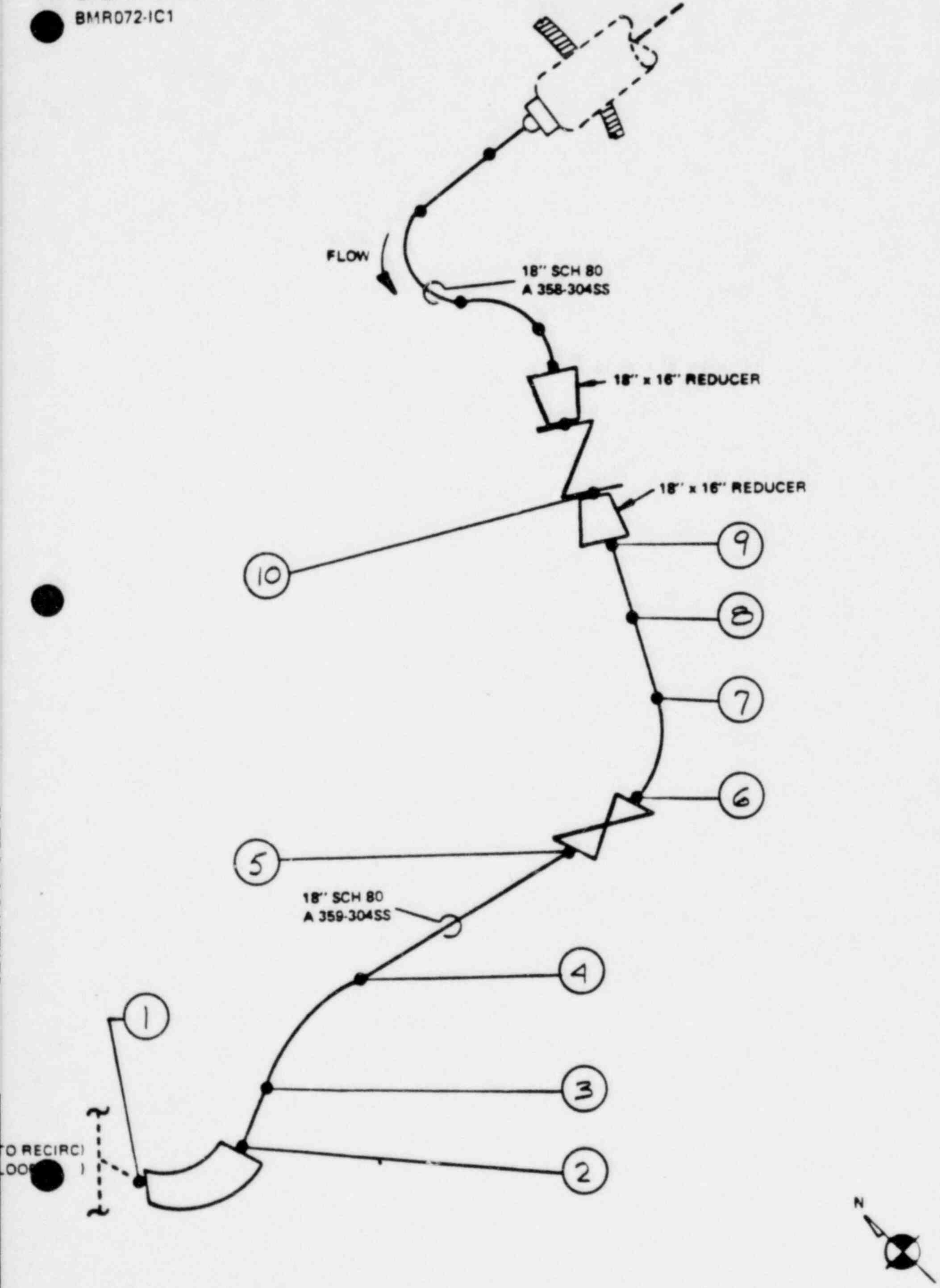
BMR072-1C5

REV.1-6/1/77



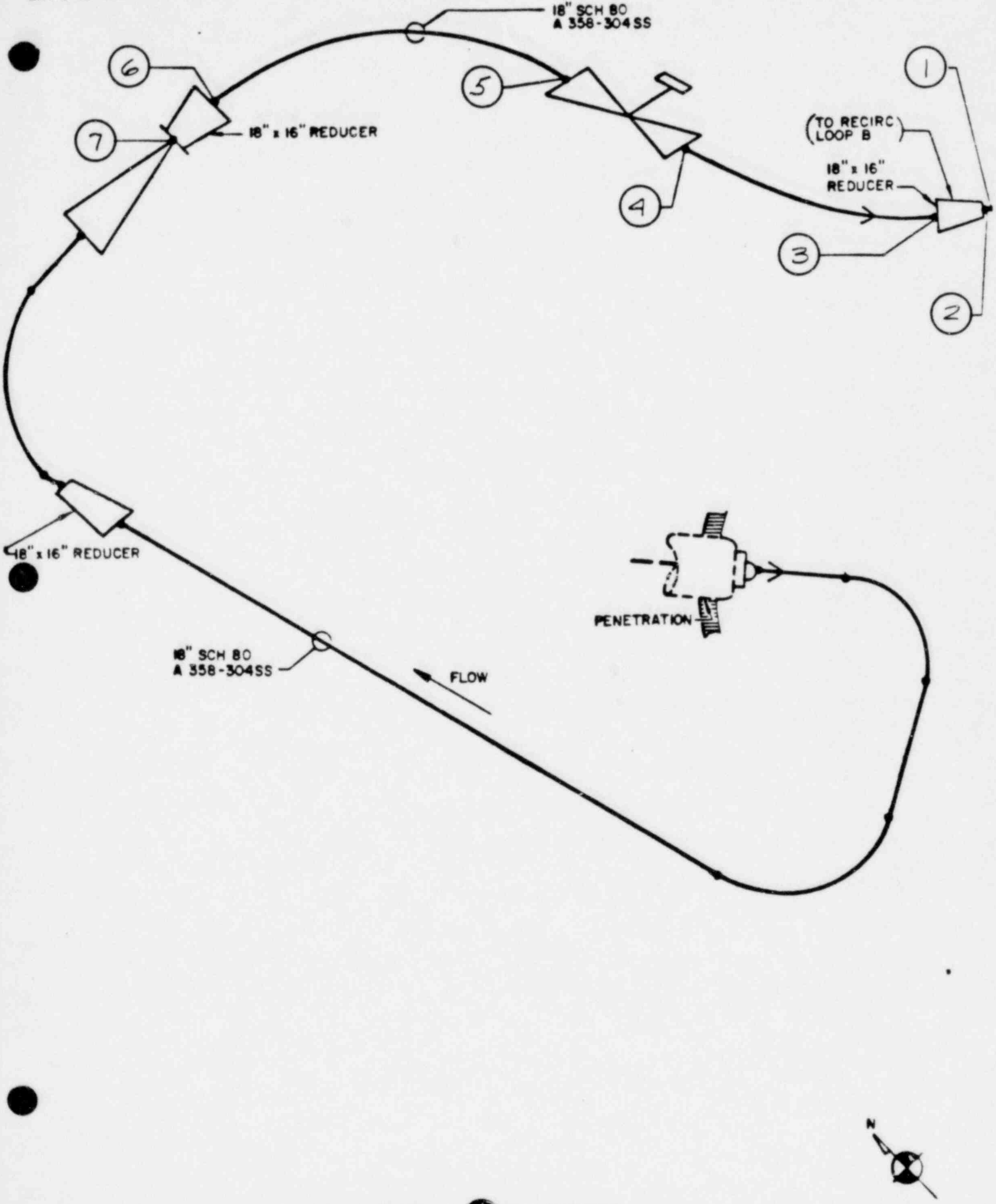
Rev. 2 3/12/79

LPCI SYSTEM (A-1)
BMR072-IC1



LPCI SYSTEM B-1
BMR072-IC3

REV. 1 – 6/1/77



APPENDIX B

INTERACTION EVALUATION MATRICES

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	ISOLATION CONDENSER
LINE	A (SUPPLY)
DRAWING	BMR072-IC15
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	—	—	—	—	—	—	—
(10" Return)	B	N	N	N	N	N	N	N
CORE SPRAY	A							
	B							
MAIN STEAM	A						A	A
	B						N	N
	C							
	D							
REACTOR CLEANUP (8" Supply)	A							
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B							
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL								
REACTOR VESSEL								
DRYWELL LINER								

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	Isolation Condenser
LINE	A
DRAWING	BMR072-IC15
BREAK LOCATION	

TARGET		8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	—	—	—	—	—	—	—
(10" Return)	B	N	N	N	N	N	N	N
CORE SPRAY	A							
	B	↓	↓	↓	↓			
MAIN STEAM	A	A	A	A	A			
	B	N	N	N	N			
	C							
	D							
REACTOR CLEANUP (8" Supply)	A							
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B							
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING					↓			
REACTOR VENT					D			
STANDBY LIQUID CONTROL					N	↓		
BIOLOGICAL SHIELD WALL						A	↓	
REACTOR VESSEL		↓	↓	↓	↓	N	A	
DRYWELL LINER		A	A	A	A	↓	N	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	ISOLATION CONDENSER
LINE	A
DRAWING	BMZ072-IC15
BREAK LOCATION	

TARGET		15	16	17
ISOLATION CONDENSER (14" Supply)	A	—	—	—
(10" Return)	B	N	N	N
CORE SPRAY	A	↓	↓	↓
	B	↓	↓	↓
MAIN STEAM	A	↓	↓	↓
	B	↓	↓	↓
	C	↓	↓	↓
	D	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓
(8" Return)	B	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓
(12")	A	↓	↓	↓
(18")	B	↓	↓	↓
(12")	B	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓
	B	↓	↓	↓
	C	↓	↓	↓
	D	↓	↓	↓
	E	↓	↓	↓
	F	↓	↓	↓
	G	↓	↓	↓
	H	↓	↓	↓
	J	↓	↓	↓
	K	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓
	B	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓
	B	↓	↓	↓
	C	↓	↓	↓
	D	↓	↓	↓
	E	↓	↓	↓
	F	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓
	Northwest Bank	↓	↓	↓
	Southeast Bank	↓	↓	↓
	Southwest Bank	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓
REACTOR VENT		↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓
REACTOR VESSEL		A	A	A
DRYWELL LINER		N	N	N

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	ISOLATION CONDENSER
LINE	B (RETURN)
DRAWING	BMR072-IC16
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	—	—	—	—	—	—	—
CORE SPRAY	A	N	N	N	N	N	N	N
	B							
MAIN STEAM	A							
	B							
	C							
	D							
REACTOR CLEANUP (8" Supply)	A							
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B							
→ (12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL								
REACTOR VESSEL								↓
DRYWELL LINER		↓	↓	↓	↓	↓	↓	D

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	ISOLATION CONDENSER
LINE	B
DRAWING	BMRO72-IC16
BREAK LOCATION	

TARGET		8	9	10	11	12
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N
(10" Return)	B	—	—	—	—	—
CORE SPRAY	A	N	N	N	N	N
	B					
MAIN STEAM	A					
	B					
	C					
	D					
REACTOR CLEANUP (8" Supply)	A					
(8" Return)	B					
SHUTDOWN COOLING	A					
FEEDWATER (18")	A					
(12")	A					
(18")	B					
(12")	B					
REACTOR RECIRCULATION (12" Risers)	A					
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	J					
	K					
PRIMARY CONTAINMENT COOLING (LPCI)	A					
	B					
MAIN STEAM RELIEF VALVE DISCHARGE	A					
	B					
	C					
	D					
	E					
	F					
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank					
	Northwest Bank					
	Southeast Bank					
	Southwest Bank					
REACTOR HEAD COOLING						
REACTOR VENT			↓	↓	↓	
STANDBY LIQUID CONTROL			D	D	D	↓
BIOLOGICAL SHIELD WALL			A	A	A	A
REACTOR VESSEL		↓	N	N	N	N
DRYWELL LINER		D	D	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CORE SPRAY
LINE	A
DRAWING	BMR072- IC11
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	—	—	—	—	—	—	—
	B	N	N	N	N	N	N	N
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓	↓	↓	↓
(12")	B	↓	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	↓	↓	↓	↓
REACTOR VESSEL		↓	↓	↓	↓	↓	↓	↓
DRYWELL LINER		↓	↓	↓	↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CORE SPRAY
LINE	A
DRAWING	BHR072-IC11
BREAK LOCATION	

TARGET		8	9	10	11
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N
(10" Return)	B	↓	↓	↓	↓
CORE SPRAY	A	—	—	—	—
	B	N	N	N	N
MAIN STEAM	A	↓	↓	↓	↓
	B	A	A	A	A
	C	N	N	N	N
	D	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓
(12")	B	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
	G	↓	↓	↓	↓
	H	↓	↓	↓	↓
	J	↓	↓	↓	↓
	K	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	↓
REACTOR VESSEL		↓	↓	↓	↓
DRYWELL LINER		↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CORE SPRAY
LINE	B
DRAWING	BMR072-IC12

BREAK LOCATION

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply) (10" Return)	A B	N ↓	N ↓	N ↓	N ↓	N ↓	N ↓	N ↓
CORE SPRAY	A B	↓ —	↓ —	↓ —	↓ —	↓ —	↓ —	↓ —
MAIN STEAM	A B C D	N ↓	N ↓	N ↓	N ↓	N ↓	N ↓	N ↓
REACTOR CLEANUP (8" Supply) (8" Return)	A B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓	↓	↓	↓
FEEDWATER (18") (12") (18") (12")	A A B B	↓	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A B C D E F G H J K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A B C D E F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank Northwest Bank Southeast Bank Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	↓	↓	↓	↓
REACTOR VESSEL		↓	↓	↓	↓	↓	↓	↓
DRYWELL LINER		↓	↓	↓	↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CORE SPRAY
LINE	B
DRAWING	BMR072-IC12
BREAK LOCATION	

TARGET		8	9	10	11
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N
(10" Return)	B	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓
	B	—	—	—	—
MAIN STEAM	A	N	N	N	N
	B	↓	↓	↓	↓
	C	A	A	A	A
	D	N	N	N	N
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓
(12")	B	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
	G	↓	↓	↓	↓
	H	↓	↓	↓	↓
	J	↓	↓	↓	↓
	K	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	↓
REACTOR VESSEL		↓	↓	↓	↓
DRYWELL LINER		↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	A
DRAWING	BMR072-IC10
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	—	—	—	—	—	—	—
	B	N	N	N	N	N	N	N
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	D
(18")	B	↓	↓	↓	↓	↓	↓	N
→ (12")	B	↓	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	D	D	D
	B	↓	↓	↓	↓	N	N	N
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓	↓	↓	D
	B	↓	↓	↓	↓	↓	↓	N
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		D	D	D	D	↓	↓	↓
STANDBY LIQUID CONTROL		N	N	N	N	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	↓	A	A	A
REACTOR VESSEL		↓	↓	↓	↓	N	N	N
DRYWELL LINER		A	A	A	A	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	A
DRAWING	BMR072-IC10

TARGET		BREAK LOCATION 8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	—	—	—	—	—	—	—
	B	N	N	N	N	N	N	N
	C							
	D							
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓		
(8" Return)	B	D	D	D	D	D		
SHUTDOWN COOLING	A	N	N	N	N	N		
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	D	D	D	D	D	D	D
(18")	B	N	N	N	N	N	N	N
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C	↓	↓	↓	↓	↓		
	D	D	D	D	D	D		
	E	N	N	N	N	N		
	F							
	G							
	H							
	J							
	K	↓	↓	↓	↓	↓		
PRIMARY CONTAINMENT COOLING (LPCI)	A	D	D	D	D	D		
	B	N	N	N	N	N	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	D	D	D	D	D	D	D
	B	N	N	N	N	N	N	N
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL								
REACTOR VESSEL								
DRYWELL LINER		↓	↓	↓	↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	A
DRAWING	BMR072-IC10
BREAK LOCATION	

TARGET		15	16	17	18	19	20	21
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	—	—	—	—	—	—	—
	B	N	N	N	N	N	N	N
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	D	D	D	D
FEEDWATER (18")	A	D	D	D	N	N	N	N
(12")	A	D	D	D	D	D	D	D
(18")	B	N	N	N	N	N	N	N
(12")	B	↓	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	D	D	D	D	D	D	D
	B	N	N	N	D	D	D	D
	C	↓	↓	↓	N	N	N	N
	D	↓	↓	↓	D	D	D	D
	E	↓	↓	↓	N	N	N	N
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	↓	↓	↓	↓
REACTOR VESSEL		↓	↓	↓	↓	↓	↓	↓
DRYWELL LINER		↓	↓	↓	A	A	A	A

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	A
DRAWING	BHR072-IC10
BREAK LOCATION	

TARGET		22	23	24	25	26
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N
(10" Return)	B					
CORE SPRAY	A					
	B	↓	↓	↓	↓	↓
MAIN STEAM	A	—	—	—	—	—
	B	N	A	A	A	A
	C		N	N	N	N
	D					
REACTOR CLEANUP (8" Supply)	A					
(8" Return)	B	↓				
SHUTDOWN COOLING	A	D				
FEEDWATER (18")	A	N				
(12")	A	D				
(18")	B	N				
(12")	B					
REACTOR RECIRCULATION (12" Risers)	A					
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	J					
	K					
PRIMARY CONTAINMENT COOLING (LPCI)	A					
	B	↓				
MAIN STEAM RELIEF VALVE DISCHARGE	A	D				
	B	D				
	C	N				
	D	D				
	E	N				
	F					
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank					
	Northwest Bank					
	Southeast Bank					
	Southwest Bank					
REACTOR HEAD COOLING						
REACTOR VENT						
STANDBY LIQUID CONTROL						
BIOLOGICAL SHIELD WALL						
REACTOR VESSEL		↓				
DRYWELL LINER		A	↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	B
DRAWING	BMR072-IC9
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B	—	—	—	—	—	—	—
	C	N	N	N	N	N	N	N
	D							
REACTOR CLEANUP (8" Supply)	A							D
(8" Return)	B							N
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							D
(12")	A							N
(18")	B							
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B					D	D	
	C					N	N	
	D							
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL								A
REACTOR VESSEL								N
DRYWELL LINER		A	A	A	A			

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	B
DRAWING	BMR072-IC9

TARGET			BREAK LOCATION 8	9	10	11	12	13	14
ISOLATION CONDENSER	(14" Supply)	A	N	N	N	N	N	N	N
	(10" Return)	B						↓	↓
CORE SPRAY		A						D	D
		B		↓	↓			N	N
MAIN STEAM		A	↓	A	A	↓	↓	A	A
		B	—	—	—	—	—	—	—
		C	N	N	N	N	N	N	N
		D	↓						
REACTOR CLEANUP	(8" Supply)	A	D						
	(8" Return)	B	N						
SHUTDOWN COOLING		A							
FEEDWATER	(18")	A	↓	↓	↓				
	(12")	A	D	D	D				
	(18")	B	N	N	N				
	(12")	B							
REACTOR RECIRCULATION (12" Risers)		A							
		B						↓	↓
		C						D	D
		D						N	N
		E							
		F							
		G							
		H							
		J							
		K						↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)		A						D	D
		B						N	N
MAIN STEAM RELIEF VALVE DISCHARGE		A						↓	↓
		B						D	D
		C				↓	↓	N	N
		D				D	D	D	D
		E				N	N	N	N
		F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank								
	Northwest Bank								
	Southeast Bank					↓	↓		
	Southwest Bank					D	D		
REACTOR HEAD COOLING						N	N		
REACTOR VENT									
STANDBY LIQUID CONTROL			↓	↓	↓				
BIOLOGICAL SHIELD WALL			A	A	A				
REACTOR VESSEL			N	N	N				
DRYWELL LINER			↓	A	A	↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	B
DRAWING	BMR072-IC9

TARGET		BREAK LOCATION 15	16	17	18	19	20	21
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A	A	A	A				
	B	—	—	—	—	—	—	—
	C	N	N	N	N	N	N	N
	D							
REACTOR CLEANUP (8" Supply)	A		D	D	D	D	D	D
(8" Return)	B		N	N	N	N	N	N
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B							
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C	D	D					
	D	N	N					
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A	D	D					
	B	N	N					
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B	D	D	D	D	D	D	D
	C	N	N	N	N	N	N	N
	D	D	D	D				
	E	N	N	N				
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL					A	A	A	
REACTOR VESSEL					N	N	N	
DRYWELL LINER								A

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	Main Steam
LINE	B
DRAWING	BMR072-IC9
BREAK LOCATION	

TARGET		22	23	24	25
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N
(10" Return)	B	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓
	B	—	—	—	—
	C	N	N	N	N
	D	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓
(12")	B	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
	G	↓	↓	↓	↓
	H	↓	↓	↓	↓
	J	↓	↓	↓	↓
	K	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		A	A	A	A
REACTOR VESSEL		N	N	N	N
DRYWELL LINER		↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	C
DRAWING	BMR072-IC8
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B	↓	↓	↓	↓	↓	↓	↓
	C	—	—	—	—	—	—	—
	D	N	N	N	N	N	N	N
REACTOR CLEANUP (8" Supply)	A							
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B					↓	↓	↓
(12")	B					D	D	D
REACTOR RECIRCULATION (12" Risers)	A					N	N	N
	B							
	C							
	D							
	E							
	F							
	G							
	H					↓	↓	
	J					D	D	
	K					N	N	
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								↓
BIOLOGICAL SHIELD WALL								A
REACTOR VESSEL		↓	↓	↓	↓			N
DRYWELL LINER		A	A	A	A	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

SOURCE
SYSTEM MAIN STEAM
LINE C
DRAWING BHR07Z-IC8
BREAK LOCATION

TARGET		8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B						D	D
MAIN STEAM	A						N	N
	B							
	C	—	—	—	—	—	—	—
	D	N	A	A	N	A	A	A
REACTOR CLEANUP (8" Supply)	A		N	N		N	N	N
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B							
(12")	B	D						
REACTOR RECIRCULATION (12" Risers)	A	N						
	B							
	C							
	D							
	E							
	F							
	G							
	H						D	D
	J						N	N
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B		D	D			D	D
MAIN STEAM RELIEF VALVE DISCHARGE	A		N	N			N	N
	B							
	C						D	D
	D						N	N
	E				D	D	D	D
	F				N	N	N	N
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank				D	D		
	Southeast Bank				N	N		
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL		A	A	A				
REACTOR VESSEL		N	N	N				
DRYWELL LINER			A	A	A	A		

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

SOURCE
SYSTEM MAIN STEAM
LINE C
DRAWING BMR072-IC8
BREAK LOCATION

TARGET		15	16	17	18	19	20	21
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	—	—	—	—	—	—	—
	D	A	A	A	N	N	N	N
REACTOR CLEANUP (8" Supply)	A	N	N	N	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	D	↓	↓	↓	↓	↓
FEEDWATER (18")	A	↓	N	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	↓	↓	↓	D	D	D	D
(12")	B	↓	↓	↓	N	N	N	N
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	D	D	D	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	N	N	N	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	D	D	D	D	D	D	D
	D	N	N	N	N	N	N	N
	E	D	D	D	D	D	D	D
	F	N	N	N	N	N	N	N
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	A	A	A	A
REACTOR VESSEL		↓	↓	↓	N	N	N	N
DRYWELL LINER		↓	↓	↓	↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	C
DRAWING	BMR072-ICB
BREAK LOCATION	

TARGET			22	23	24	25	26
ISOLATION CONDENSER	(14" Supply)	A	N	N	N	N	N
	(10" Return)	B					
CORE SPRAY		A					
		B					
MAIN STEAM		A					
		B					
		C	—	—	—	—	—
		D	N	N	N	N	N
REACTOR CLEANUP	(8" Supply)	A					
	(8" Return)	B					
SHUTDOWN COOLING		A					
FEEDWATER	(18")	A					
	(12")	A					
	(18")	B					
	(12")	B	D				
REACTOR RECIRCULATION (12" Risers)		A	N				
		B					
		C					
		D					
		E					
		F					
		G					
		H					
		J					
		K					
PRIMARY CONTAINMENT COOLING (LPCI)		A					
		B					
MAIN STEAM RELIEF VALVE DISCHARGE		A					
		B					
		C	D				
		D	N				
		E	D				
		F	N				
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank						
	Northwest Bank						
	Southeast Bank						
	Southwest Bank						
REACTOR HEAD COOLING							
REACTOR VENT				D	D	D	D
STANDBY LIQUID CONTROL				N	N	N	N
BIOLOGICAL SHIELD WALL				A	A	A	A
REACTOR VESSEL				N	N	N	N
DRYWELL LINER			A				

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	D
DRAWING	BMR072-IC7
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D	—	—	—	—	—	—	—
REACTOR CLEANUP (8" Supply)	A	N	N	N	N	N	N	N
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B							
→ (12")	B							D
REACTOR RECIRCULATION (12" Risers)	A							N
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							D
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							N
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL						A	A	A
REACTOR VESSEL						N	N	N
DRYWELL LINER		A	A	A	A			

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	D
DRAWING	BMR072-IC7
BREAK LOCATION	

TARGET		8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D	—	—	—	—	—	—	—
REACTOR CLEANUP (8" Supply)	A	N	N	N	N	N	N	N
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A							
(12")	A							
(18")	B							
(12")	B	D	D	D	D	D	D	D
REACTOR RECIRCULATION (12" Risers)	A	N	N	N	N	N	N	N
	B							
	C							
	D							
	E							
	F							
	G		D	D	D	D	D	D
	H		N	N	N	N	N	N
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F	D	D	D	D	D	D	D
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	N	N	N	N	N	N	N
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL		A						
REACTOR VESSEL		N						
DRYWELL LINER								

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	D
DRAWING	BMR072-IC7
BREAK LOCATION	

TARGET		15	16	17	18	19	20	21
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	—	—	—	—	—	—	—
REACTOR CLEANUP (8" Supply)	A	N	N	N	N	N	N	N
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	D	D	D	↓	↓	↓	↓
(12")	B	N	N	N	D	D	D	D
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	N	N	N	N
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	D	D	↓	↓	↓	↓	↓
	H	N	N	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	D	D	D	D
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	N	N	N	N
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	D	D	D	D
	D	↓	↓	↓	N	N	N	N
	E	↓	↓	↓	↓	↓	↓	↓
	F	D	D	D	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	N	N	N	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	A	A	A	A
REACTOR VESSEL		↓	↓	↓	N	N	N	N
DRYWELL LINER		↓	↓	↓	↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	MAIN STEAM
LINE	D
DRAWING	BMRO72-IC7
BREAK LOCATION	

TARGET		22	23	24	25	26
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N
(10" Return)	B					
CORE SPRAY	A					
	B					
MAIN STEAM	A					
	B		↓	↓	↓	↓
	C	↓	A	A	A	A
	D	—	—	—	—	—
REACTOR CLEANUP (8" Supply)	A	N	N	N	N	N
(8" Return)	B					
SHUTDOWN COOLING	A					
FEEDWATER (18")	A					
(12")	A					
(18")	B	↓				
(12")	B	D				
REACTOR RECIRCULATION (12" Risers)	A	N				
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	J					
	K					
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓				
	B	D				
MAIN STEAM RELIEF VALVE DISCHARGE	A	N				
	B	↓				
	C	D				
	D	N				
	E					
	F					
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank					
	Northwest Bank					
	Southeast Bank					
	Southwest Bank					
REACTOR HEAD COOLING						
REACTOR VENT						
STANDBY LIQUID CONTROL			↓	↓	↓	↓
BIOLOGICAL SHIELD WALL			A	A	A	A
REACTOR VESSEL		↓	N	N	N	N
DRYWELL LINER		A	↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

		SOURCE
SYSTEM		CLEAN UP WATER
LINE		A (SUPPLY)
DRAWING		BMR072-IC17
BREAK LOCATION		

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	—	—	—	—	—	—	—
(8" Return)	B	N	N	N	N	N	N	N
SHUTDOWN COOLING	A					A	A	A
FEEDWATER (18")	A					N	N	N
(12")	A					↓	↓	↓
(18")	B					A	A	A
(12")	B					N	N	N
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL								
REACTOR VESSEL								
DRYWELL LINER		↓	↓	↓	↓	↓	↓	↓

LEGEND:
- D = Damage Possible, Further Evaluation Required.
- A = Acceptable Interaction (Damage Not Possible)
- N = No Interaction

	SOURCE
SYSTEM	CLEAN UP WATER
LINE	A (SUPPLY)
DRAWING	BMR072-IC17
BREAK LOCATION	

TARGET		8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	—	—	—	—	—	—	—
(8" Return)	B	N	N	N	N	N	N	N
SHUTDOWN COOLING	A	A	A	A	↓	↓	↓	↓
FEEDWATER (18")	A	N	N	N	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	A	↓	↓	↓	↓	↓	↓
(12")	B	N	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	A	A	A	A
REACTOR VESSEL		↓	↓	↓	N	N	N	N
DRYWELL LINER		↓	↓	↓	↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CLEAN UP WATER
LINE	A (SUPPLY)
DRAWING	BMR072-IC17
BREAK LOCATION	

TARGET			15
ISOLATION CONDENSER	(14" Supply)	A	N
	(10" Return)	B	↓
CORE SPRAY		A	↓
		B	↓
MAIN STEAM		A	↓
		B	↓
		C	↓
		D	↓
REACTOR CLEANUP	(8" Supply)	A	—
	(8" Return)	B	N
SHUTDOWN COOLING		A	↓
FEEDWATER	(18")	A	↓
	(12")	A	↓
	(18")	B	↓
	(12")	B	↓
REACTOR RECIRCULATION (12" Risers)		A	↓
		B	↓
		C	↓
		D	↓
		E	↓
		F	↓
		G	↓
		H	↓
		J	↓
		K	↓
PRIMARY CONTAINMENT COOLING (LPCI)		A	↓
		B	↓
MAIN STEAM RELIEF VALVE DISCHARGE		A	↓
		B	↓
		C	↓
		D	↓
		E	↓
		F	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank		↓
	Northwest Bank		↓
	Southeast Bank		↓
	Southwest Bank		↓
REACTOR HEAD COOLING			↓
REACTOR VENT			↓
STANDBY LIQUID CONTROL			↓
BIOLOGICAL SHIELD WALL			A
REACTOR VESSEL			N
DRYWELL LINER			↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CLEAN UP WATER
LINE	B (RETURN)
DRAWING	BMR072-IC19

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D							
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	—	—	—	—	—	—	—
SHUTDOWN COOLING	A	N	N	N	N	N	N	N
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	A	A	A	A	A	A	A
(18")	B	N	N	N	N	N	N	N
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K				↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A				A	A	A	A
	B				N	N	N	N
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL								
BIOLOGICAL SHIELD WALL								
REACTOR VESSEL		↓	↓	↓				
DRYWELL LINER		D	D	D	↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CLEAN UP WATER
LINE	B (RETURN)
DRAWING	BMR072-IC19
BREAK LOCATION	

TARGET		8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	—	—	—	—	—	—	—
SHUTDOWN COOLING	A	N	N	N	N	N	N	N
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓	↓	↓	↓
(12")	B	↓	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	A	A	A	A	A	A
REACTOR VESSEL		↓	N	N	N	N	N	N
DRYWELL LINER		D	↓	↓	↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	CLEAN UP WATER
LINE	B (RETURN)
DRAWING	BMR072-IC19
BREAK LOCATION	

TARGET		15	16	17	18
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N
(10" Return)	B	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓
(8" Return)	B	—	—	—	—
SHUTDOWN COOLING	A	N	N	N	N
FEEDWATER (18")	A	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓
(12")	B	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
	G	↓	↓	↓	↓
	H	↓	↓	↓	↓
	J	↓	↓	↓	↓
	K	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		A	A	↓	↓
REACTOR VESSEL		N	N	↓	↓
DRYWELL LINER		↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	SHUTDOWN COOLING
LINE	A (SUPPLY)
DRAWING	BMR072-IC13
BREAK LOCATION	

TARGET			1	2	3	4	5
ISOLATION CONDENSER	(14" Supply)	A	N	N	N	N	N
	(10" Return)	B					
CORE SPRAY		A					
		B					
MAIN STEAM		A					
		B					
		C					
		D					↓
REACTOR CLEANUP	(8" Supply)	A					D
	(8" Return)	B	↓	↓	↓	↓	N
SHUTDOWN COOLING		A	—	—	—	—	—
FEEDWATER	(18")	A	N	N	N	N	N
	(12")	A					
	(18")	B					
	(12")	B					
REACTOR RECIRCULATION (12" Risers)		A					
		B					
		C					
		D					
		E					
		F					
		G					
		H					
		J					
		K					
PRIMARY CONTAINMENT COOLING (LPCI)		A					
		B					
MAIN STEAM RELIEF VALVE DISCHARGE		A					
		B					
		C					
		D					
		E					
		F					
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank						
	Northwest Bank						
	Southeast Bank						
	Southwest Bank						
REACTOR HEAD COOLING							
REACTOR VENT							
STANDBY LIQUID CONTROL							↓
BIOLOGICAL SHIELD WALL							A
REACTOR VESSEL							N
DRYWELL LINER			↓	↓	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

SOURCE	
SYSTEM	FEEDWATER
LINE	A
DRAWING	BMR072-IC6

BREAK LOCATION

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D							
REACTOR CLEANUP (8" Supply)	A							
(8" Return)	B							
SHUTDOWN COOLING	A							
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	—	—	—	—	—	—	—
(18")	B	N	N	N	N	N	N	N
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K							↓
PRIMARY CONTAINMENT COOLING (LPCI)	A							A
	B							N
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL					↓	↓	↓	↓
BIOLOGICAL SHIELD WALL					A	A	A	A
REACTOR VESSEL		↓	↓	↓	N	N	N	N
DRYWELL LINER		D	D	D	↓	D	D	D

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	A
DRAWING	BMR072-IC6

BREAK LOCATION

TARGET		8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	D	D	D	D	D	D	D
SHUTDOWN COOLING	A	N	N	N	N	N	N	N
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	—	—	—	—	—	—	—
(18")	B	N	N	N	N	N	N	N
→ (12")	B	↓	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	D	D	D	D	D	D	D
	B	N	N	N	N	N	N	N
MAIN STEAM RELIEF VALVE DISCHARGE	A	D	D	D	D	D	D	D
	B	N	N	N	N	N	N	N
	C	↓	↓	↓	↓	↓	↓	↓
	D	D	D	D	D	D	D	D
	E	N	N	N	N	N	N	N
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		D	D	D	D	D	D	D
BIOLOGICAL SHIELD WALL		N	N	N	N	N	N	N
REACTOR VESSEL		↓	↓	↓	↓	↓	↓	↓
DRYWELL LINER		D	D	D	D	D	D	D

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	A
DRAWING	BMR072-IC6

BREAK LOCATION

TARGET		15	16	17	18	19	20	21
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D							
REACTOR CLEANUP (8" Supply)	A	↓	↓					
(8" Return)	B	D	D					
SHUTDOWN COOLING	A	N	N			↓		
FEEDWATER (18")	A	↓	↓	↓	↓	—	↓	↓
(12")	A	—	—	—	—	N	—	—
(18")	B	N	N	N	N		N	N
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K	↓						
PRIMARY CONTAINMENT COOLING (LPCI)	A	D						
	B	N	↓	↓	↓	↓		
MAIN STEAM RELIEF VALVE DISCHARGE	A	D	D	D	D	D		
	B	N	N	D	D	D		
	C	↓	↓	N	N	N		
	D	D	D	D	D	D		
	E	N	N	N	N	N		
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT		↓	↓					
STANDBY LIQUID CONTROL		D	D					
BIOLOGICAL SHIELD WALL		N	N					
REACTOR VESSEL		↓	↓	↓	↓	↓	↓	↓
DRYWELL LINER		D	D	D	D	D	D	D

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	A
DRAWING	BM2072-IC6
BREAK LOCATION	

TARGET		22	23	24	25	26	27	28
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D				↓	↓	↓	
REACTOR CLEANUP (8" Supply)	A				D	D	D	
(8" Return)	B				N	N	N	
SHUTDOWN COOLING	A							
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	—	—	—	—	—	—	—
(18")	B	N	N	N	N	N	N	N
(12")	B							
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H							
	J							
	K							
PRIMARY CONTAINMENT COOLING (LPCI)	A							
	B							
MAIN STEAM RELIEF VALVE DISCHARGE	A							
	B							
	C							
	D							
	E							
	F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank							
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL				↓	↓	↓	↓	
BIOLOGICAL SHIELD WALL				A	A	A	A	
REACTOR VESSEL		↓	↓	N	N	N	N	↓
DRYWELL LINER		D	D	↓	D	D	D	D

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

			SOURCE						
			SYSTEM	FEEDWATER					
			LINE	A					
			DRAWING	BMR072-IC6					
			BREAK LOCATION						
TARGET			29	30	31	32	33	34	35
ISOLATION CONDENSER	(14" Supply)	A	N	N	N	N	N	N	N
	(10" Return)	B							
CORE SPRAY		A							
		B							
MAIN STEAM		A							
		B							
		C							
		D							
REACTOR CLEANUP	(8" Supply)	A			D	D			
	(8" Return)	B			N	N			
SHUTDOWN COOLING		A			D	D	D	D	D
FEEDWATER	(18")	A	—	—	—	—	—	—	—
	(12")	A	N	N	N	N	N	N	N
	(18")	B							
	(12")	B							
REACTOR RECIRCULATION (12" Risers)		A							
		B							
		C							
		D							
		E							
		F							
		G							
		H							
		J							
		K							
PRIMARY CONTAINMENT COOLING (LPCI)		A							
		B							
MAIN STEAM RELIEF VALVE DISCHARGE		A	D	D					
		B	D	D		D			
		C	N	N		N			
		D	D	D	D	D			
		E	N	N	N	N			
		F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank								
	Northwest Bank								
	Southeast Bank								
	Southwest Bank								
REACTOR HEAD COOLING									
REACTOR VENT									
STANDBY LIQUID CONTROL									
BIOLOGICAL SHIELD WALL							A	A	
REACTOR VESSEL							N	N	
DRYWELL LINER			A	A	A	A	A	A	A

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	A
DRAWING	BMR072-IC6
BREAK LOCATION	

TARGET		36	37	38	39
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N
(10" Return)	B	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓
SHUTDOWN COOLING	A	D	↓	↓	↓
FEEDWATER (18")	A	—	—	—	—
(12")	A	N	N	N	N
(18")	B	↓	↓	↓	↓
(12")	B	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
	G	↓	↓	↓	↓
	H	↓	↓	↓	↓
	J	↓	↓	↓	↓
	K	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓
	B	↓	↓	↓	↓
	C	↓	↓	↓	↓
	D	↓	↓	↓	↓
	E	↓	↓	↓	↓
	F	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	A	A	A
REACTOR VESSEL		↓	N	N	N
DRYWELL LINER		A	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	B
DRAWING	BMR072-IC5
BREAK LOCATION	

TARGET			1	2	3	4	5	6	7
ISOLATION CONDENSER	(14" Supply)	A	N	N	N	N	N	N	N
	(10" Return)	B							
CORE SPRAY		A							
		B							
MAIN STEAM		A							
		B							
		C							
		D							
REACTOR CLEANUP	(8" Supply)	A							
	(8" Return)	B							
SHUTDOWN COOLING		A							
FEEDWATER	(18")	A							
	(12")	A							
	(18")	B	↓	↓	↓	↓	↓	↓	↓
	(12")	B	—	—	—	—	—	—	—
REACTOR RECIRCULATION (12" Risers)		A	N	N	N	N	N	N	N
		B							
		C							
		D							
		E							
		F							
		G							
		H							
		J							
		K							
PRIMARY CONTAINMENT COOLING (LPCI)		A							
		B							
MAIN STEAM RELIEF VALVE DISCHARGE		A							
		B							
		C							
		D							
		E							
		F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank								
	Northwest Bank								
	Southeast Bank								
	Southwest Bank								
REACTOR HEAD COOLING									
REACTOR VENT									
STANDBY LIQUID CONTROL							↓	↓	↓
BIOLOGICAL SHIELD WALL							A	A	A
REACTOR VESSEL			↓	↓	↓	↓	N	N	N
DRYWELL LINER			D	D	D	D	↓	D	D

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	B
DRAWING	BMR072-IC5
BREAK LOCATION	

TARGET		8	9	10	11	12	13	14
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓	↓	↓	↓
→ (12")	B	—	—	—	—	—	—	—
REACTOR RECIRCULATION (12" Risers)	A	N	N	N	N	N	N	N
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		A	↓	↓	↓	↓	↓	A
REACTOR VESSEL		N	↓	↓	↓	↓	↓	N
DRYWELL LINER		D	D	D	D	D	D	↓

LEGEND:
- D = Damage Possible, Further Evaluation Required.
- A = Acceptable Interaction (Damage Not Possible)
- N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	B
DRAWING	BMR072-IC5
BREAK LOCATION	

TARGET		15	16	17	18	19	20	21
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓	↓	↓	—
(12")	B	—	—	—	—	—	—	N
REACTOR RECIRCULATION (12" Risers)	A	N	N	N	N	N	N	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	D	D	↓
	G	↓	↓	↓	↓	N	N	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	D
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	N
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM RELIEF VALVE DISCHARGE	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	D
	D	↓	↓	↓	↓	↓	↓	N
	E	↓	↓	↓	↓	D	D	D
	F	↓	↓	↓	↓	D	D	D
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	N	N	N
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		A	A	A	↓	↓	↓	↓
REACTOR VESSEL		N	N	N	↓	↓	↓	↓
DRYWELL LINER		D	D	D	D	D	D	D

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

		SOURCE
SYSTEM		FEEDWATER
LINE		B
DRAWING		BMR072-IC5
BREAK LOCATION		

TARGET		22	23	24	25	26	27	28
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B							
CORE SPRAY	A							
	B							
MAIN STEAM	A							
	B							
	C							
	D			↓	↓			
REACTOR CLEANUP (8" Supply)	A			D	D			
(8" Return)	B			N	N			
SHUTDOWN COOLING	A			D	D			
FEEDWATER (18")	A			N	N			
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	—	—	—	—	—	—	—
(12")	B	N	N	N	N	N	N	N
REACTOR RECIRCULATION (12" Risers)	A							
	B							
	C							
	D							
	E							
	F							
	G							
	H	↓	↓					
	J	D	D					
	K	N	N					
PRIMARY CONTAINMENT COOLING (LPCI)	A					↓	↓	↓
	B					D	D	D
MAIN STEAM RELIEF VALVE DISCHARGE	A					N	N	N
	B	↓	↓		↓	↓	↓	↓
	C	D	D		D	D	D	D
	D	N	N	↓	N	N	N	N
	E	D	D	D	D			
	F	D	D	D	D			
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	N	N	N	N			
	Northwest Bank							
	Southeast Bank							
	Southwest Bank							
REACTOR HEAD COOLING								
REACTOR VENT								
STANDBY LIQUID CONTROL						↓	↓	
BIOLOGICAL SHIELD WALL						A	A	
REACTOR VESSEL		↓	↓	↓	↓	N	N	↓
DRYWELL LINER		A	A	A	A	A	A	A

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	FEEDWATER
LINE	B
DRAWING	BMR072-IC5
BREAK LOCATION	

TARGET		29	30	31	32
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N
(10" Return)	B				
CORE SPRAY	A				
	B				
MAIN STEAM	A				
	B				
	C				
	D				
REACTOR CLEANUP (8" Supply)	A				
(8" Return)	B				
SHUTDOWN COOLING	A				
FEEDWATER (18")	A				
(12")	A	↓	↓	↓	↓
(18")	B	—	—	—	—
(12")	B	N	N	N	N
REACTOR RECIRCULATION (12" Risers)	A				
	B				
	C				
	D				
	E				
	F				
	G				
	H				
	J				
	K				
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓			
	B	D			
MAIN STEAM RELIEF VALVE DISCHARGE	A	N			
	B	↓			
	C	D			
	D	N			
	E				
	F				
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank				
	Northwest Bank				
	Southeast Bank				
	Southwest Bank				
REACTOR HEAD COOLING					
REACTOR VENT					
STANDBY LIQUID CONTROL			↓	↓	↓
BIOLOGICAL SHIELD WALL			A	A	A
REACTOR VESSEL		↓	N	N	N
DRYWELL LINER		A	↓	↓	↓

LEGEND:
D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	LPCI
LINE	A
DRAWING	BMR072-IC1
BREAK LOCATION	

TARGET			1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)		A	N	N	N	N	N	N	N
(10" Return)		B							
CORE SPRAY		A							
		B		↓	↓	↓	↓	↓	
MAIN STEAM		A		A	A	A	A	A	
		B		N	N	N	N	N	
		C							
		D							
REACTOR CLEANUP (8" Supply)		A							
(8" Return)		B							
SHUTDOWN COOLING		A							
FEEDWATER	(18")	A							↓
	(12")	A							D
	(18")	B							N
	(12")	B							
REACTOR RECIRCULATION (12" Risers)		A							
		B							
		C							
		D							
		E							
		F							
		G							
		H							
		J							
		K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)		A	—	—	—	—	—	—	—
		B	N	N	N	N	N	N	N
MAIN STEAM RELIEF VALVE DISCHARGE		A							
		B							
		C							
		D							
		E							
		F							
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank								
	Northwest Bank								
	Southeast Bank								
	Southwest Bank								
REACTOR HEAD COOLING									
REACTOR VENT									
STANDBY LIQUID CONTROL									
BIOLOGICAL SHIELD WALL									
REACTOR VESSEL									
DRYWELL LINER			↓	↓	↓	↓	↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	LPCI
LINE	A
DRAWING	BMR072-IC1
BREAK LOCATION	

TARGET		8	9	10
ISOLATION CONDENSER (14" Supply)	A	N	N	N
(10" Return)	B			
CORE SPRAY	A			
	B			
MAIN STEAM	A			
	B			
	C			
	D			
REACTOR CLEANUP (8" Supply)	A			
(8" Return)	B			
SHUTDOWN COOLING	A			
FEEDWATER (18")	A	↓	↓	↓
(12")	A	D	D	D
(18")	B	N	N	N
(12")	B			
REACTOR RECIRCULATION (12" Risers)	A			
	B			
	C			
	D			
	E			
	F			
	G			
	H			
	J			
	K	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	—	—	—
	B	N	N	N
MAIN STEAM RELIEF VALVE DISCHARGE	A			
	B			
	C			
	D			
	E			
	F			
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank			
	Northwest Bank			
	Southeast Bank			
	Southwest Bank			
REACTOR HEAD COOLING				
REACTOR VENT				
STANDBY LIQUID CONTROL				
BIOLOGICAL SHIELD WALL				
REACTOR VESSEL				
DRYWELL LINER		↓	↓	↓

LEGEND: D = Damage Possible, Further Evaluation Required.
A = Acceptable Interaction (Damage Not Possible)
N = No Interaction

	SOURCE
SYSTEM	LPCI
LINE	B
DRAWING	BMR072-IC3
BREAK LOCATION	

TARGET		1	2	3	4	5	6	7
ISOLATION CONDENSER (14" Supply)	A	N	N	N	N	N	N	N
(10" Return)	B	↓	↓	↓	↓	↓	↓	↓
CORE SPRAY	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
MAIN STEAM	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
REACTOR CLEANUP (8" Supply)	A	↓	↓	↓	↓	↓	↓	↓
(8" Return)	B	↓	↓	↓	↓	↓	↓	↓
SHUTDOWN COOLING	A	↓	↓	↓	↓	↓	↓	↓
FEEDWATER (18")	A	↓	↓	↓	↓	↓	↓	↓
(12")	A	↓	↓	↓	↓	↓	↓	↓
(18")	B	↓	↓	↓	↓	↓	↓	↓
→ (12")	B	↓	↓	↓	↓	↓	↓	↓
REACTOR RECIRCULATION (12" Risers)	A	↓	↓	↓	↓	↓	↓	↓
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
	G	↓	↓	↓	↓	↓	↓	↓
	H	↓	↓	↓	↓	↓	↓	↓
	J	↓	↓	↓	↓	↓	↓	↓
	K	↓	↓	↓	↓	↓	↓	↓
PRIMARY CONTAINMENT COOLING (LPCI)	A	↓	↓	↓	↓	↓	↓	↓
	B	—	—	—	—	—	—	—
MAIN STEAM RELIEF VALVE DISCHARGE	A	N	N	N	N	N	N	N
	B	↓	↓	↓	↓	↓	↓	↓
	C	↓	↓	↓	↓	↓	↓	↓
	D	↓	↓	↓	↓	↓	↓	↓
	E	↓	↓	↓	↓	↓	↓	↓
	F	↓	↓	↓	↓	↓	↓	↓
CONTROL ROD DRIVE (Supply & Return)	Northeast Bank	↓	↓	↓	↓	↓	↓	↓
	Northwest Bank	↓	↓	↓	↓	↓	↓	↓
	Southeast Bank	↓	↓	↓	↓	↓	↓	↓
	Southwest Bank	↓	↓	↓	↓	↓	↓	↓
REACTOR HEAD COOLING		↓	↓	↓	↓	↓	↓	↓
REACTOR VENT		↓	↓	↓	↓	↓	↓	↓
STANDBY LIQUID CONTROL		↓	↓	↓	↓	↓	↓	↓
BIOLOGICAL SHIELD WALL		↓	↓	↓	↓	↓	↓	↓
REACTOR VESSEL		↓	↓	↓	↓	↓	↓	↓
RYWELL LINER		↓	↓	↓	↓	↓	↓	↓

APPENDIX C

INTERACTION EVALUATION AND SAFE SHUTDOWN SCENARIOS

INTERACTION EVALUATION/SHUTDOWN SCENARIOS SUMMARY

DAMAGED PIPING IN ADDITION TO SOURCE	SOURCE	LINE A		LINE B		LINE C		LINE D		SAFE* SHUTDOWN SCENARIO
		BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	
—	IC	1-10,12-17	1-3	1-8, 12	4, 5	—	—	—	—	1
RV	↓	11	2	—	—	—	—	—	—	1
SLC	↓	—	—	9-11	5	—	—	—	—	1
—	CS	1-11	6, 7	—	—	—	—	—	—	6
—	↓	—	—	1-11	8, 9	—	—	—	—	7
—	CUW	1-15	26-28	1-18	29-31	—	—	—	—	1
—	SDC	1-4	32	—	—	—	—	—	—	1
CUW	↓	5	32	—	—	—	—	—	—	1
—	LPCI	1-6	44	1-7	46	—	—	—	—	2
FW	↓	7-10	44, 45	—	—	—	—	—	—	2
—	FW	1-7, 20-24, 28, 37-39	33, 35, 36, 38	1-18, 30-32	39-41, 43	—	—	—	—	1
LPCI + CUW + SRV + SLC	↓	8-15	34, 35	—	—	—	—	—	—	2

*In all safe shutdown scenarios, the following is conservatively assumed.

1. Loss of off-site power.
2. The most limiting single active failure, concurrently with the break.
3. All electrical trays and cables in the vicinity of the breaks are wiped out.

INTERACTION EVALUATION/SHUTDOWN SCENARIOS SUMMARY

DAMAGED PIPING IN ADDITION TO SOURCE	SOURCE	LINE A		LINE B		LINE C		LINE D		SAFE* SHUTDOWN SCENARIO
		BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	
CUW + SRV + SLC	FW	16	35	—	—	—	—	—	—	1
SRV		17-19, 29, 30	35, 37	—	—	—	—	—	—	1
CUW		25-27	36	—	—	—	—	—	—	1
CUW + SDC + SRV		31, 32	37	24, 25	42	—	—	—	—	1
SDC		33-36	37, 38	—	—	—	—	—	—	1
Recirc. + SRV		—	—	19-23	41,42	—	—	—	—	4
LPCI + SRV		—	—	26-29	42, 43	—	—	—	—	4
RV	MS	1-4	10	—	—	23-26	21	—	—	1
LPCI		5, 6	10	—	—	—	—	—	—	2
LPCI + FW + SRV		7	10	—	—	—	—	—	—	2
LPCI + FW + SRV + CUW + Recirc.		8-12	11	—	—	—	—	—	—	2
FW + SRV		13-17	11, 12	—	—	18-22	20, 21	7, 8, 17	22-24	1
FW + SRV + SDC	MS	18-22	12, 13	—	—	—	—	—	—	1

*In all safe shutdown scenarios, the following is conservatively assumed.

1. Loss of off-site power.
2. The most limiting single active failure, concurrently with the break.
3. All electrical trays and cables in the vicinity of the breaks are wiped out.

INTERACTION EVALUATION/SHUTDOWN SCENARIOS SUMMARY

DAMAGED PIPING IN ADDITION TO SOURCE	SOURCE	LINE A		LINE B		LINE C		LINE D		SAFE* SHUTDOWN SCENARIO
		BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	
————	MS	23-26	1[illegible]	1-4, 22-25	14, 17	1-4	18	1-6, 23-26	22, 25	1
Recirc	↓	———	———	5, 6	14	———	———	———	———	2
FW + CUW	↓	———	———	7, 8	14, 15	———	———	———	———	1
FW	↓	———	———	9, 10	15	7, 8	18, 19	———	———	1
CRD + SRV	↓	———	———	11, 12	15	11, 12	19	———	———	3
CS + LPCI + Recirc + SRV	↓	———	———	13, 14	15	———	———	———	———	8
LPCI + SRV + Recirc	↓	———	———	15	16	———	———	———	———	2
LPCI + SRV + Recirc + CUW	↓	———	———	16	16	———	———	———	———	2
CUW + SRV	↓	———	———	17-21	16	———	———	———	———	1
FW + Recirc	↓	———	———	———	———	5, 6	18	———	———	4
CS + LPCI + Recirc + SRV	↓	———	———	———	———	13, 14	19	———	———	5
LPCI + SRV	↓	———	———	———	———	15, 17	20	———	———	4

*In all safe shutdown scenarios, the following is conservatively assumed.

1. Loss of off-site power.
2. The most limiting single active failure, concurrently with the break.
3. All electrical trays and cables in the vicinity of the breaks are wiped out.

INTERACTION EVALUATION/SHUTDOWN SCENARIOS SUMMARY

DAMAGED PIPING IN ADDITION TO SOURCE	SOURCE	LINE A		LINE B		LINE C		LINE D		SAFE* SHUTDOWN SCENARIO
		BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	BREAK PT.	SHEET # B	
LPCI + SRV + SDC	MS ↓	—	—	—	—	16	20	—	—	4
LPCI		—	—	—	—	9, 10	19	—	—	4
FW + Recirc + SRV		—	—	—	—	—	—	9-16	23, 24	4
FW + LPCI + SRV		—	—	—	—	—	—	18-22	24, 25	4

*In all safe shutdown scenarios, the following is conservatively assumed.

1. Loss of off-site power.
2. The most limiting single active failure, concurrently with the break.
3. All electrical trays and cables in the vicinity of the breaks are wiped out.

SAFE SHUTDOWN SCENARIOS

1.a Vessel depressurization will be accomplished through the postulated and resulting breaks.

1.b All emergency core cooling systems are available to obtain a safe shutdown condition including all LPCI/core spray lines, the control rod drive lines, and FWCI.

1.c Assuming loss of off-site power and the most limiting single active failure, failure to start the gas turbine, LPCI-A and core spray A lines are still available for safe shutdown with the additional makeup capability of the CRD pumps (reactor head cooling).

1.d All safety equipment inside the drywell (i.e., valves or pumps) are in the required position and the damage to the electrical trays and cables will not affect the safe shutdown scenario.

2.a Vessel depressruization will be accomplished through the postulated and resulting breaks.

2.b Of the ECCS system, LPCI-A line or the recirculation loop associated with it, is unavailable.

2.c Assuming loss of off-site power and the most limiting single active failure, failure to start the gas turbine, causes the loss of the ECCS-B train and the FWCI system. A safe shutdown condition can be obtained using the core spray A line and CRD pumps.

2.d All safety equipment inside the drywell (i.e., valves or pumps) are in the required position and the damage to the electrical trays and cables will not affect the presented safe shutdown scenario.

3.a Vessel depressurization will be accomplished through the postulated and resulting breaks.

3.b The interaction with the CRD lines leads to an unacceptable situation. The CRD system is designed so that reactor pressure can adequately scram the control rods without the use of the CRD lines. In fact, if the CRD lines are severed by the break, reactor pressure will automatically scram the reactor. However, if the withdraw line for any control rod is crimped to the point where flow is restricted, that control rod will not be inserted by reactor or accumulator pressure. Thus, a different approach must be used.

3.c Using a mechanistic approach as outlined in Appendix G, the break locations which cause the unacceptable interactions may be eliminated. Cases I and II of the Appendix address these situations in detail. By using this approach, the locations on main steam lines B and C which cause the unacceptable situation are excluded from being considered break locations and therefore the situation will never develop.

4.a Vessel depressurization will be accomplished through the postulated and resulting breaks.

4.b The LPCI-B line or the recirculation loop associated with it is unavailable.

4.c Assuming loss of off-site power and the most limiting single active failure, failure to start the diesel generator, causes the loss of the ECCS-A train. A safe shutdown may be obtained by using core spray B line, the FWCI system, and CRD pumps for additional makeup.

4.d All safety equipment inside the drywell (i.e., valves or pumps) are in the required position and the damage to the electrical trays and cables will not affect the presented safe shutdown scenario.

5.a Vessel depressurization will be accomplished through the postulated and resulting breaks.

5.b Of the ECCS system, core spray B line and LPCI B line or the recirculation loop associated with it, are not available.

5.c Assuming the loss of off-site power and the most limiting single active failure, failure to start the diesel generator, causes the loss of core spray and LPCI A lines. However, a safe shutdown may be obtained using FWCI and the CRD pumps.

6.a Vessel depressurization will be accomplished through the postulated and resulting breaks.

6.b Of the ECCS system, core spray A line is lost.

6.c Assuming loss of off-site power and the most limiting single active failure, failure to start the gas turbine, causes the loss of core spary and LPCI B lines and FWCI. Shutdown may be obtained using LPCI A line and CRD pumps.

6.d All safety equipment inside the drywell (i.e., valves or pumps) are in the required position and the damage to the electrical trays and cables will not affect the presented safe shutdown scenario.

7.a Vessel depressurization will be accomplished through the postulated and resulting breaks.

7.b Of the ECCS system, core spray B line is unavailable.

7.c Assuming loss of off-site power and the most limiting single active failure, failure to start the diesel generator, causes the loss of the ECCS A train. A safe shutdown may be obtained using LPCI B line, FWCI, and the CRD systems.

7.d All safety equipment inside the drywell (i.e., valves or pumps) are in the required position and the damage to the electrical trays and cables will not affect the presented safe shutdown scenario.

8.a Vessel depressurization will be accomplished through the postulated and resulting breaks.

8.b Due to the pipe rupture, the A train of the ECCS system is unavailable.

8.c Assuming loss of off-site power and the most limiting single active failure, failure to start the gas turbine, causes the loss of the ECCS B train and the FWCI system. A safe shutdown condition cannot be obtained by using the CRD pumps only. Therefore, further analysis is needed.

8.d Using the mechanistic approach as outlined in Appendix G the break locations causing the unacceptable interactions may be eliminated. Case III of the Appendix addresses the situation in detail. By using this approach, locations 13 and 14 may be excluded from being considered break locations and therefore the unacceptable interactions will not develop.

The reactor vent, reactor head cooling, and standby liquid control systems are not included in the interaction matrices as sources. A break in any of these systems cannot affect the core spray, LPCI, or ADS systems, and the following shutdown scenario applies.

a. Vessel depressurization will be accomplished partially through the break but mainly through the ADS valves.

b. Core spray, LPCI and FWCI systems are available for shutdown.

c. Assuming loss of off-site power and the most limiting single active failure, failure to start the gas turbine, causes the loss of the ECCS B train and FWCI. However, a safe shutdown may be obtained using core spray and LPCI A systems.

d. All safety equipment inside the drywell (i.e., valves or pumps) are in the required position and the damage to the electrical trays and cables will not affect the presented safe shutdown scenario.

APPENDIX D

JERSEY CENTRAL POWER & LIGHT COMPANY

OYSTER CREEK
NUCLEAR GENERATING STATION

EVALUATION OF STRUCTURAL INTEGRITY
OF THE BIOLOGICAL SHIELD WALL
UNDER PIPE WHIP LOADINGS

June, 1974

TABLE OF CONTENTS

DESCRIPTION PAGE

1.0 INTRODUCTION

This report, prepared by EDS Nuclear Inc. for Jersey Central Power & Light Company, describes the analyses performed to determine the effects of pipe impact on the biological shield wall of the Oyster Creek Nuclear Generating Station, and to evaluate the structural adequacy of the shield wall under pipe impact, in combination with other types of concurrent loading.

The purpose of these studies was to evaluate the structural response of the biological shield wall following a postulated high-energy line break and subsequent unrestrained pipe whip. The structural integrity of the shield wall was evaluated with respect to both the gross structural response and local damage predictions, including perforation of the steel and depth of concrete penetration.

All analyses were performed for postulated "worst case" conditions of impact. The gross structural response was evaluated by performing dynamic time history analyses corresponding to the impact of a 24-inch diameter pipe at the top of the shield wall. Elastic analyses were performed, as the gross response of the shield wall was expected to remain in the elastic range. Local damage predictions were evaluated according to conservative penetration equations currently specified by the AEC.

The results of the analyses indicate that no gross structural damage will occur under "worst case" impact loadings, and that the shield wall is capable of withstanding the full spectrum of postulated breaks without incurring significant loss of load-carrying capability. Damage to the shield wall will be restricted to the local region of impact and will not significantly effect the overall structural capability.

2.0 DESCRIPTION OF STRUCTURE

The biological shield wall is a cylindrical structure composed of steel plate, steel column sections and concrete. The structure is approximately 45 feet high, has an inside diameter of 20 feet, 10 inches, and a total thickness of 29 inches. The shield wall functions as both a radiation shield for protection of plant personnel, and as a load-carrying structure for support of inside-containment piping.

The shield wall consists of the following structural components:

1. Twenty-five steel columns (27 WF 177 sections) at approximately uniform spacing circumferentially.
2. Steel plate (5/16-inch) comprising the outside surface, and 1/4-inch plate comprising the inside surface of the wall.
3. Poured concrete infill.

Both the inside and outside steel plate are provided with 1/2-inch studs at approximately 1'-6" spacing to ensure composite response of the steel and concrete. High density concrete is provided in the portion of the wall adjacent to the reactor core, with a specified unit weight of 210 lbs/ft^3, and standard weight concrete is provided for the remainder of the shield wall.

3.0 DISCUSSION OF ANALYSES

Analyses were performed to determine conservative estimates of both the overall response of the structure and the extent of local damage resulting from "worst case" pipe impact effects.

The gross structural response under impact loads was combined with conservative estimates of the response to other types of concurrent loadings, which were then compared to the structural capability of the shield wall. The capability of the structure for moments, shears and axial loads was evaluated in accordance with the following assumptions:

1. Composite behavior of the steel and concrete was assumed. (This is discussed further in Section 3.1 below.)

2. The concrete cannot sustain either tensile or shear stresses.

3. The compressive strength of the concrete was assumed to be 3,000 psi, with an associated allowable compressive stress equal to $0.75f'_c$.

4. The yield strength of the steel was assumed to be 36 ksi, with an associated allowable stress equal to $0.9\,f_y$.

The capability of the shield wall to sustain local damage was evaluated directly from empirical relationships derived from projectile impact experiments. The equations used to determine perforation or depth of penetration were those discussed by Amirikian (Reference 4.01) and Cottrell and Savolainen (Reference 5.01). These equations are currently accepted by the USAEC for use in local damage predictions associated with pipe impact.

3.1 Gross Structural Response Analysis

A mathematical model of the shield wall was constructed for the gross structural response analyses. The model consisted of lumped masses connected by massless elastic three-dimensional beam elements. A sufficient number of mass points was selected to accurately represent the relatively high-frequency wave transmission characteristics of the shield wall necessary for representing the response to impact loadings. Cross section properties of the elements included the composite behavior of the steel plate exterior, steel column interior and concrete infill material, as the steel plates are provided with studs to ensure composite structural response. In addition, equivalent cross section properties were calculated and included at all elevations corresponding to the locations of hatches and penetrations.

An idealized impact force time history was constructed based on the blowdown force time histories developed by EDS for the pipe whip analyses of the Oyster Creek Emergency Condenser piping system. (Reference 2.02). The forcing function was constructed by extrapolating the previously-developed blowdown forces occurring at the break location to a 24-inch diameter pipe size. In addition, the initial portion of the resulting time history was further increased by a factor of 2.0, to account for the short-duration forces developed during impact. The force time history was postulated to act at the top of the cylindrical shield wall, as this impact location results in the largest dynamic response shears, moments and axial forces throughout the shield wall. It should be noted that this impact location would not be predicted from the postulated break locations (based on pipe stress criteria) for the 24-inch piping. Instead, the most conservative impact location was chosen for purposes of evaluating the maximum shield wall capability.

Dynamic elastic time history analyses were performed on the mathematical model discussed above, subjected to the postulated impact force time history. The analyses were performed using EDS program EDSGAP, originally developed by Wilson (Reference 6.01), and modified extensively by EDS. The program may be used to analyze three-dimensional structural systems of arbitrary geometry subjected to static or dynamic loading. The assumption of elastic behavior was considered to be appropriate for the analyses, as the gross stresses over the shield wall cross sections were expected to remain within the elastic range. A value of five percent structural damping was assumed in the analyses, corresponding to a combined material damping for steel and concrete.

Time histories of cross section moments and shears under the "worst case" impact loadings were obtained. The maximum shears and moments, in combination with those occurring from other types of concurrent loadings, were compared with the overall capability of the shield wall in accordance with the AEC criteria for factored load combinations. The load combinations considered in this study were those specified in Section C.1 of Reference 1.02.01, with the ultimate load capacities calculated as discussed in Section 3.0 above.

The results of the response analyses and evaluation of structural adequacy are discussed in Section 4.1 below.

3.2 Local Damage Analyses

Prediction of local damage was evaluated by calculating "threshold penetration" thicknesses of steel and concrete subjected to impact of both a segment of 10-inch diameter and 24-inch diameter pipe. Rigid-body impact was assumed for the calculations, as the assumption that no energy is absorbed by the impacting pipe results in conservative penetration predictions.

From an examination of the postulated break locations (Reference 2.01) for the case of a 10-inch diameter pipe, it was considered that a "worst case" impact would correspond to a missile consisting of an unfolded segment of 10-inch pipe striking the shield wall on edge. The kinetic energy of the missile was assumed to be equivalent to the change in internal energy of the enclosed steam in undergoing a change of state from the operating conditions of the fluid to ambient conditions (Reference 3.01). This impact case is more severe than the case of impact by a whipping pipe of the same size, as the cross-sectional area of impact for the postulated case is smaller than the impact area of a whipping pipe, and hence higher stresses will be developed in the local region of the shield wall.

In the case of a 24-inch pipe break, it was found that no conditions exist for generation of a small missile, based on postulated break locations. It was therefore assumed that the most severe impact case consisted of a circumferential break and subsequent whip of the longest segment of pipe for which the shield wall is a possible target. The impact velocity and kinetic energy of impact were calculated from the mass of the pipe, maximum blowdown force and the maximum distance between the pipe segment and shield wall.

Spalling of the concrete will not occur for the Oyster Creek shield wall design, as steel plates are provided over both the entire inside and outside wall surfaces. Hence, concrete spalling was not included in the local damage evaluation.

The results of the local damage analyses are discussed in Section 4.2 below.

4.0 DISCUSSION OF RESULTS

The results of both the overall structural integrity analyses and the local damage analyses indicate that the shield wall is capable of withstanding the effects of a "worst case" pipe impact without incurring gross structural failure, perforation or significant loss of load-carrying capability. The results from the two phases of the study are discussed in separate sections below.

4.1 Gross Structural Response

The maximum dynamic moments and shears obtained from the structural response analyses discussed in Section 3.1 occur at the base of the shield wall. For the case of impact by a 24-inch diameter pipe, the maximum moment and shear are approximately 55,000 k-ft. and 1,350 kips, respectively.

Approximate seismic moments and shears were evaluated for combination with the above loads. Horizontal seismic loadings were based on a conservatively-estimated horizontal spectral acceleration of 0.5g at a frequency of 15 Hz, the first fundamental translational frequency of the shield wall. A factor of 1.5 was applied to the resulting base moment and shear to account for the contribution of higher modes of response. The moment and shear calculated at the base of the shield wall using the above procedure were 30,000 k-ft. and 950 kips, respectively.

It was found that the moments at the base of the shield wall control the capability of the structure for pipe impact and seismic loadings. The combination of pipe whip and SSE loadings results in a total base moment of slightly less than 30 percent of the structural capability. It was found that the capability of the shield wall for shears and axial forces was substantially larger than this margin.

It is concluded that the shield wall is capable of withstanding the postulated "worst case" pipe whip loadings without gross structural damage. The maximum loadings encountered are considerably less than the capability of the structure.

4.2 Local Damage

The results of the penetration calculations indicate that the case of a missile generated by a 10-inch diameter pipe break is more severe with regard to depth of penetration than the case of impact of a 24-inch pipe. This results from the fact that the impact area is considerably smaller for the 10-inch pipe break.

The results of the calculations indicate that a concrete thickness of approximately 22 inches is sufficient to prevent perforation. The depth of penetration of the shield wall will be less than this amount, as the steel plate will absorb some of the energy of impact. The calculations for required steel plate thickness indicate that approximately one inch of steel is necessary to prevent perforation. Therefore, it is possible that the steel plate at the impact location will be penetrated, as the plate thickness on the outside surface of the shield wall is less than this amount. Similar calculations for the case of impact by a 24-inch pipe resulted in a considerably smaller estimate of concrete penetration depth.

Damage caused by pipe impact will be restricted to the local region of impact, as the design of the shield wall includes steel column members continuous through the height of the shield wall at approximately three-foot intervals over the circumference. (Reference 1.01.01). It is considered that these columns will restrict the development of cracking or crushing of the concrete to the region of impact enclosed by two adjacent columns. Such an extent of local damage will not significantly affect the gross structural capability of the shield wall, as the region of local damage is a small percentage of the shield wall cross section.

It is concluded that a whipping pipe or missile generated by pipe rupture will not perforate the shield wall, although perforation of the outer steel plate may possibly occur for the "worst case" impact. The depth of penetration will be less than 22 inches of concrete, and the region of damage to the concrete and outer steel plate will be restricted to approximately three feet of the shield wall circumference.

5.0 CONCLUSIONS

The conclusions developed from these studies may be summarized as follows:

1. The overall load-carrying capability of the structure is significantly greater than the combinations of loadings associated with the maximum structural responses resulting from the load types specified in Reference 1.02.01.

2. Perforation of the shield wall will not occur for the "worst case" pipe impact. Depth of penetration is predicted to be less than 22 inches of concrete, using the experimentally-derived relationships specified in Reference 1.02.01.

3. Damage will be restricted to the local region of impact, and will not significantly effect the overall structural capability of the shield wall.

Moreover, it is concluded that the shield wall is capable of withstanding the full spectrum of postulated breaks without incurring gross damage or significant loss of load-carrying capability, and that the design of the structure is such that impact by a whipping pipe is a condition which can be toleratted in the Oyster Creek Nuclear Plant.

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REFERENCES

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        07. (GE) 2095PR, Sheet 2 of 2
        08. (GE) 706E206, revision 1

    02. Correspondence

        01. Letter from R. J. Schemel (USAEC) to I. R. Finfrock (Jersey Central Power & Light Company), dated August 7, 1973, with Attachment A and Enclosure 1.

2. EDS Nuclear Inc.

    01. Report to GPU Service Corporation entitled, "Oyster Creek Nuclear Plant, Pipe Whip Protection Inside Containment", May, 1974.

    02. Report to GPU Service Corporation, entitled, "Nonlinear Pipe Whip Analysis of the Emergency Condenser Piping Inside Containment, Oyster Creek Nuclear Plant", May, 1974.

3. Moore, C. V.

    01. "The Design of Barricades for Hazardous Pressure Systems", Nuclear Engineering and Design, 5 (1967), North-Holland Publishing Company, Amsterdam.

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APPENDIX

EDS COMPUTER PROGRAM DESCRIPTION

EDSGAP

EDS program EDSGAP is a general-purpose finite element program for linear elastic analyses of arbitrary structural systems. The program contains the following element types:

1. General beam
2. Truss
3. Two-dimensional plane stress/plane strain
4. Three-dimensional solid
5. Axisymmetric solid
6. Plate and shell
7. Translational/rotational spring

These element types may be used both singly and in compatible combinations. The program includes static and dynamic options, as discussed below. Out-of-core storage may be utilized for solution of the equations of equilibrium, storage of problem data and storage of solution results. The program has virtually no restrictions on size of the structural system to be analyzed. EDSGAP is based on the program SAP developed by E. L. Wilson of the University of California at Berkeley. However, many improvements have been incorporated into EDSGAP to increase its capabilities and efficiency.

Static analyses are performed using the Direct Stiffness Method, in which element stiffness matrices are formed according to virtual work principles and assembled to form a global stiffness matrix for the system, relating external forces and moments to joint displacements and rotations. Applied static loads may be specified as combinations of concentrated forces, thermal expansion loads, pressure forces, and inertia (body) forces. The equations of equilibrium of the system are solved for joint displacements and rotations by Gaussian reduction techniques.

Dynamic options within the program include calculation of undamped natural frequencies and normal modes of vibration using either the Determinant Search or Subspace Interaction techniques, and computation of time history response by either the Mode Superposition technique or direct integration of the equations of dynamic equilibrium. Dynamic loadings may be specified as combinations of arbitrary applied force and moment time histories and three independent orthogonal component time histories of acceleration.

EDSGAP has been used for soil-structure interaction analyses on several nuclear power facilities, including Atlantic Generating Station, Newbold Island and Douglas Point, for pressure transient piping response analyses on Rancho Seco, Oconee, Calvert Cliffs, Donald C. Cook and Salem Generating Stations, and for conceptual design review studies on the GE MARK III Reactor Building.

The program has been verified for the various element types by an extensive set of sample problems, including comparisons with hand calculations or theoretical solutions, wherever possible, and has been benchmarked against EDS programs PISOL1A and PISOL3A for static and dynamic analyses of complex piping systems.

QUESTION

14.G.

Justify the assumption that in case of a pipe break the insulation will be crushed and/or blown away, and that the whole volume between the reactor, pipes, and biological shield will be empty and without obstruction to flow.

RESPONSE

Instead of justifying the assumption, the blowdown calculation has been revised in order to account for the possibility of the insulation remaining intact. Flow was assumed to occur through the following openings: (1) the annulus between the insulation and the shield, (2) the openings between the insulation and the shield gates around the recirculation lines, (3) the opening in the shield gates for the liquid poison line, and (4) the five HVAC ducts at elevation 39'-5". All other openings were conservatively assumed to be 100% blocked. The total vent area, as described above, was found to be 60.1 square feet.

The blowdown calculation was revised to account for the reduced vent area of 60.1 square feet, and it was determined that the peak pressure within the biological shield to vessel annulus would be 23.7 psig. The biological shield had previously been found to be adequate for 74 psig, but the shield gates had been found to be adequate for only 9 psig. The limiting component within the gates had been found to be the structural shield plates. All other components of the gates had been found to be adequate for a minimum pressure of 25 psig. The original analysis of the structural shield plates was reviewed, and it was found to be extremely conservative. In order to demonstrate the adequacy of the shield plates, it was apparent that a more refined analysis was necessary. The analysis was performed, and the results indicated that the shield plates are capable of withstanding the peak pressure of 23.7 psig. Therefore, the biological shield and shield gates have the capacity to withstand the peak pressure resulting from the worst credible discharge into the vessel shieldwall annulus, even with the insulation remaining intact.

QUESTION

14.H.

Present a sketch of the arrangement of the welds in the biological shield structure. Indicate the type of electrode used for the fillet welds, the grade of structural steel of plates and columns, and the quality control provided during construction of the shield.

RESPONSE

The steel structure of the biological shield, which encases the concrete, is made up of column sections (27WF177) on 12-degree centers, whose flanges are lap welded together with ½-inch plate panels at the column-flange inner radius (10'-7-1/16") and 5/16-inch plate panels at the column-flange outer radius (12'-9-1/4"). A typical plate installation detail is shown in Figure 1.

The electrodes used for the fillet welds were in accordance with the applicable requirements of: (1) the AISC Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, and (2) the American Welding Society Publication D1.0, Standard Code for Arc and Gas Welding in Building Construction.

The column sections were made of steel which conforms to ASTM Specification A36. The plate panels conform to ASTM Specification A36 and/or A283, Grade C or D.

The quality control which was provided during construction was in accordance with: (1) the AISC Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, and (2) the American Welding Society Publication D1.0, Standard Code for Arc and Gas Welding in Building Construction. All welding procedures and welders were qualified in accordance with the AWS Code prior to the start of fabrication.

FIGURE 1

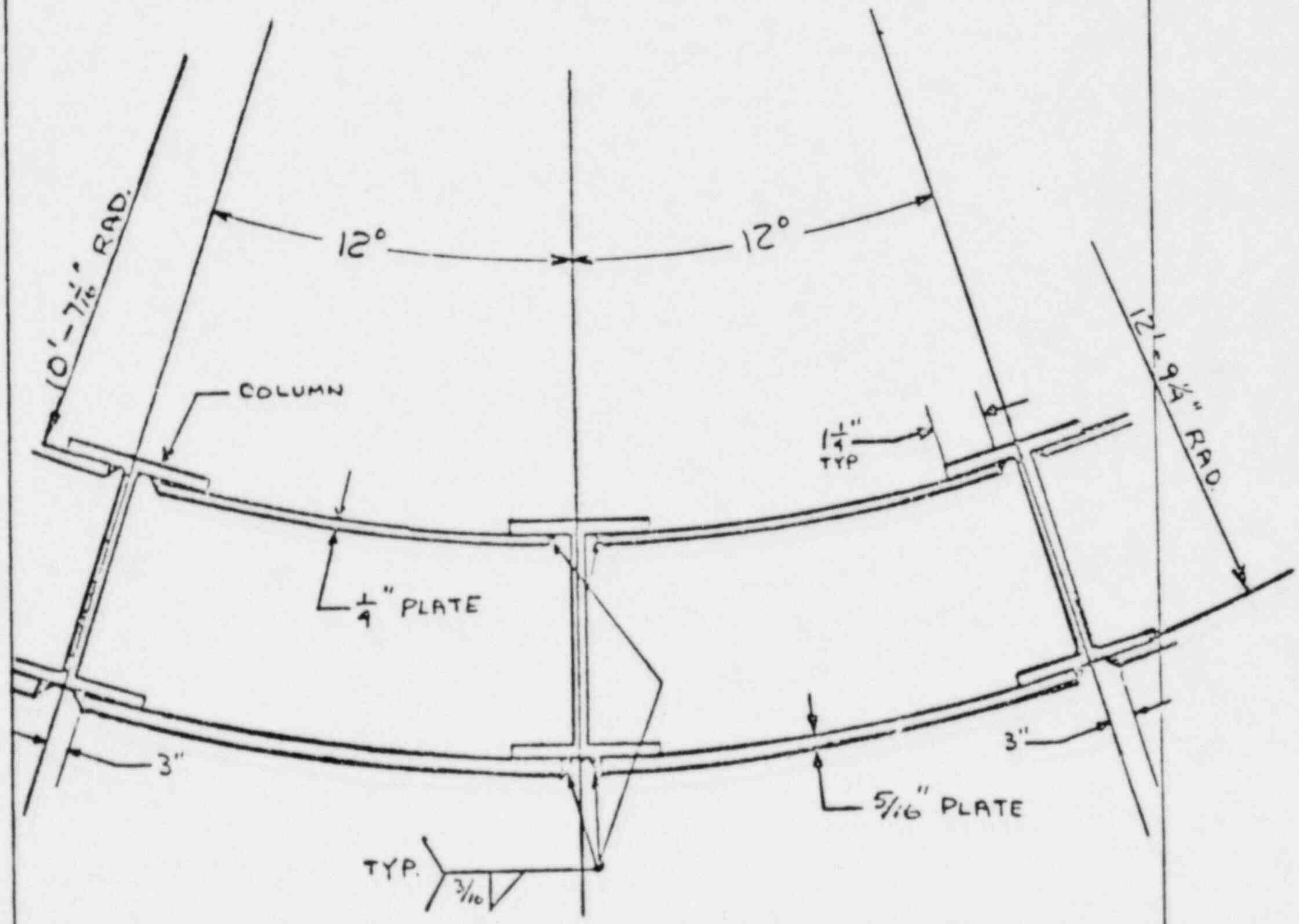
BIOLOGICAL SHIELD—

ARRANGEMENT OF FILLET WELDS

COLUMNS — 27 WF 177; MATERIAL= ASTM A36.

PLATES — THICKNESSES AS SHOWN; MATERIAL= ASTM A36
AND/OR ASTM A283, GRADE C OR D.

ALL WELDING PER AWS D1.0



QUESTION

14.I.

The break-size assumption that you use to arrive at the conclusion that the shield gates will not be blown out is not acceptable. To what extent can the attachments of the gates to the shield be strengthened to provide protection against larger breaks?

RESPONSE

The following provides amplification to Amendment 68, paragraph 5.7.3 and 5.7.4.

A. The geometry of all nozzles penetrating the sacrificial shield wall were examined with respect to their shield opening, and shield gates. Two types of pipe rupture were postulated. These are as follows:

1. Circumferential pipe break at the nozzle-to safe end interface or at the safe-end to pipe interface.

2. Longitudinal split, commencing at the nozzle-to safe end connection, and proceeding through the safe end and the pipe to which it is attached.

B. Based on the relative location of the sacrificial shield components, a determination was made of which portions of the area of the postulated break discharges into the annular space between the sacrifical shield and the RPV. In this evaluation the following assumptions were made:

1. Circumferential break

   a. The pipe downstream of the break was assumed to deflect clear of the shield gate opening.

   b. That portion of the fluid which impinges on the inside surface of the shield or shield gate was assumed to discharge inward and contribute to differential pressure buildup in the annular space.

   c. That portion of the fluid which occupies the opening through the shield gate, was assumed to pass through this opening and discharge into the drywell.

   d. The permali neutron shielding was assumed not to mitigate the impingement.

2. Longitudinal split

   a. The longitudinal split was conservatively assumed to be rectangular in shape as illustrated in Figure 1.

The actual shape of a pipe split would be mouth shaped and could be more realistically approximated by a rectangle bracketed by isoceles triangles at the beginning and end of the split.

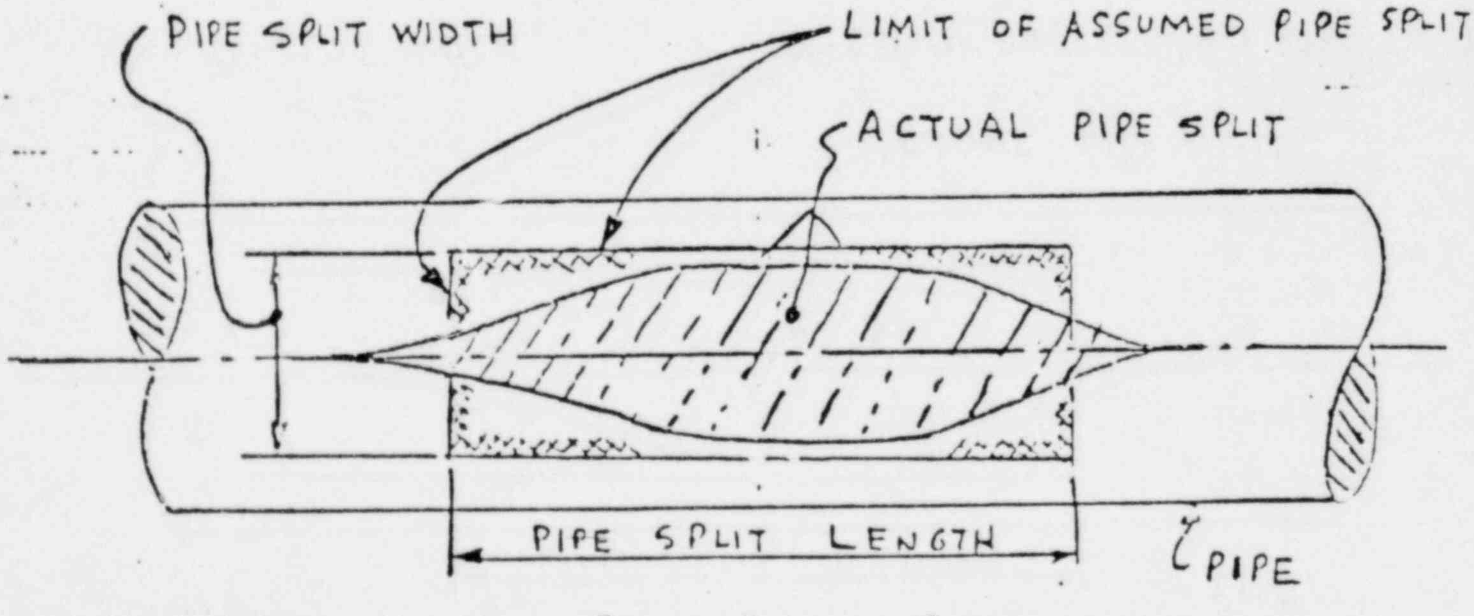
b. The width of the break was assumed to be equal to the full inside diameter of the pipe. For the larger pipes the shield gate opening is not large enough to permit the pipe to open a full 180 degrees arc, therefore, the pipe could not open to the full width but would be smaller than the pipe I.D. at the gate. However, this mitigation was conservatively neglected.

c. The length was assumed to be such that the total break area is equal to the cross-sectional area of the broken pipe, based on the I.D.

d. The split was assumed to commence at the nozzle to safe end interface and proceed through the safe end into the pipe.

e. If the assumed split extends beyond the shield gate, only that portion of the assumed break area that is bounded by the nozzle to safe end interface and the centerline of the shield gate, was assumed to discharge inward, and contribute to differential pressure build-up in the annular space.

FIGURE 1



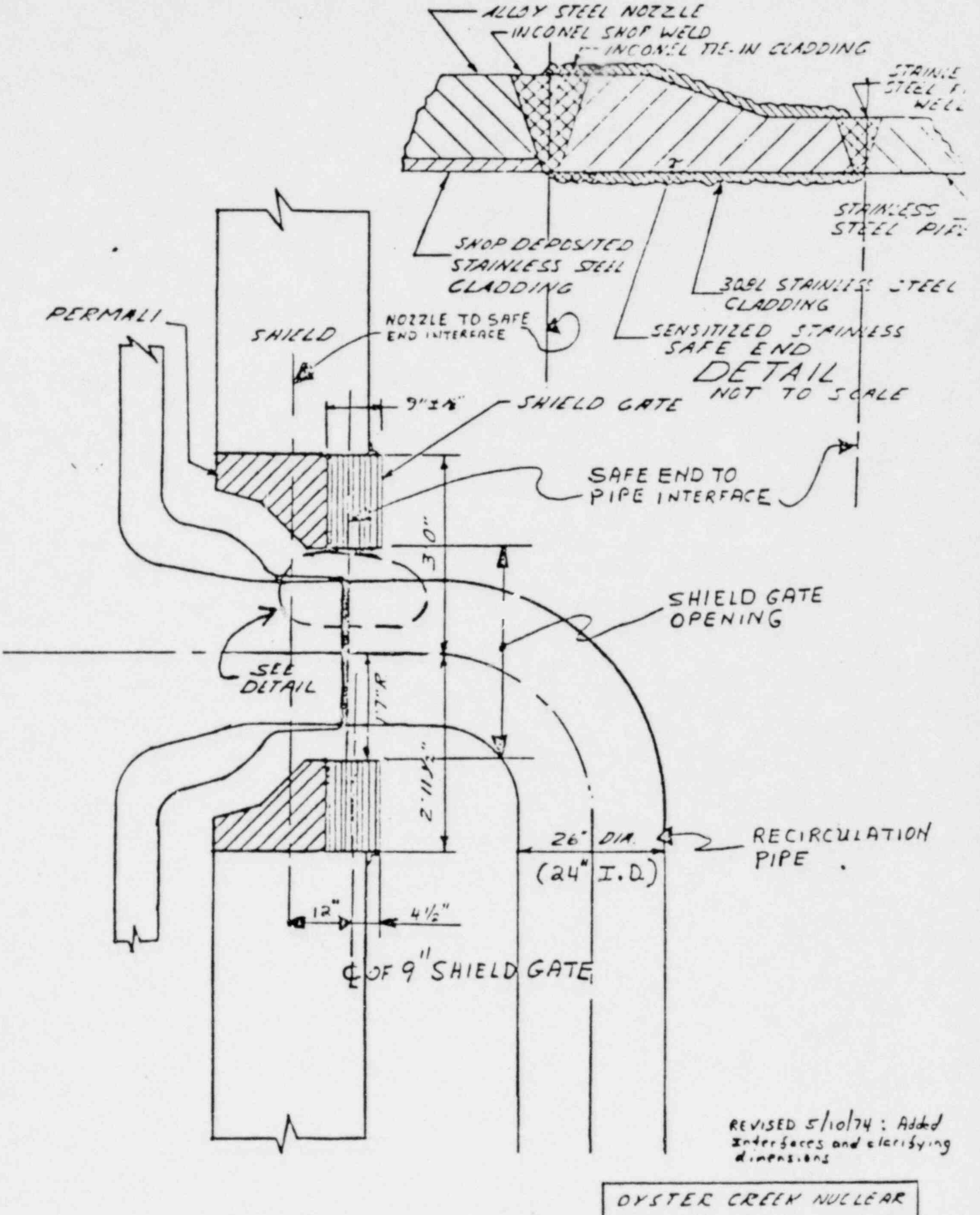
LONGITUDINAL PIPE SPLIT CONFIGURATION

C. As a result of the examination, it was determined that the longitudinal split of a recirculation pipe provided the maximum discharge into the annular space between the sacrificial shield and the RPV.

D. For a circumferential break of the recirculation pipe at either the nozzle to safe end, or the safe end to pipe interface, the entire discharge is through the opening at the shield gate and no portion of the discharge enters into the annular space between the sacrificial shield and the RPV.

E. The maximum pipe break area was found to be 2 feet (I.D.) by 1 foot (comprising the distance between the nozzle to safe end interface and the centerline of the shield gate), or 2 square feet. This resulted in a peak annular pressure of 23.7 psig (see response to Question 14.G.). All other nozzles within the sacrificial shield wall are much smaller than the recirculation lines and have cross-sectional areas at the safe ends less than one square foot. Therefore, none of these could produce peak annular pressures in excess of the 23.7 psig described above. The biological shield wall and shield gates have been found to be adequate for 23.7 psig (see response to Question 14.G.). Therefore, the gates to the shield need not be reinforced.

F. Note that Figure 5.7.2 of Amendment 68 has been revised to show typical interface locations and is attached herewith.



REVISED 5/10/74: Added Interfaces and clarifying dimensions

OYSTER CREEK NUCLEAR
GENERATING STATION

BIOLOGICAL SHIELD
PENETRATION DETAILS

SCALE 1/2" ≈ 1'0"

APPENDIX E

LOADS ON SPHERICAL SHELLS

By:- Philip Thullen

Oak Brook Engineering
Department

Approved By:
W. R. Mikesell

August 1964
Oak Brook Engineering Department

Chicago Bridge & Iron Company
Oak Brook, Illinois

LOAD DEFLECTION TESTS ON SPHERE

In pressure suppression containment systems, the nuclear reactor, steam piping, and recirculating pumps are close to the dry well shell. If a steam or feedwater line breaks, the jet from the line will impinge on the shell resulting in a concentrated load of up to 600 kips on the shell. To allow for pressure and temperature growth, the shielding concrete is separated from the dry well shell a distance of from one (1) to three (3) inches. The shell must deflect this distance before it is backed up by the concrete. Permanent deformation is acceptable, but the shell must not rupture.

PURPOSE OF TEST:

The purpose of this test was to investigate whether or not a steel shell could deflect up to three (3) inches locally without failure. Permanent deformation is not considered as failure. It was also desirable to determine the load required to produce a given deflection, and the strain at various points.

EQUIPMENT:

The basic test section, illustrated in Fig. 1, was designed to simulate a 70 foot diameter sphere. The material and plate thickness are typical of the type found in suppression containment system applications. This section was used as showin in Tests 1 and 2.

For use in Test 3, the basic section was modified by the addition of an 18 inch diameter fitting with insert type reinforcing, illustrated in Fig. 2.

For use in Test 4, the basic section was modified by the removal of the insert type fitting and the insertion of an 18 inch diameter fitting with pad type reinforcing shown in Fig. 3. Both fittings are typical of the type found in such applications.

Loading was done with a 1250 ton capacity hydraulic press fitted with a 20 inch diameter hemispherical die. The loading rate on the test piece was relatively slow because of the characteristics of the press and the time required to take strain gage readings.

When a greater load distribution area was desired, a two (2) inch thick, 14 inch diameter loading plate was placed between the die and the test section. They hydraulic pressure in the press cylinders was indicated on a pressure gage, graduated in 5 psi increments. The gage was calibrated while on the press, using a strain-gage load cell. Loading configurations for the various tests are showin in Figs. 4, 5, 6 and 7.

The test section was instrumented with three gage rosette wire resistance strain gages placed at points of expected high stress. A Baldwin Type 17 portable strain indicator was used as the read-out device. Gage locations for the various tests are shown in Figs. 8, 9 and 10.

PROCEDURE: - Press Calibration

To obtain accurate force data, the hydraulic pressure gage was calibrated while on the press with a strain gage load cell. This method of calibration accounted for the ram weight of 20 tons and friction in the moving parts. It also eliminated the need for any questionable theoretical conversions from hydraulic pressure to die force.

Loading and Data Taking

During each test, the same basic loading and data taking patterns were followed. Loading was accomplished by first allowing the ram to rest on the plate. This gave a load of 20 tons. The hydraulic pressure was then increased in convenient increments. Following each pressure increase, the amount of ram travel was noted and strain readings were taken. This pattern was repeated until the ram had traveled three (3) inches, thus indicating a three (3) inch deflection of the plate. When this deflection was obtained, the ram was withdrawn, permanent deflection noted, and final strain readings taken. All testing was done at ambient temperatures.

Photographs were taken of significant steps of the test. These will be found in the Appendix of this report.

TEST 1

The first test was run to find the effect of a load concentrated over a small area. The load was applied using the 20 inch diameter hemispherical die contacting the plate directly, as shown in Fig. 4. The load was applied only until permanent deformation of the plate was observed.

TEST 2

The second test was designed to determine the effect of a concentrated load applied over a larger area than that of Test 1. Because of the similarity of objectives, the basic test section was not reformed after the conclusion of Test 1, and some permanent deformation remained. To increase the area over which the load acted, a two (2) inch thick 14 inch diameter load plate and a 1/4 inch thick 20 inch diameter plate was placed concentrically below the hemispherical die. These plates were initially flat, as shown in Fig. 6. The 1/4 inch plate served to protect the test section from the edges of the load plate. The two inch load plate tended to distribute the load over a larger area than the hemispherical die alone.

Following the completion of Test 2, an area large enough to accept the 18 inch diameter fitting with insert type reinforcing, was cut in the basic test section. This removed most of the deformation remaining from Tests 1 and 2. The area beyond the cutout was reformed as much as possible and the insert plate was welded in place.

TEST 3

Here the objective was to load the insert plate over a localized area near its edge, as shown in Fig. 6, until a three (3) inch deflection was obtained. The two (2) inch load plate was placed beneath the hemispherical die to distribute the load. The load plate had assumed a dished configuration during Test 2 and it was employed in this form.

The insert plate to shell weld and the area surrounding the weld were magnafluxed before and after the test to find any cracks not evident in a visual inspection.

With the conclusion of Test 3, the insert fitting was removed and the test section reformed as necessary. A section containing the 18 inch diameter fitting with pad type reinforcing was then welded into the basic test section.

TEST 4

This test was run with the same objectives as Test 3. The two tests differ only in the type of reinforcing used around the 18 inch diameter fitting. The load plate was again used, and placed directly above the pad plate as shown in Fig. 7. The test was carried out in a manner similar to Test 3.

RESULTS:

The first test showed that a load concentrated over a small area would cause rapid yielding of the test section. Graphs 1 & 2 show the effect of this type of loading. The deformation is quite localized, and a load of only 60 tons was required to create an eight (8) inch diameter, 0.70 inch deep depression which conformed to the shape of the 20 inch diameter hemispherical die. It appears that a hole could have been punched in the plate rather easily if this loading had been continued.

If a concentrated load is applied to an area of dry well shell that is free of fittings, a condition similar to Test 2 will exist. In Test 2, a concentrated load of 235 tons was required to obtain a three (3) inch deflection. A maximum deflection of 3.3 inches was obtained while the die was in contact with the plate, and permanent deflection of 2.5 inches at the point of loading existed when the die was withdrawn. A profile of the permanent deformation is shown in Graph 1 and some of the deformation is evident in Figs. 8 and 9. In these two photographs the plate has been cut out for Test 3 and some of the deformed area has been removed. There was no evidence of failure in any form following the test. The plate deformed uniformly with no crackes or localized bending. From Test 2 it can be concluded that a spherical steel shell of this diameter and thickness, un under concentrated loading, will deflect three (3) inches without failure.

One severe load which can be imposed on a reinforced fitting is a concentrated load applied over a localized area near the edge of the reinforcing plate. In Test 3, this type of load was applied to an insert reinforcing plate. The load configuration is shown in Figs. 6, 10 and 11. A force of 255 tons was required to obtain a three inch deflection. The maximum deflection obtained was 3.25 inches while the die was in contact with the plate. When the die was withdrawn, 1.95 inches of permanent deflection remained. Magnaflux inspection of the insert to shell weld, both before and after the test showed no cracks. The extent of the deformation is shown in Figs. 12 thru 15. From Test 3 it is evident that a fitting with insert type reinforcing, located in a spherical steel shell, is capable of withstanding a substantial localized deflection without failure.

An alternative form of reinforcing plate, the pad or double plate, was used in Test 4. Again, a concentrated load was applied in a localized area near one edge of the reinforcing plate as shown in Fig. 7. A load of 285 tons was required to obtain a deflection of three (3) inches. The maximum deflection obtained was 3.125 inches, at which point a sudden crack developed. The crack, shown in Figs. 16 and 17, was accompanied by a loud report and a drop in the force exerted by the press from 305 tons to 200 tons. In this test, pad plate reinforcing located in a specific shell configuration and loaded eccentrically over a small area, was not capable of sustaining a 3.125 inch deflection for an extended period of time.

The failure in Test 4 can be partially justified by pointing out that the test section was not truly representative of conditions found in containment system applications. In the process of constructing the section for Test 4, a flat plate four (4) feet in diameter, was welded into the basic test section, as shown in Figs. 3, 7 and 16. The pad plate was also flat. In a normal situation,,the pad plate would have been dished and welded directly to the spherical shell. During the process of the test, the force on the pad plate caused it to pull the flat section of the shell into a dish of the same radius as the basic test section. This induced an excessive amount of bending in the shell at the toe of the pad plate fillet weld. Strain gage 7 was located on the path of the crack, (data in Graph 13), and it indicated excessive bending strains quite early in the test. This gave an indication of possible failure. It must be pointed out that the plate had held a load of 285 tons and a deflection of three (3) inches for a period of 20 minures while 72 strain gage readings were taken, and was holding a load of 305 tons and a deflection of 3.125 inches for a few minutes before it suddenly failed. While this explanation cannot change the fact that a failure occurred, it does point out a condition which caused the test to be overly severe.

An inspection of Graphs 2, 3 and 4 gives an indication of the overall reaction of the test section to the applied load. The amount of deflection due to a given load was approximately the same in each tes. This indicates that local conditions near the point of loading have very little effect on the load-deflection characteristics of the shell.

It would be expected that beyond some distance from the point of load application the effect of the fitting and reinforcing could be neglected. This is illustrated by the following strain gages:

7 of Test 2; 9 and 11 or Test 3; 11 and 13 of Test 4. The gage locations are illustrated in Figs. 8, 9 and 10, and the data is illustrated in Graphs 5 thru 11. While the bending strains differ in each case, the average or tensile strains are quite similar. At about 2'-6" from the point of load application, or 2'-6" from the reinforcing plate if one is present, the same general tensile strains will be found.

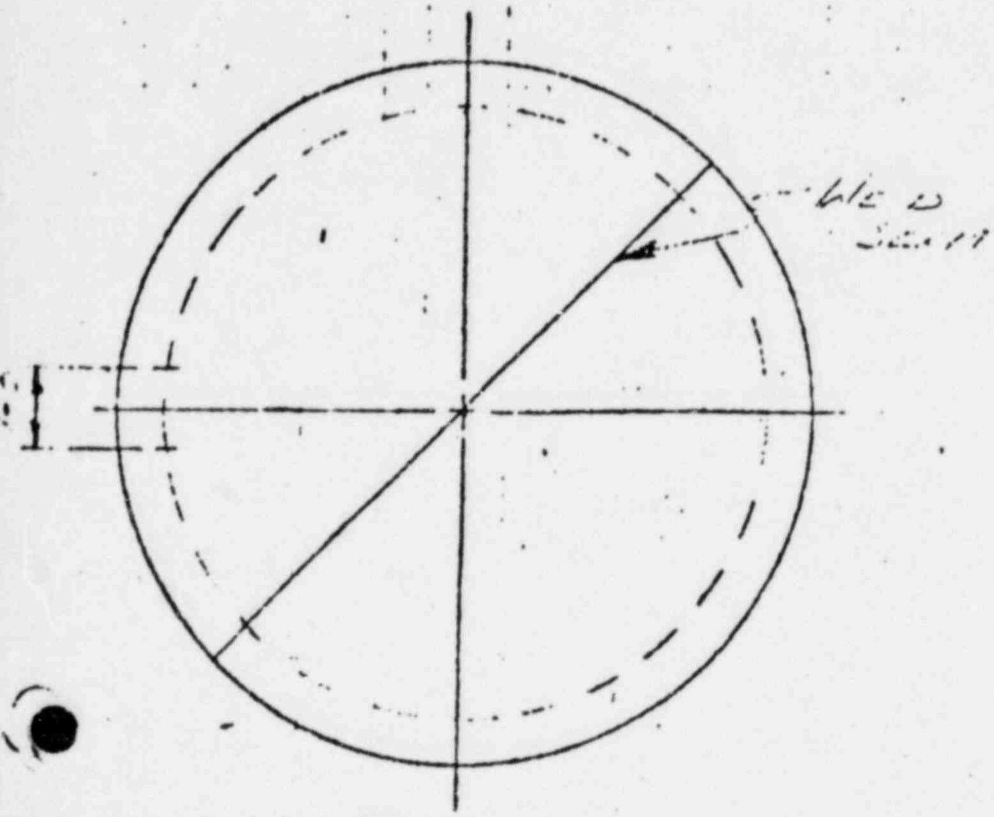
The effect of load transmission by the reinforcing plate can be seen by comparing Graphs 6 and 7 with 8 and Graphs 9 and 10 with 11. Gage locations will be found in Figs. 9 and 10. Comparison of this data indicates that the reinforcing plate was rotated as well as forced downward by the load. This type of reaction is to be expected due to the eccentricity of the point of load application on the relatively stiff reinforcing plate.

The reaction of the support ring will be found in Graph 12. A graph of the theoretical radial strain in the shell, calculated assuming the shell to be a membrane, is also shown. It will be noted that the experimental data conforms rather well to the theoretical values. This indicates that the shell was acting in close conformity to the approximate theoretical model.

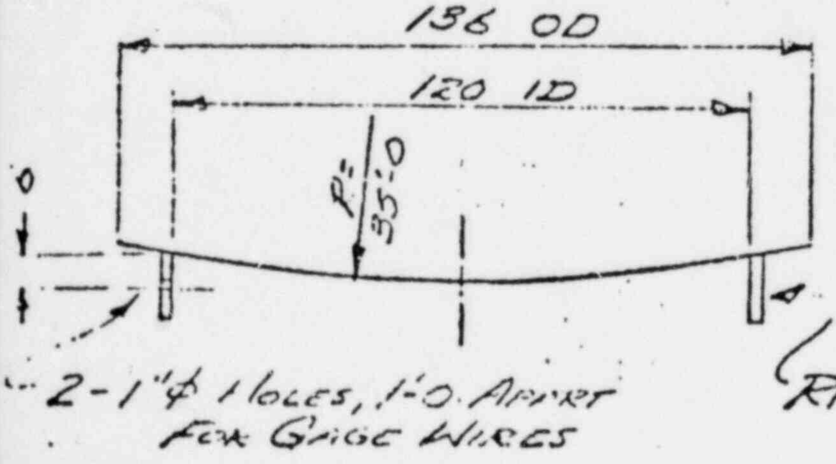
Strain data from the gages not discussed here is available in CB&I Technical file 9107-3-4.

APPENDIX

MATERIAL: NORMALIZED A201

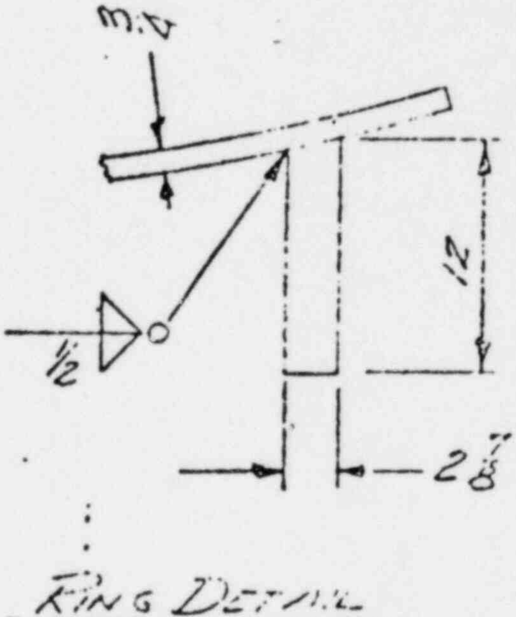


PLAN



2-1"φ HOLES, 1'-0 APART FOR GAGE WIRES

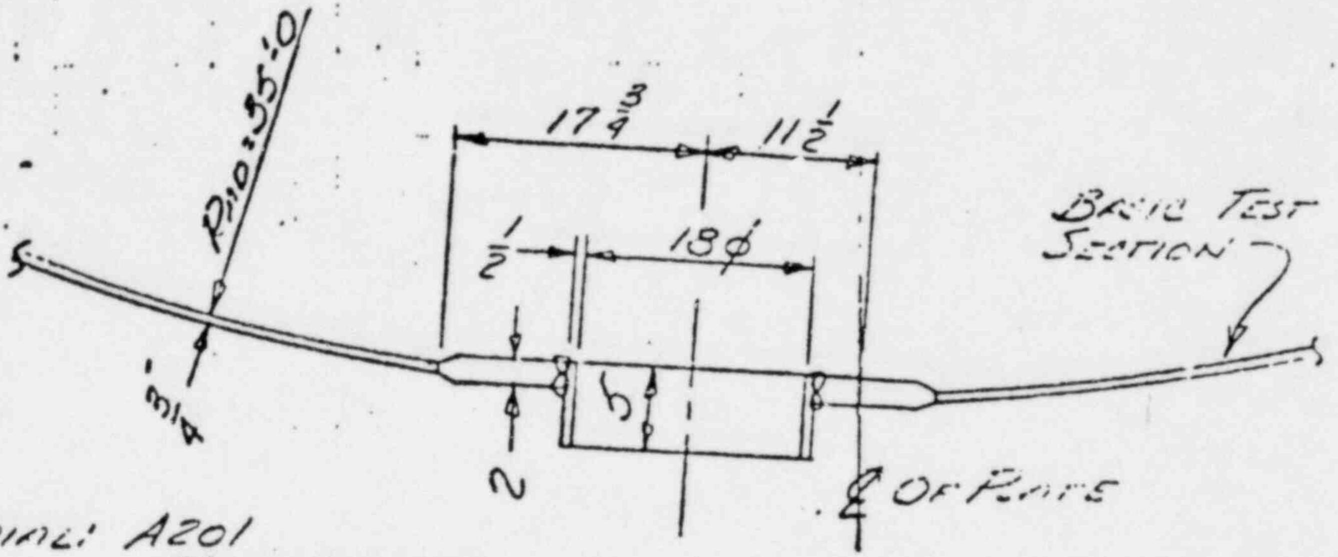
SECTION



RING DETAIL

BASIC TEST SECTION

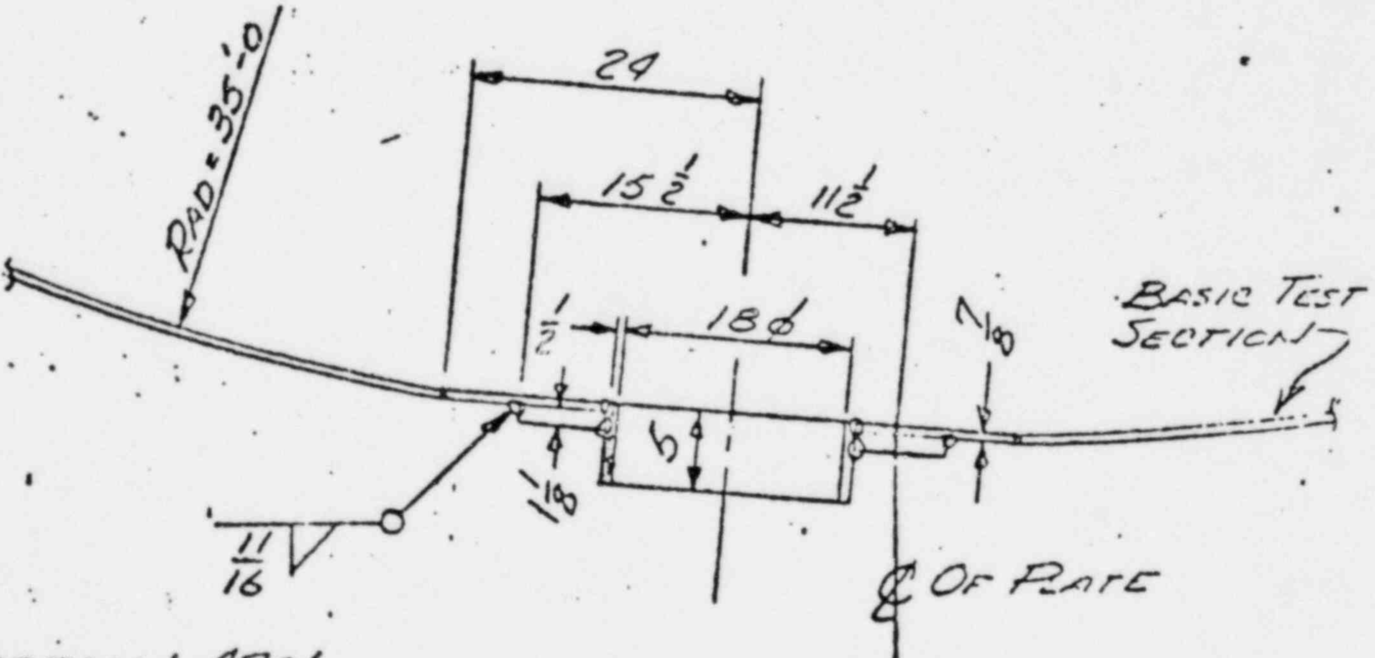
FIG. 1



MATERIAL: A201
NORMALIZED

18⌀ FITTING WITH INSERT TYPE REINFORCING

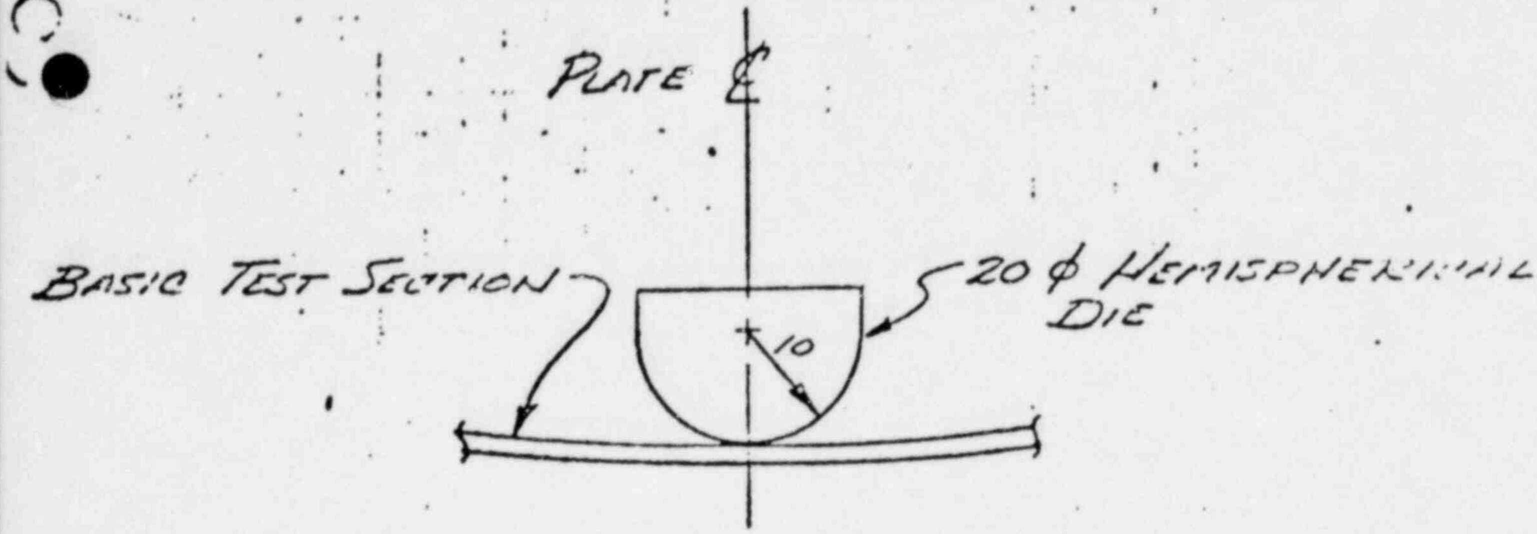
FIG. 2



MATERIAL: A201
NORMALIZED

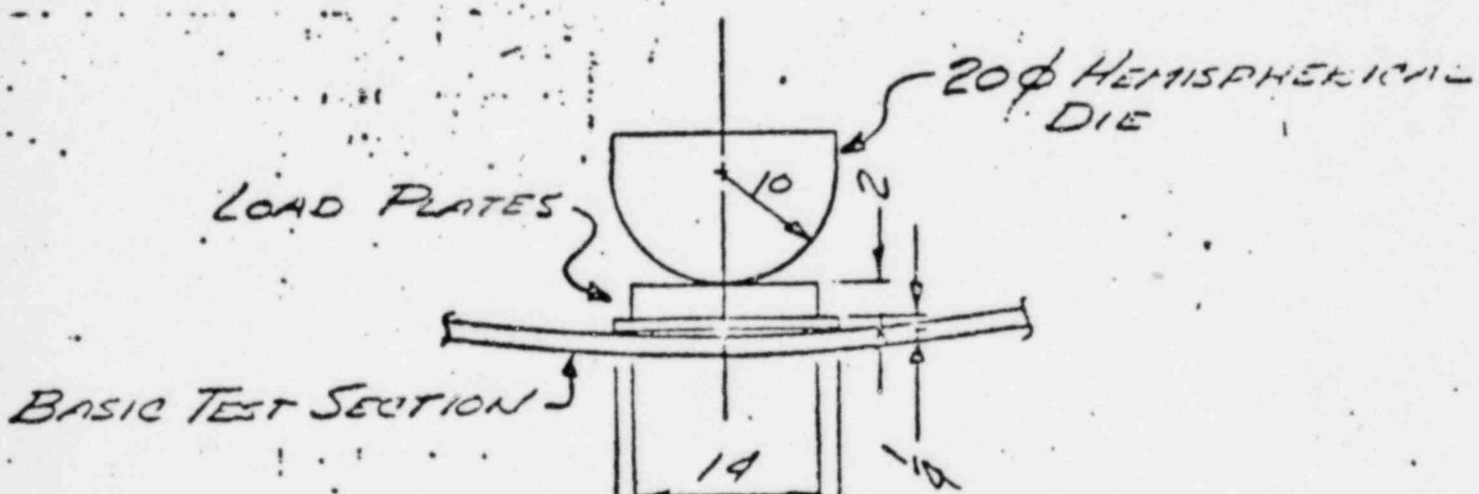
18⌀ FITTING WITH PAD TYPE REINFORCING

FIG 3



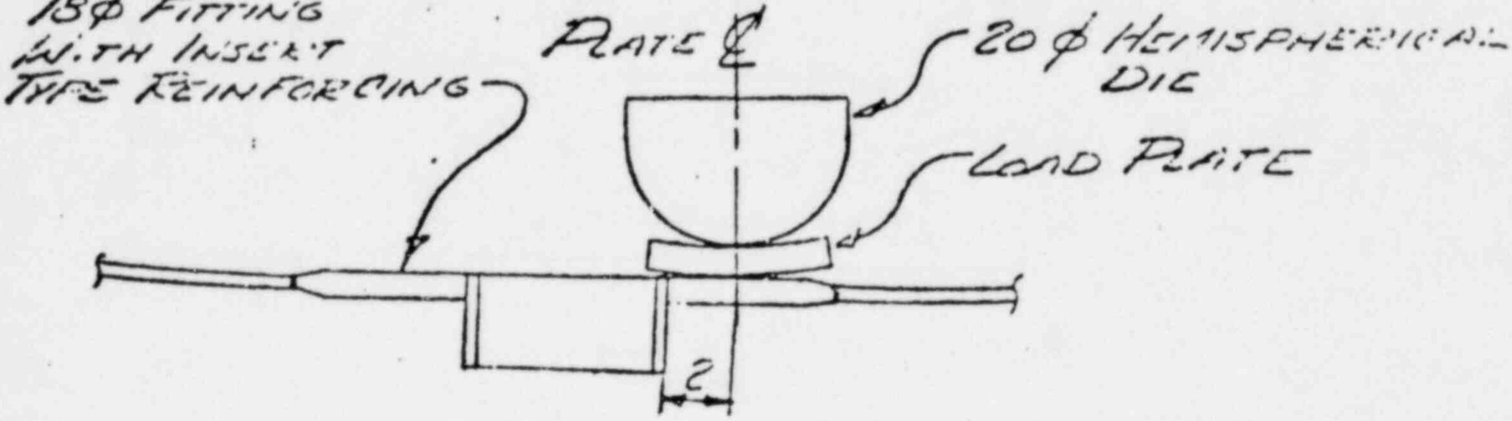
LOADING - TEST 1

FIG. 4



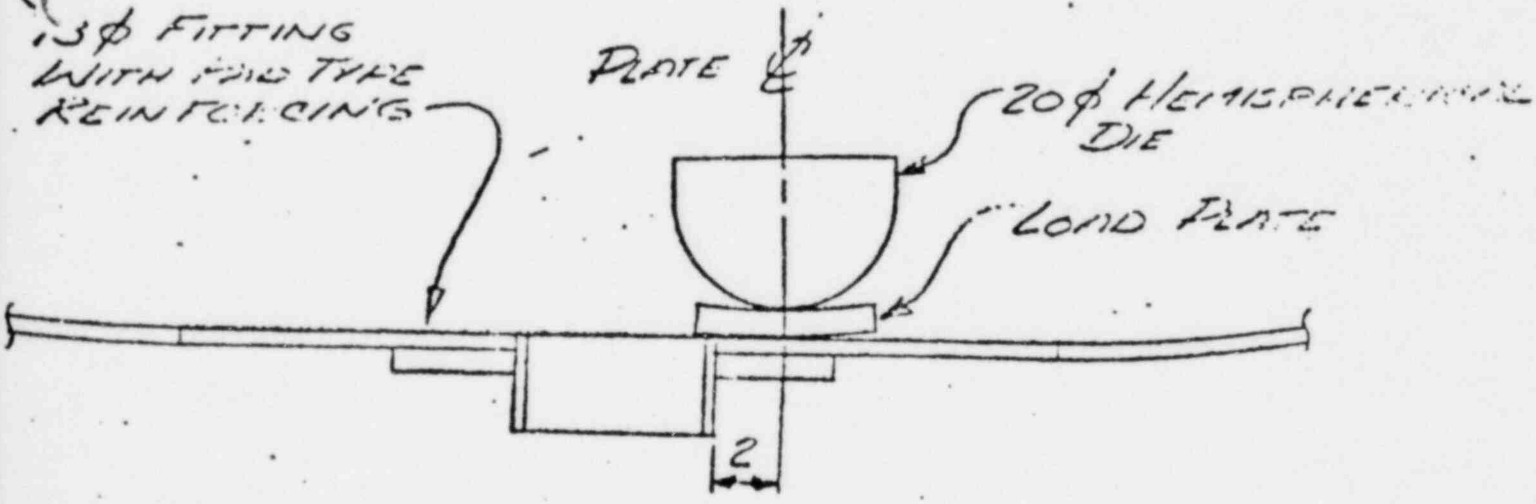
LOADING - TEST 2

FIG. 5



LOADING TEST 3

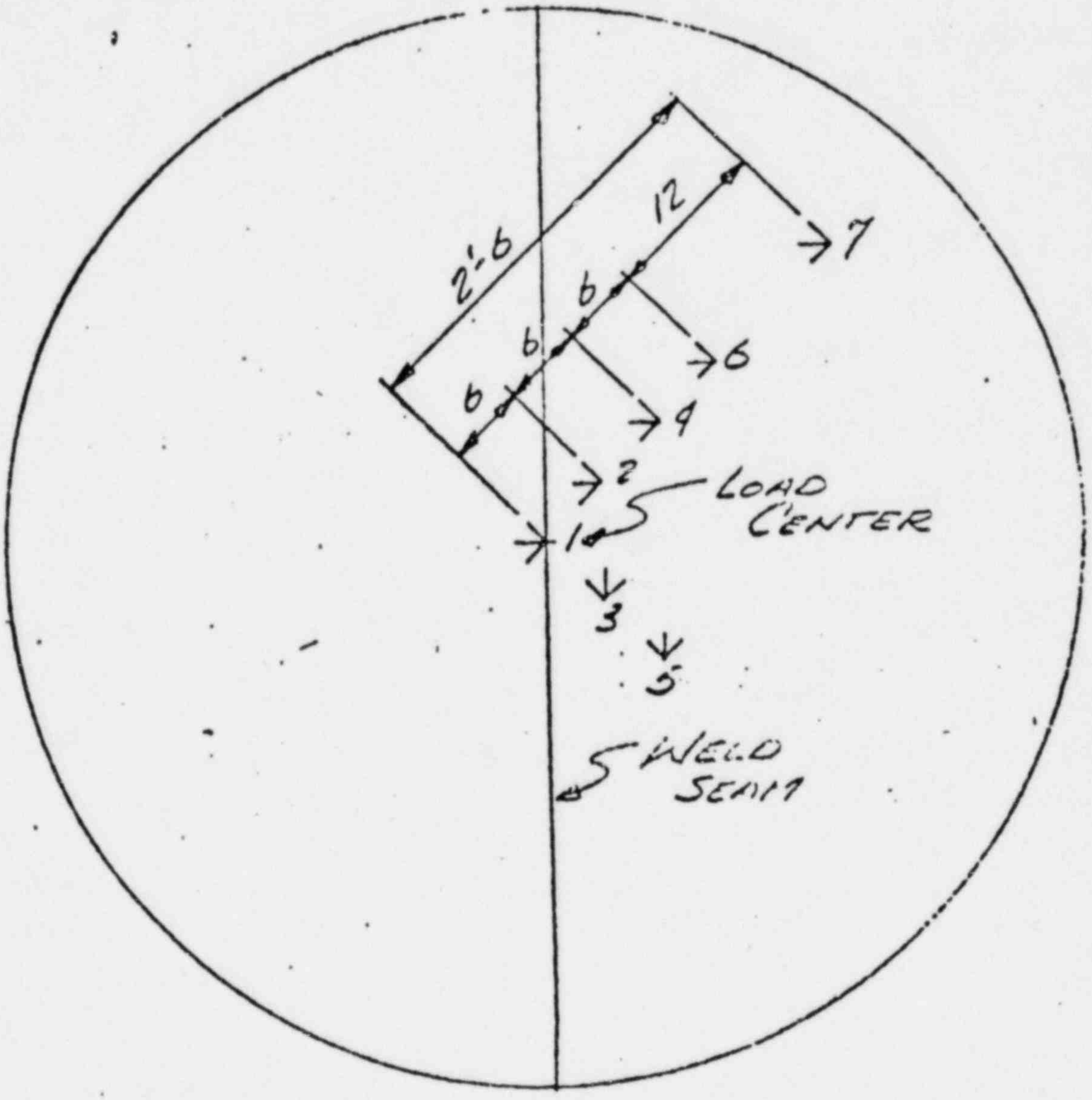
FIG. 6



LOADING TEST 4

FIG. 7

GE / BOTTOM ONLY



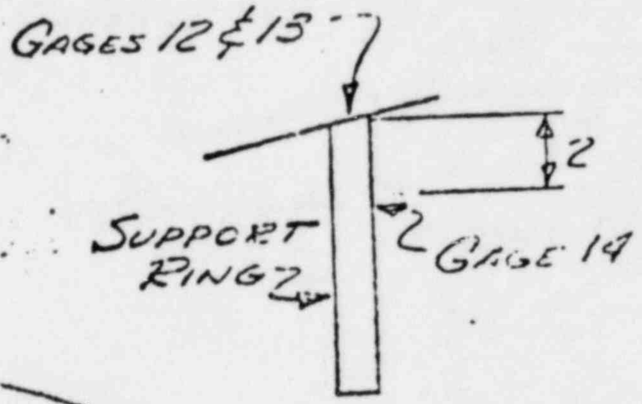
STRAIN GAGE LOCATIONS

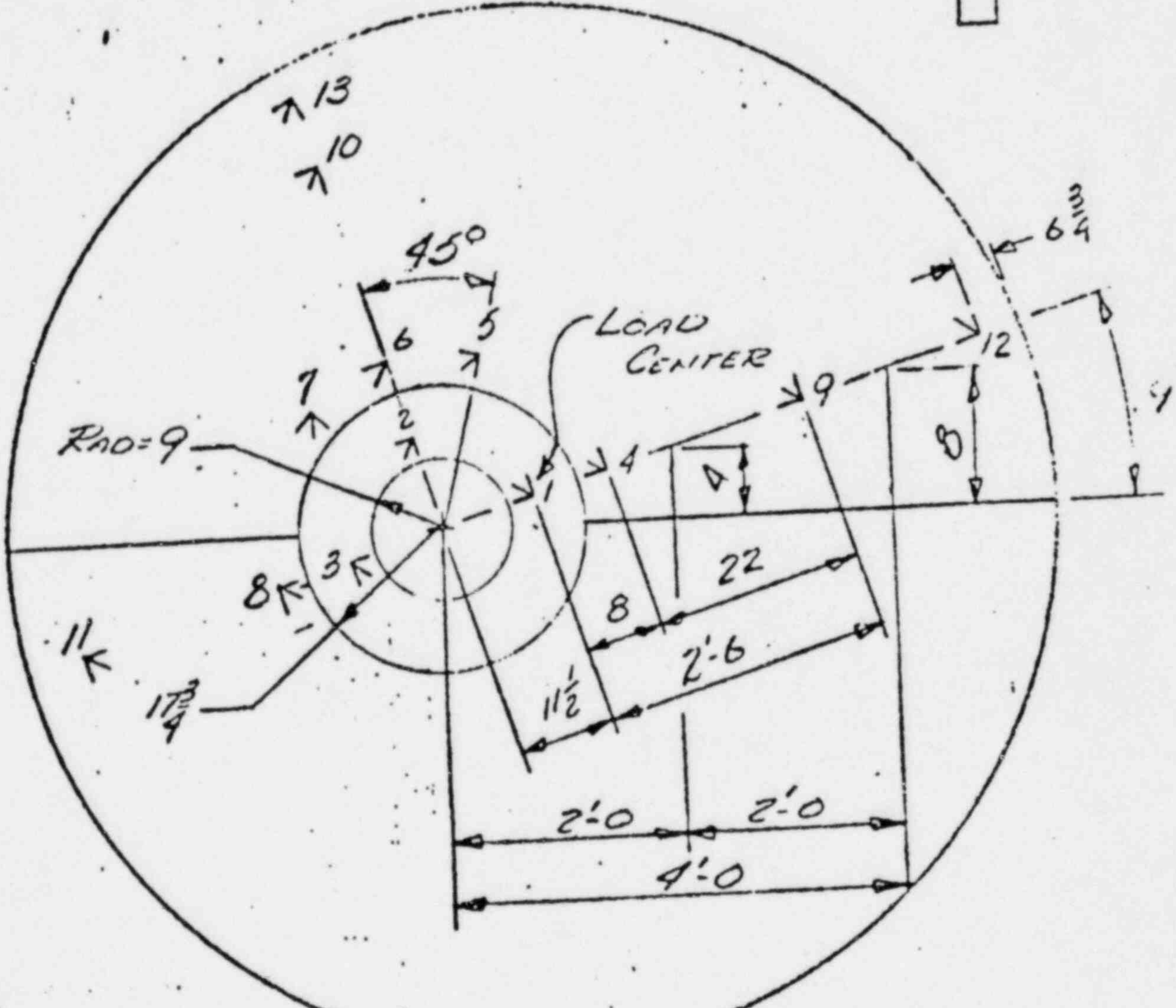
TEST 1 & 2

FIG 8

se 1 Bottom Only

Gages 12 & 13 Above Ring





Strain Gage Locations

18Ø Fitting With Insert Type Reinforcing

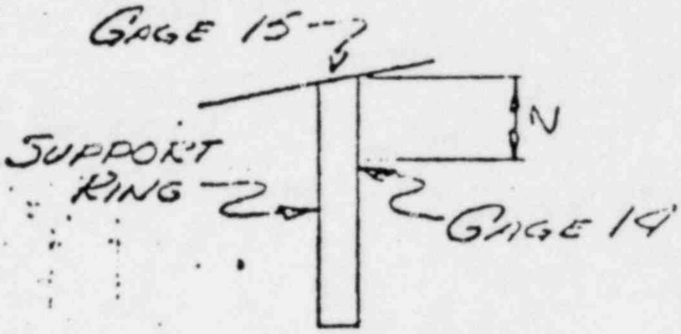
Test 3

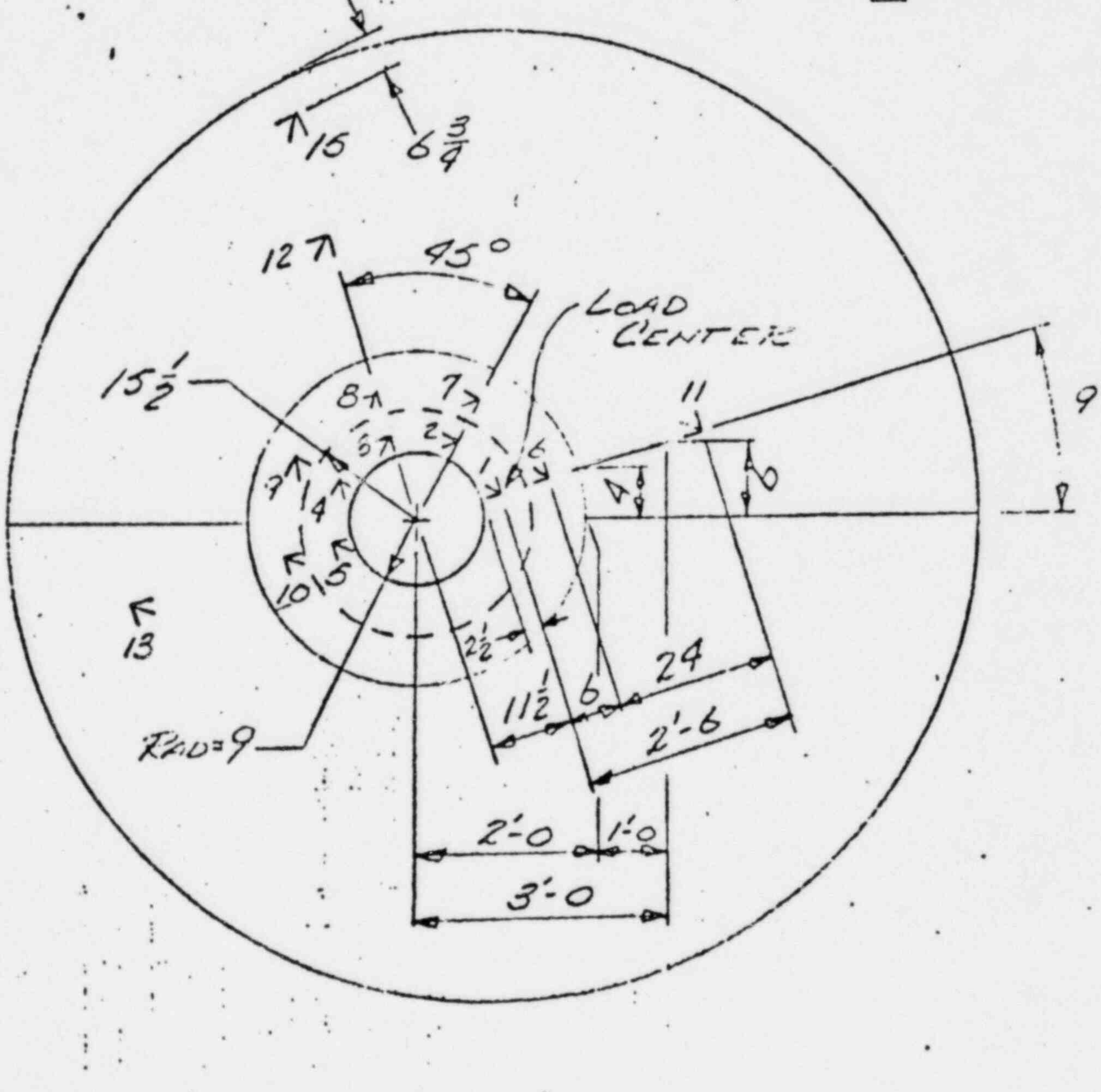
Fig 9

GAGES 1 & 6 BOTTOM ONLY

GAGES 2 & 4 TOP ONLY

GAGE 15 ABOVE RING





STRAIN GAGE LOCATIONS

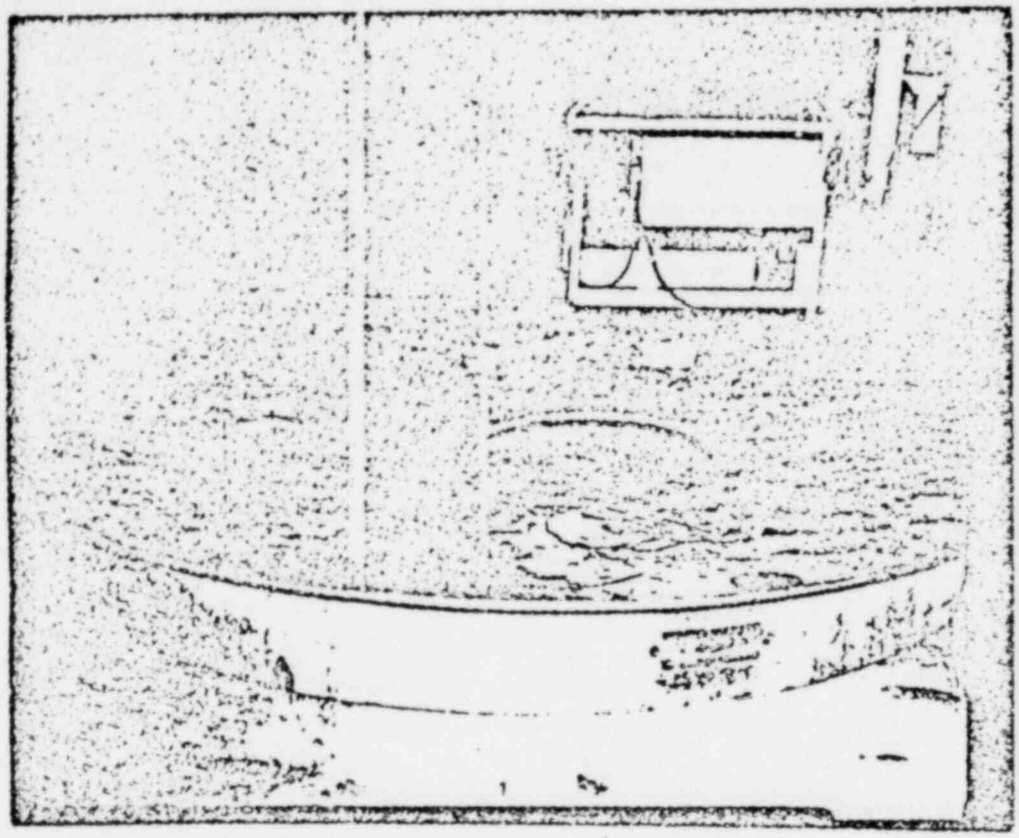
18⌀ FITTING WITH PAD TYPE REINFORCING

TEST 4

FIG. 10

KEV

GAGE LOCATIONS R1656 8 12 64 PT 5

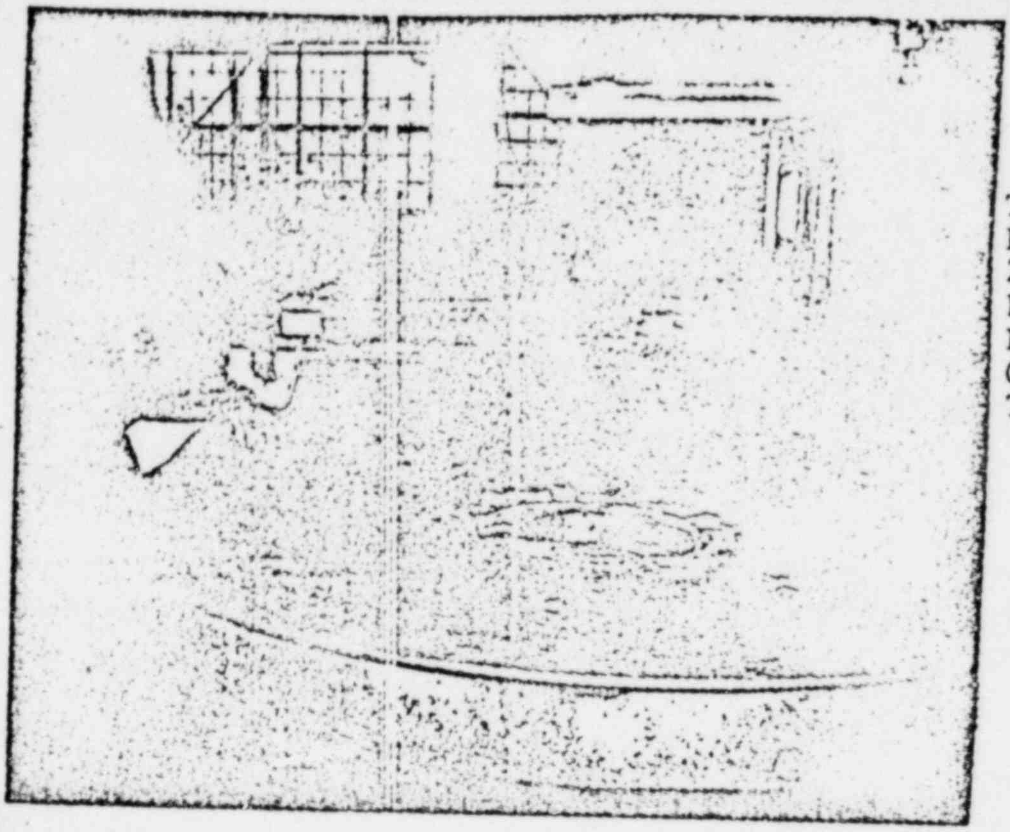


Basic Test Section Following Tests 1 & 2. Cutout for Test 3. Deformation Evident at Left of Cutout.

FIGURE 11

Basic Test Section
Following Tests 1 & 2
Cutout for Test 3
Deformation Evident
At Right of Cutout.

FIGURE 12

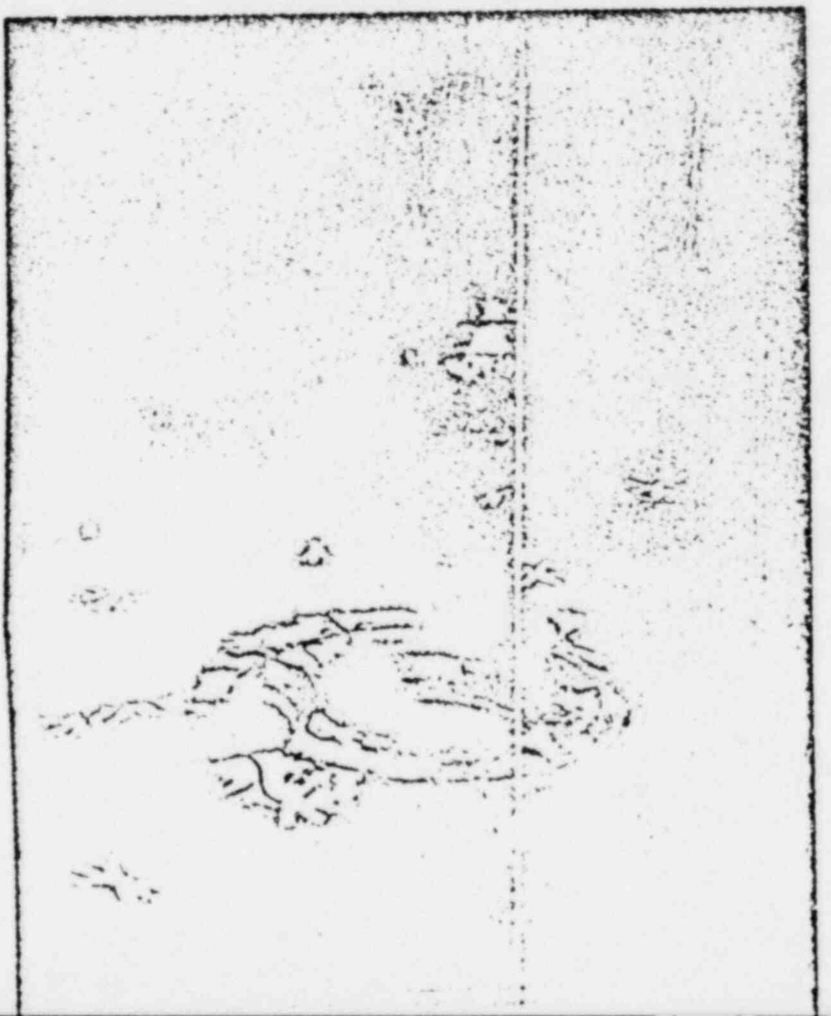


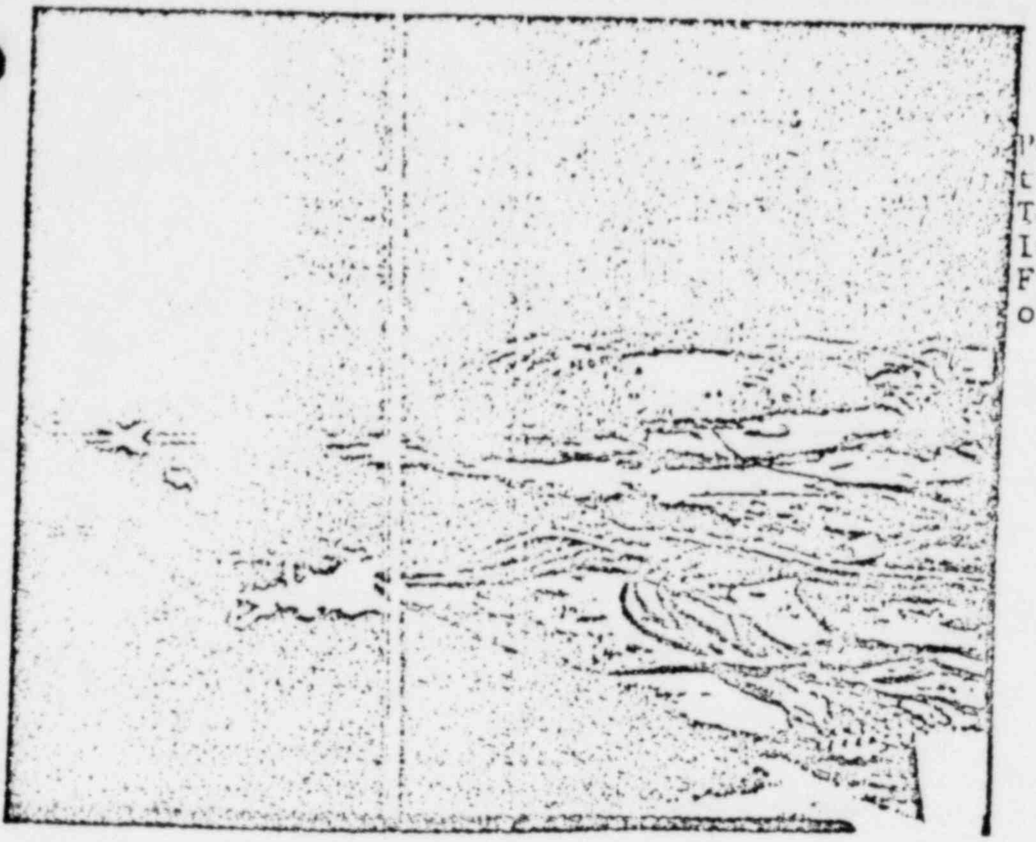
Test Section in
Position For Test 3.
20 inch Diameter Die
Directly Above Load
Plage. Initial Strain
Gage Readings Being
Taken.

FIGURE 13

Detail From Figure 10
Above

FIGURE 14



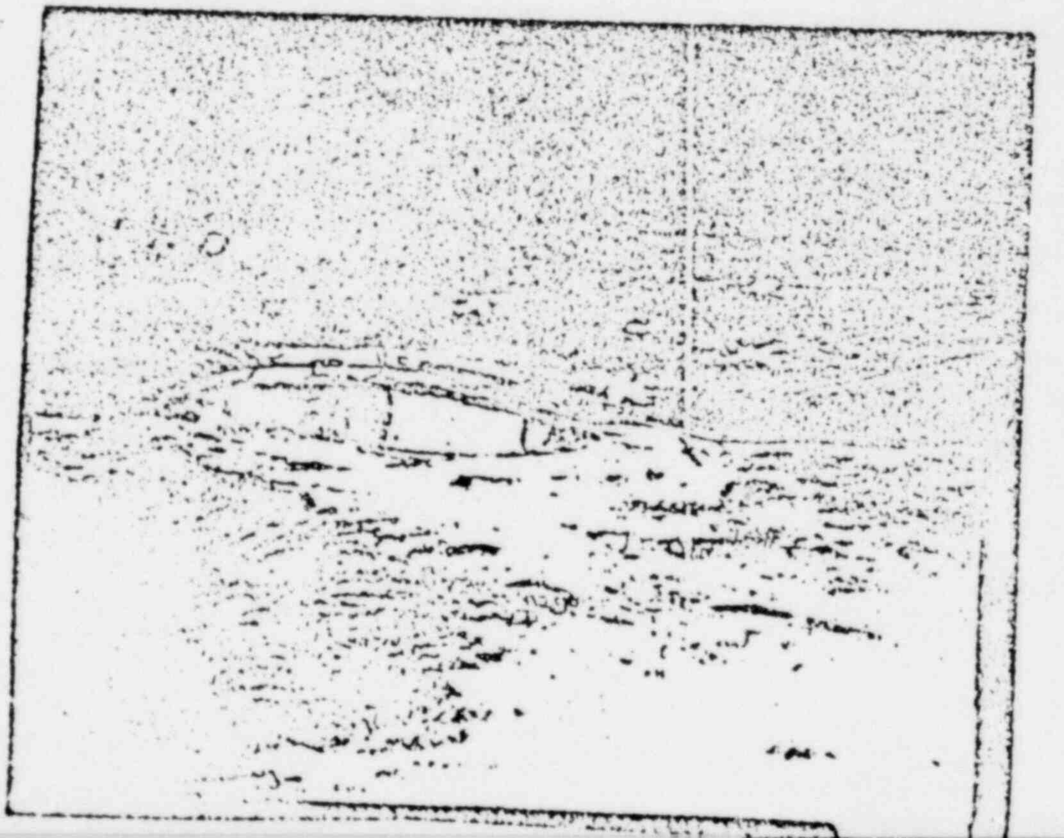


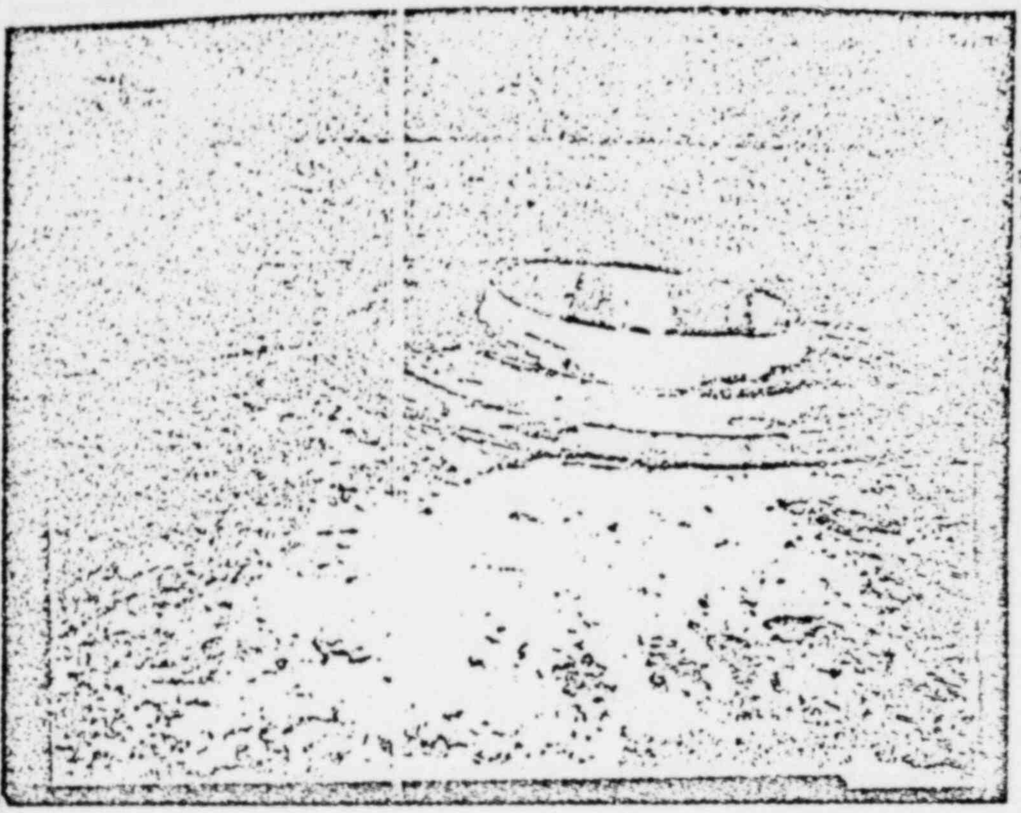
Permanent Deformation Resulting From Test 3.
Insert Plate Initially Flat. Note Evidence of Insert Rotation.

FIGURE 15

Same as Figure 12
View From Opposite Side

FIGURE 16



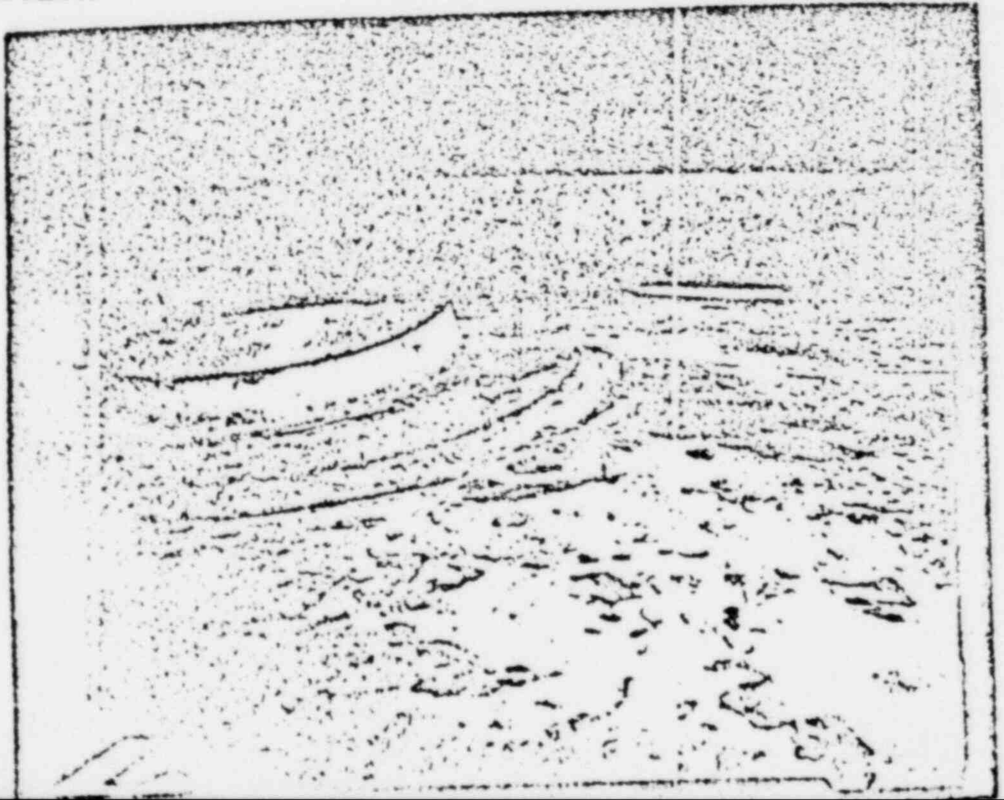


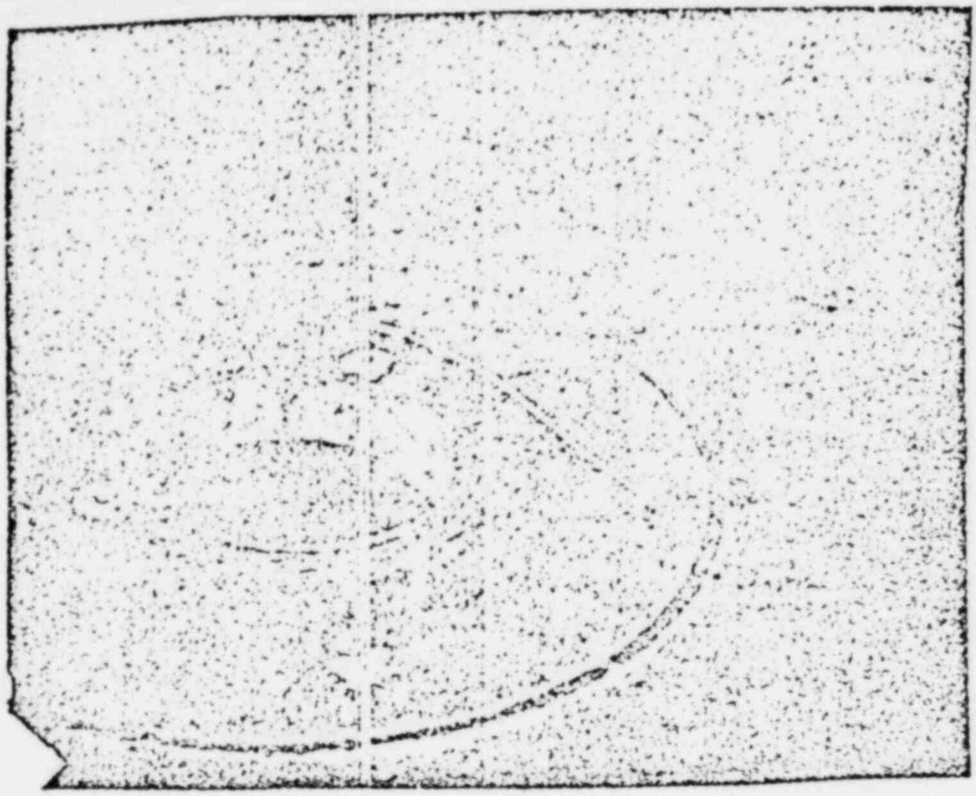
Permanent Deformation Resulting From Test 3. Bottom View.

FIGURE 17

Same As Figure 14 View From Opposite Side Insert Rotation Evident.

FIGURE 18



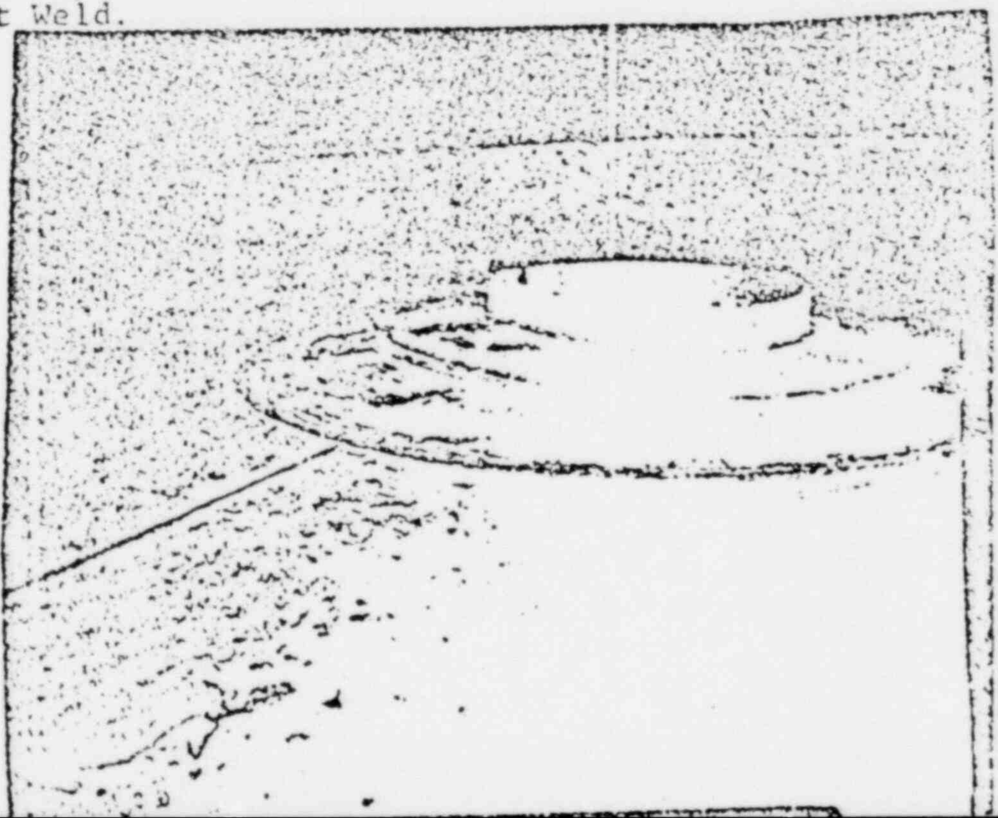


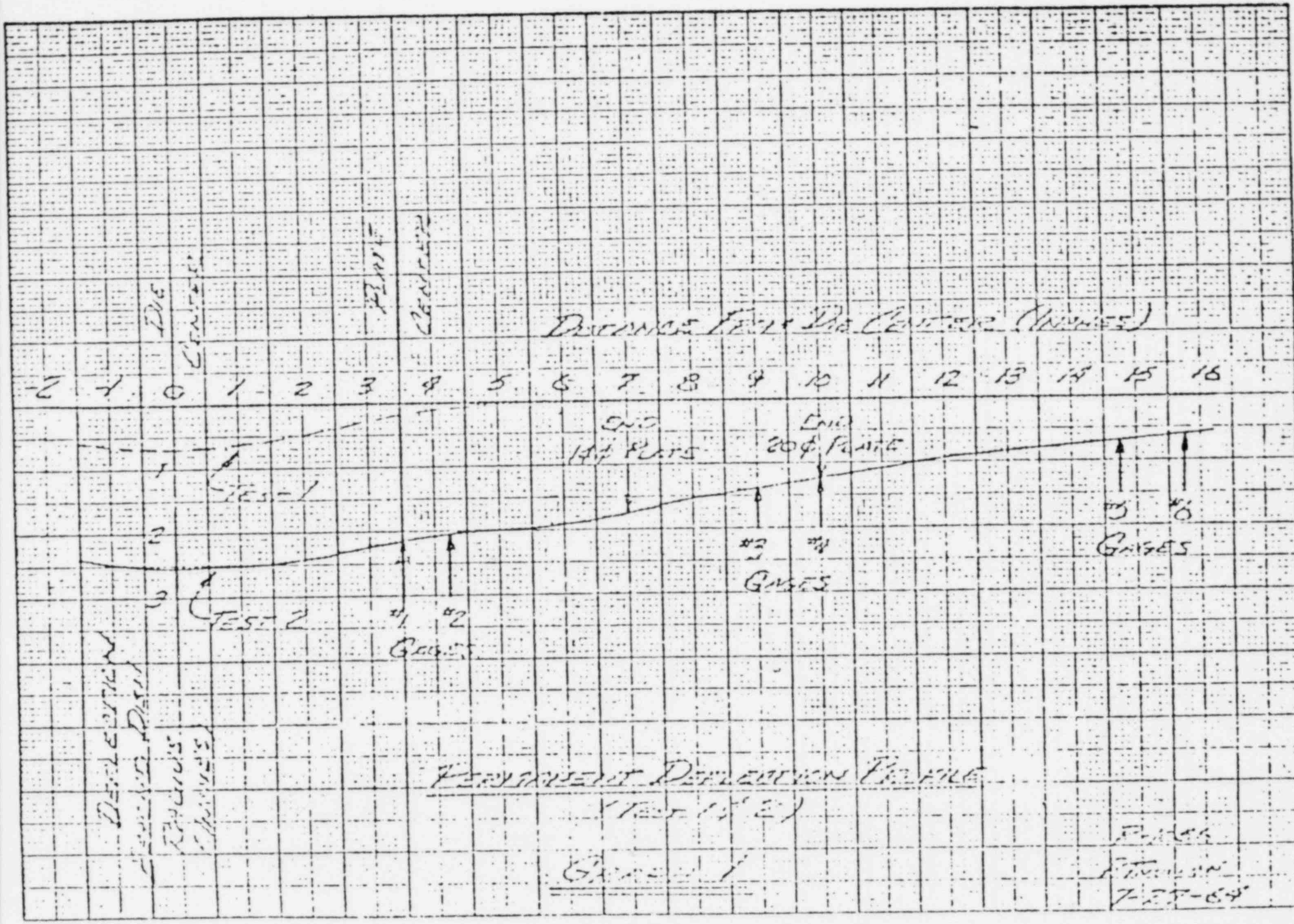
Top View, Fitting With Pad Reinforcing. Crack Which Developed During Test 4 Evident.

FIGURE 19

Bottom View, Fitting With Pad Reinforcing Note that Crack Initially Follows Toe of Fillet Weld.

FIGURE 20



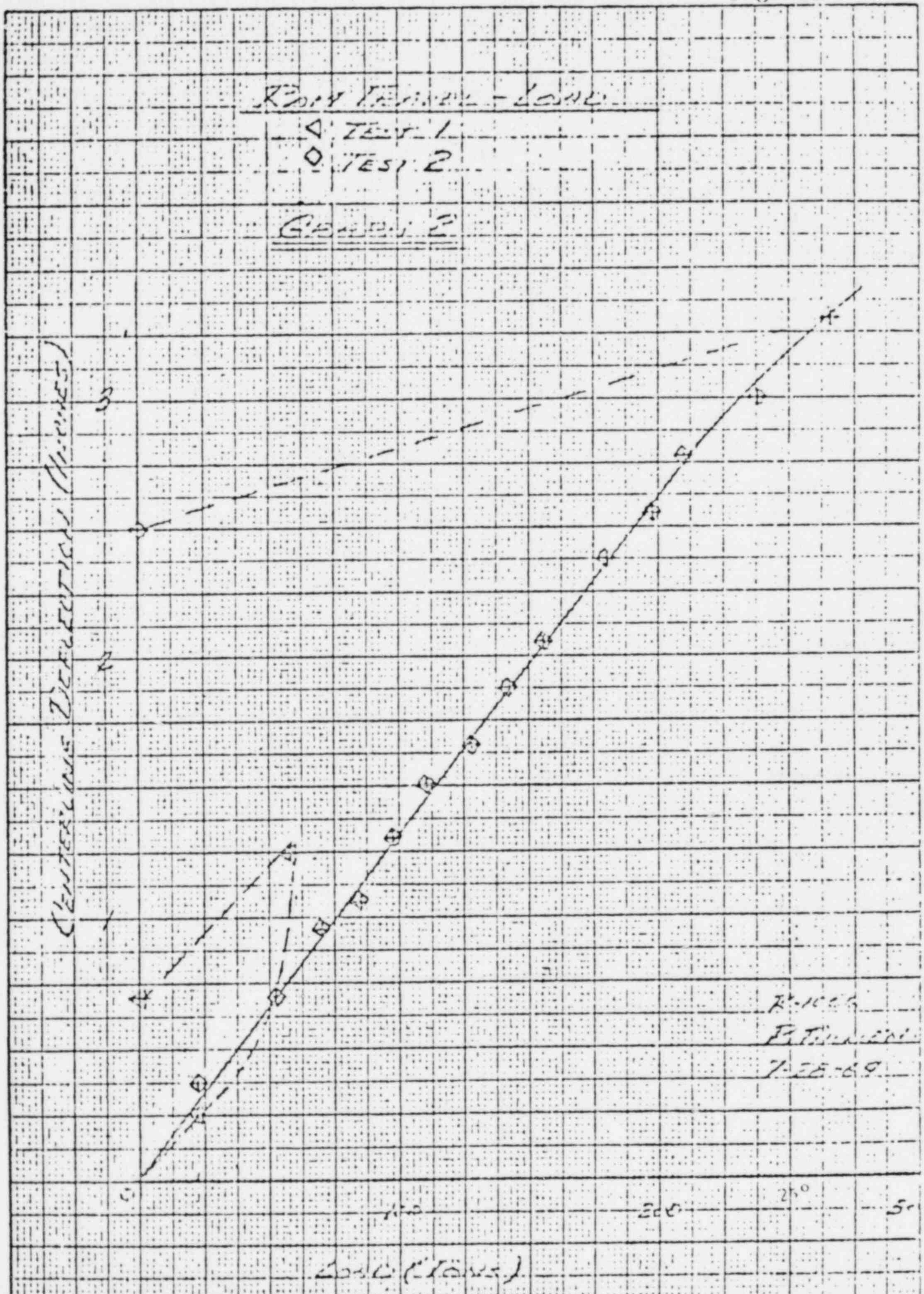


Permanent Deflection Profile

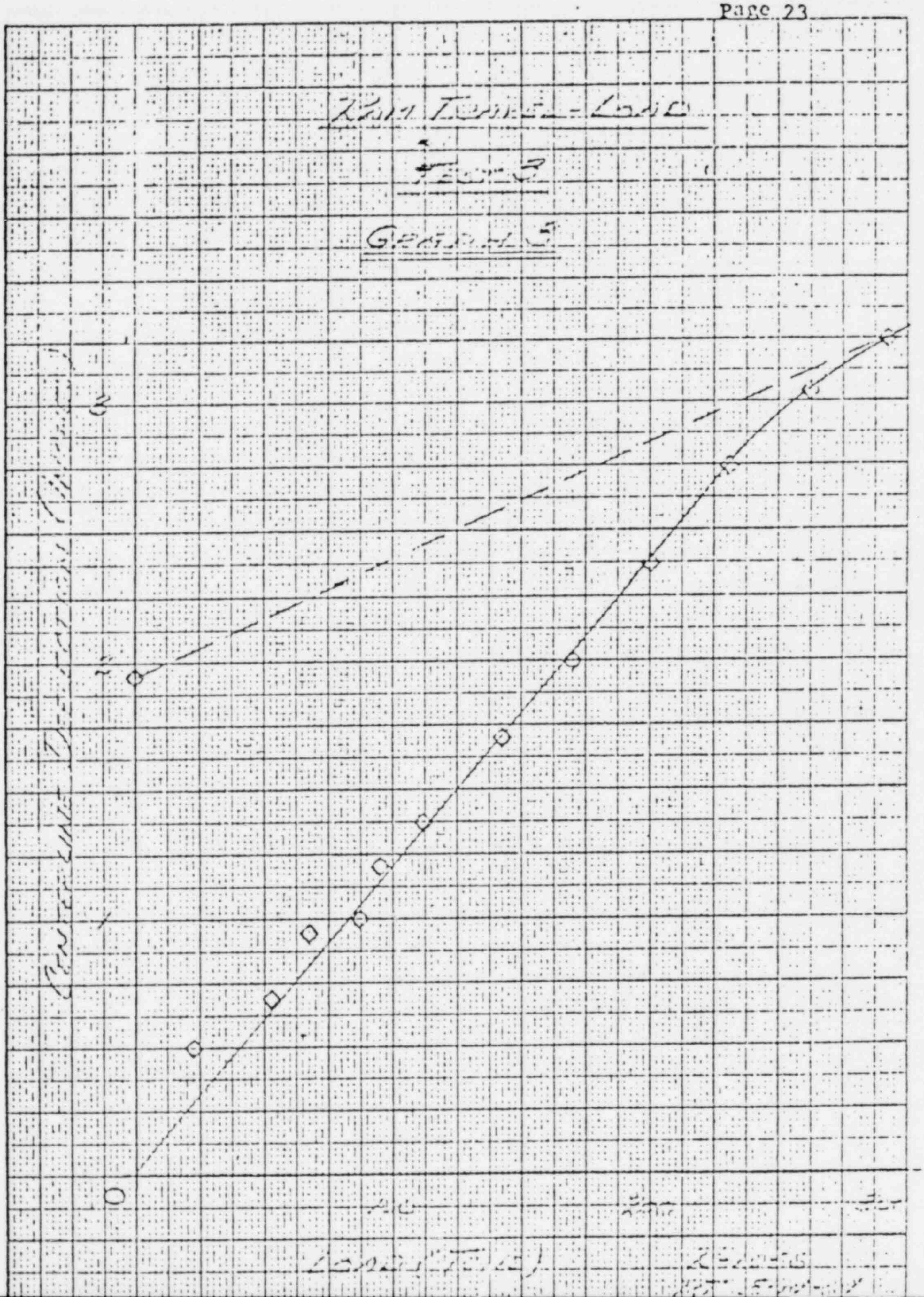
(Test 1 & 2)

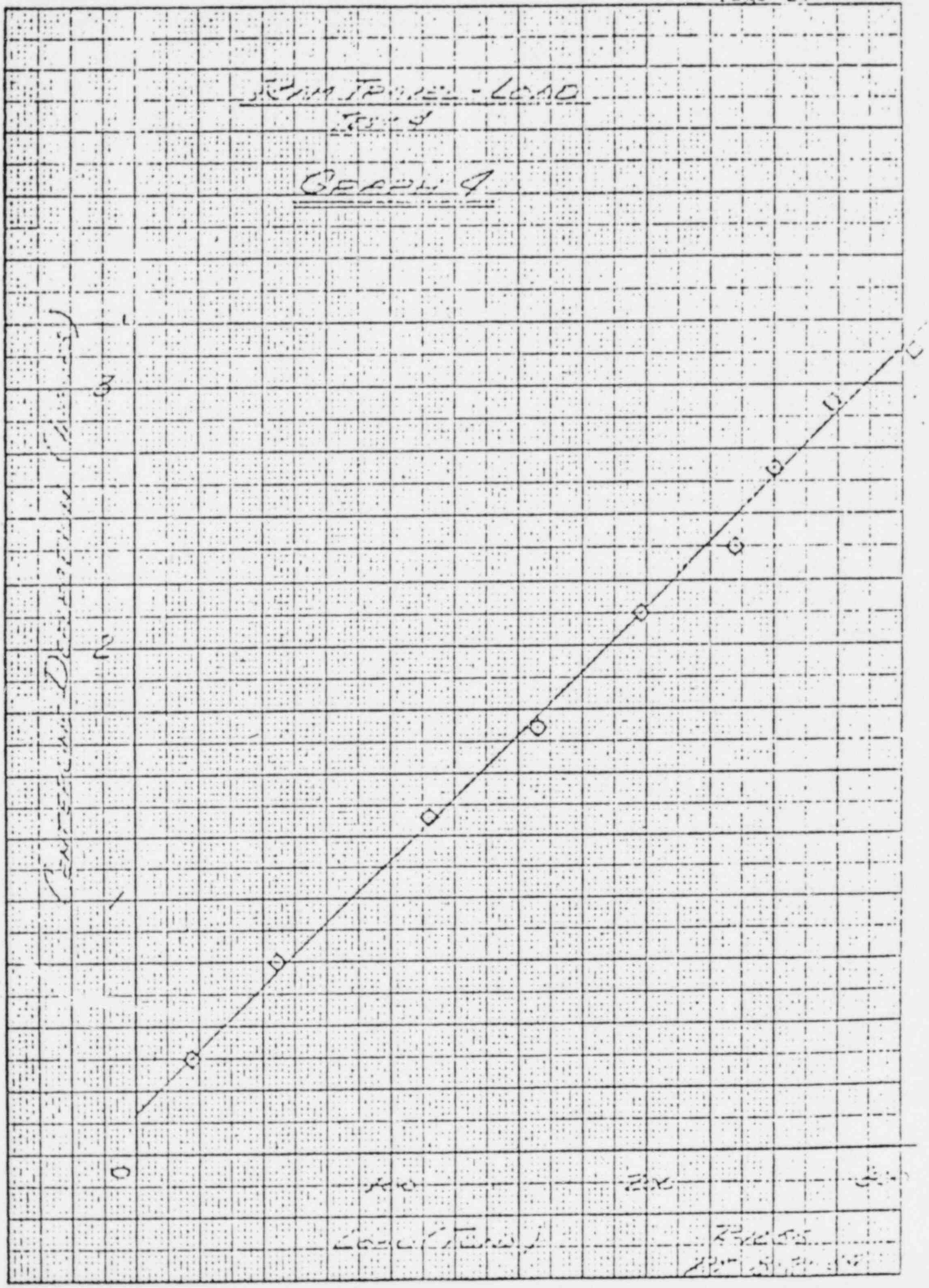
Graph 1

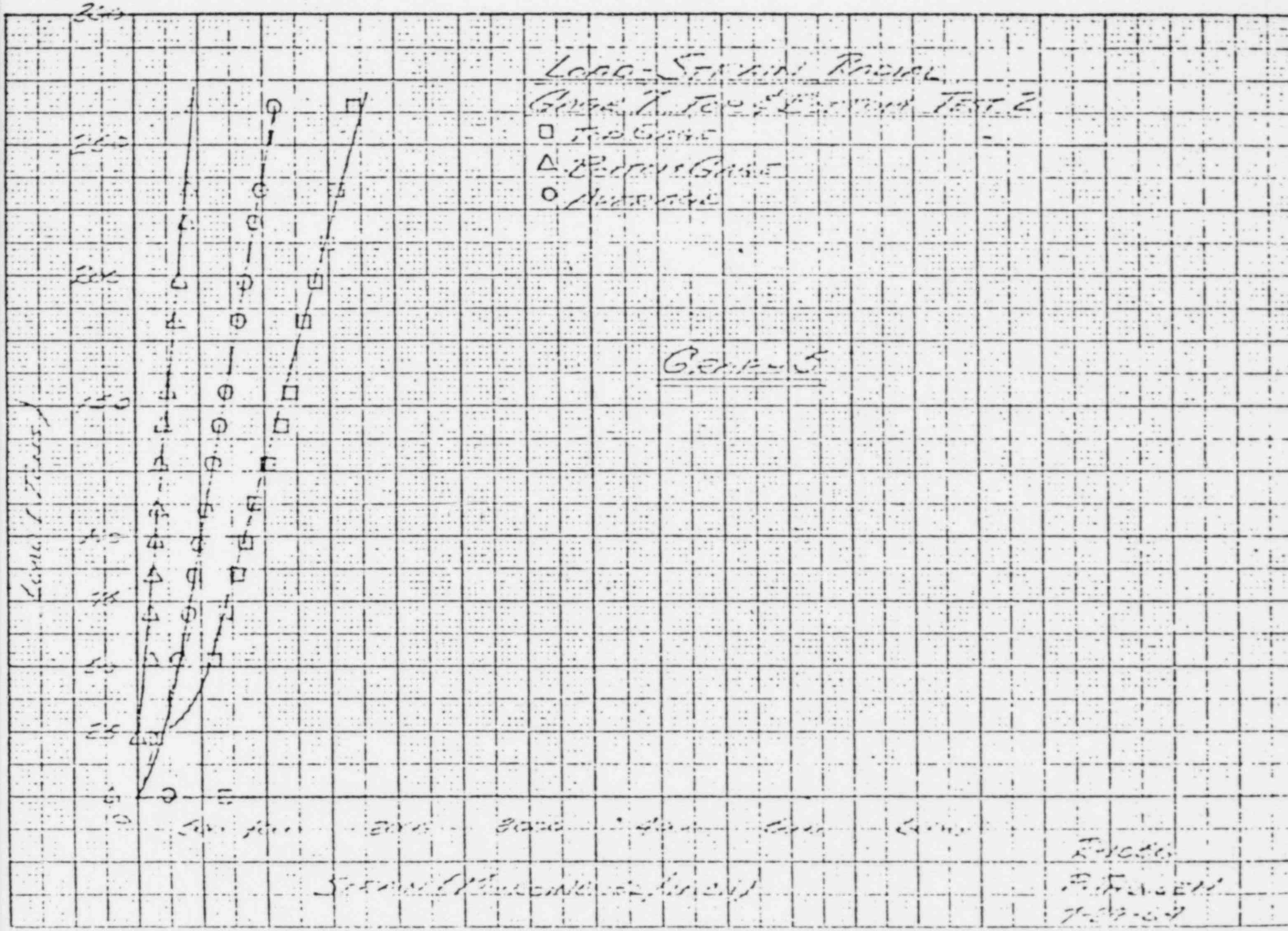
Pahl
Flavin
7-27-67

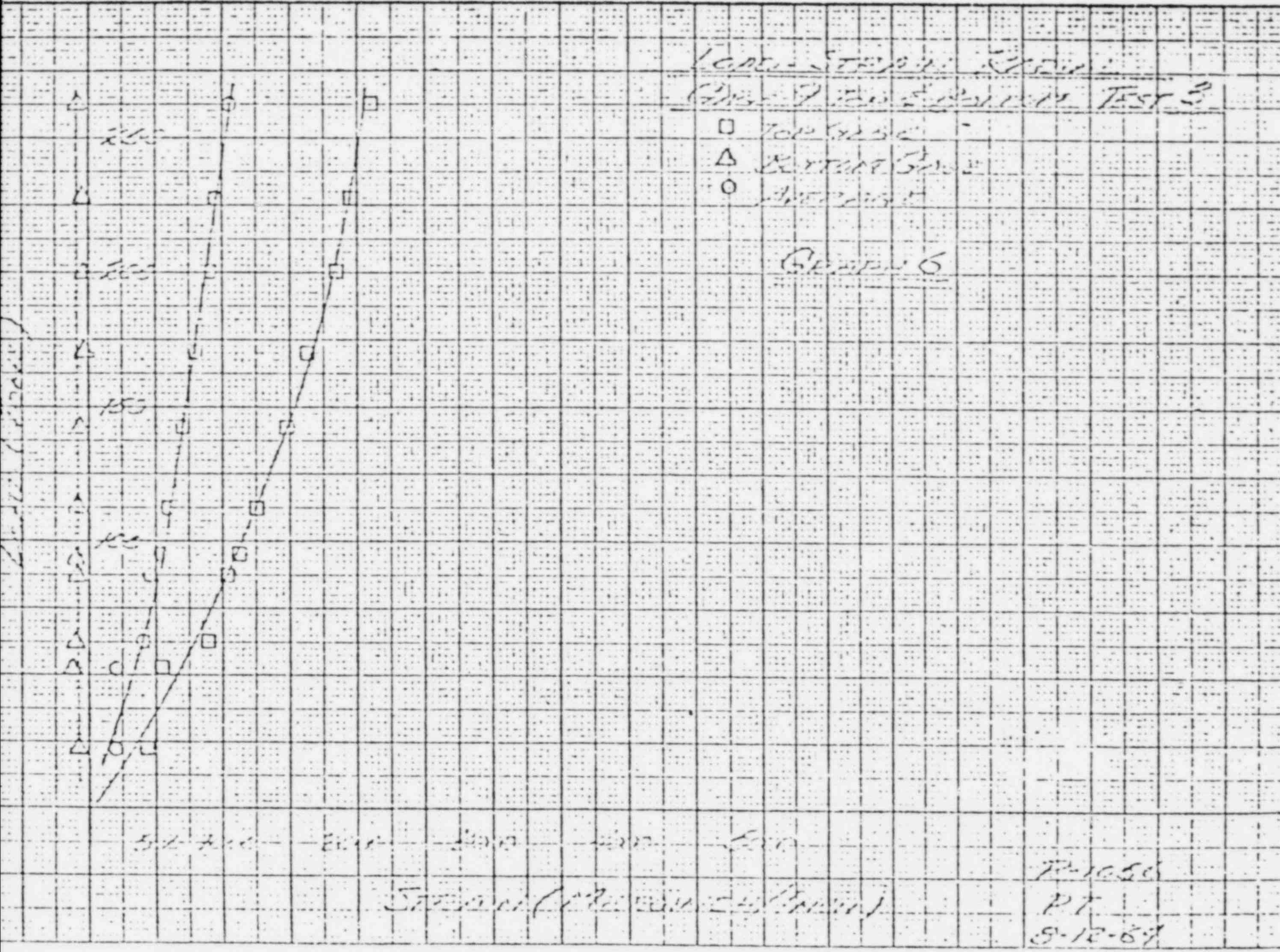


K&E 10 X 10 TO THE ½ INCH 359-11G
KEUFFEL & ESSER CO.


0

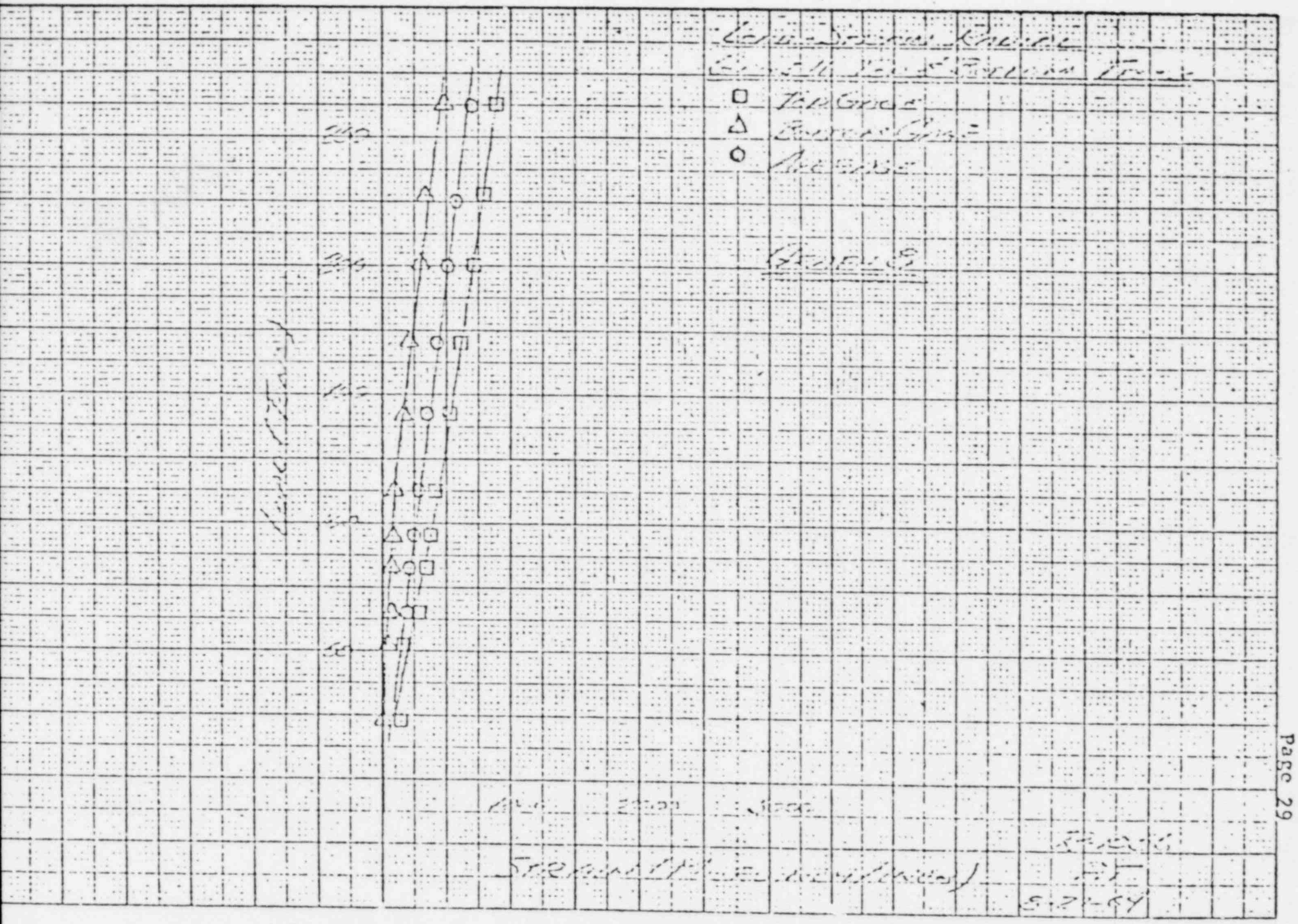

RAM TRAVEL - LOAD
GRAPH 4
3
2
1
0


Load-Strain Profile
Gage 7 Top of Earring Test 2
□ Top Gage
△ Bottom Gage
○ Average
Gage 5
Load (Tons)
0
25
50
75
100
125
150
175
200
225
1000
2000
3000
4000
5000
6000
Strain (Microinches/inch)

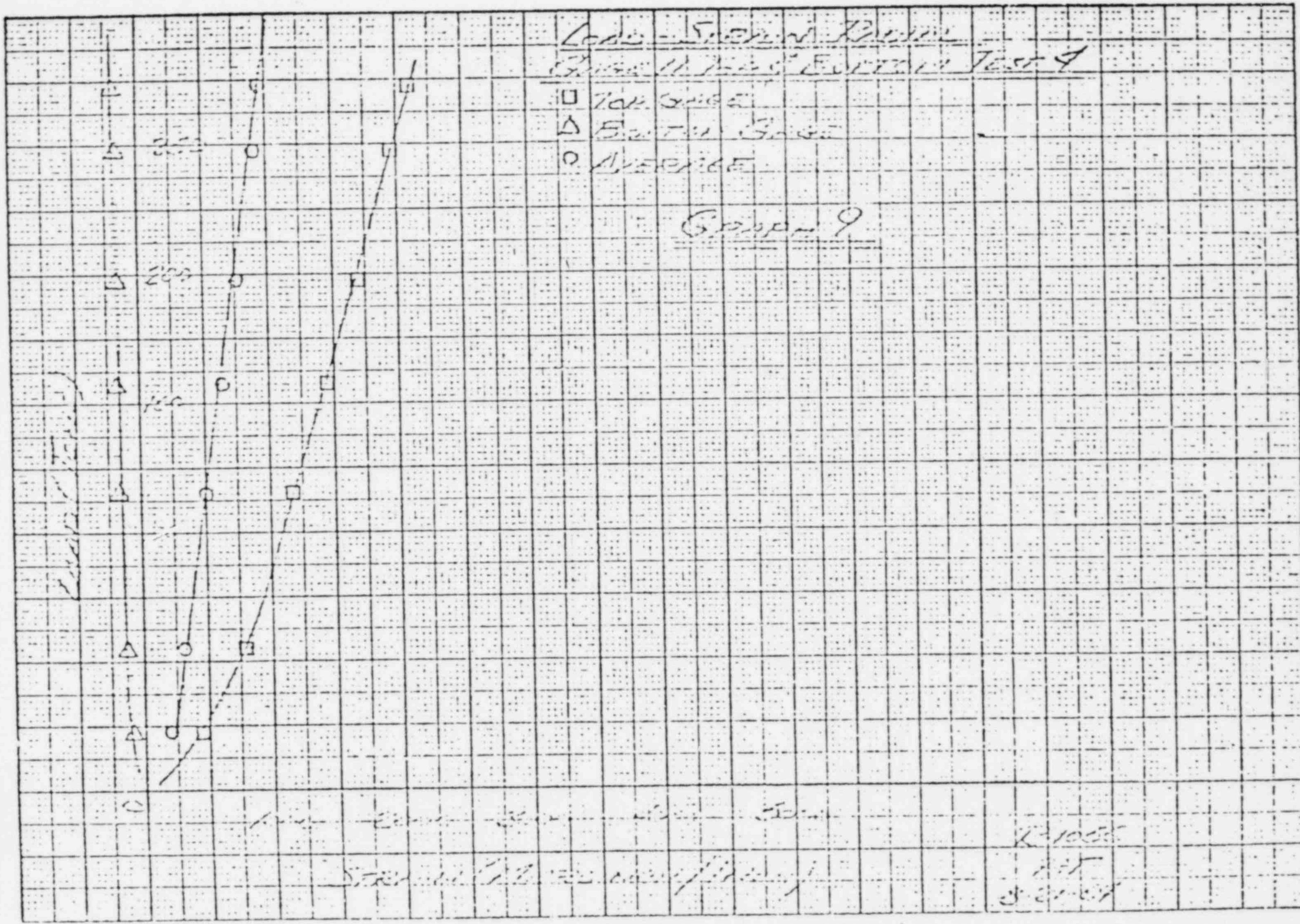

Test 3
□
△
○
Graph 6
200
150
100
9-12-87

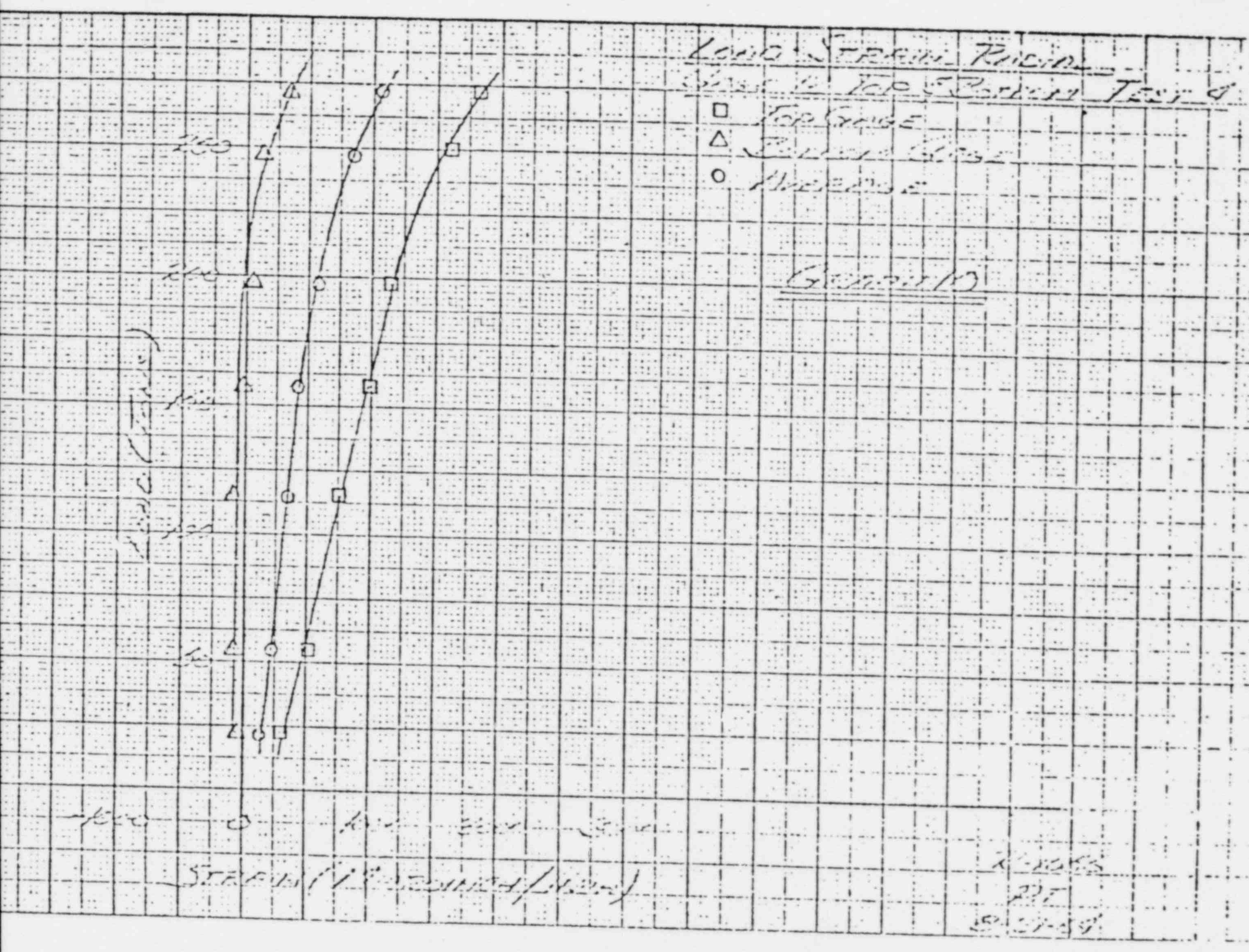

Test 3
□ Top Gage
△ Bottom Gage
○ Average
Group I
100
200
300
400
500
Steam Pressure (in...)
8-12-67

10 X 10 TO THE ½ INCH 359-11G
KEUFFEL & ESSER CO.



K+E 10 X 10 TO THE ½ INCH 359-11G
KEUFFEL & ESSER CO.




Load Strain Ratio
Gage 6 Top & Bottom Test 4
□ Top Gage
△ Bottom Gage
○ Average
Group ID
200
150
100
50
Load (kips)
zero
0
400
800
1200
Strain (1 x 10⁻⁶ inch/inch)
R.B.B.
3/27
8-?-89


Load Cell Strain Record
Test 4
□ Top Gage
○ Bottom Gage
Graph II
Load (Kips)
Strain (Microinches/inch)

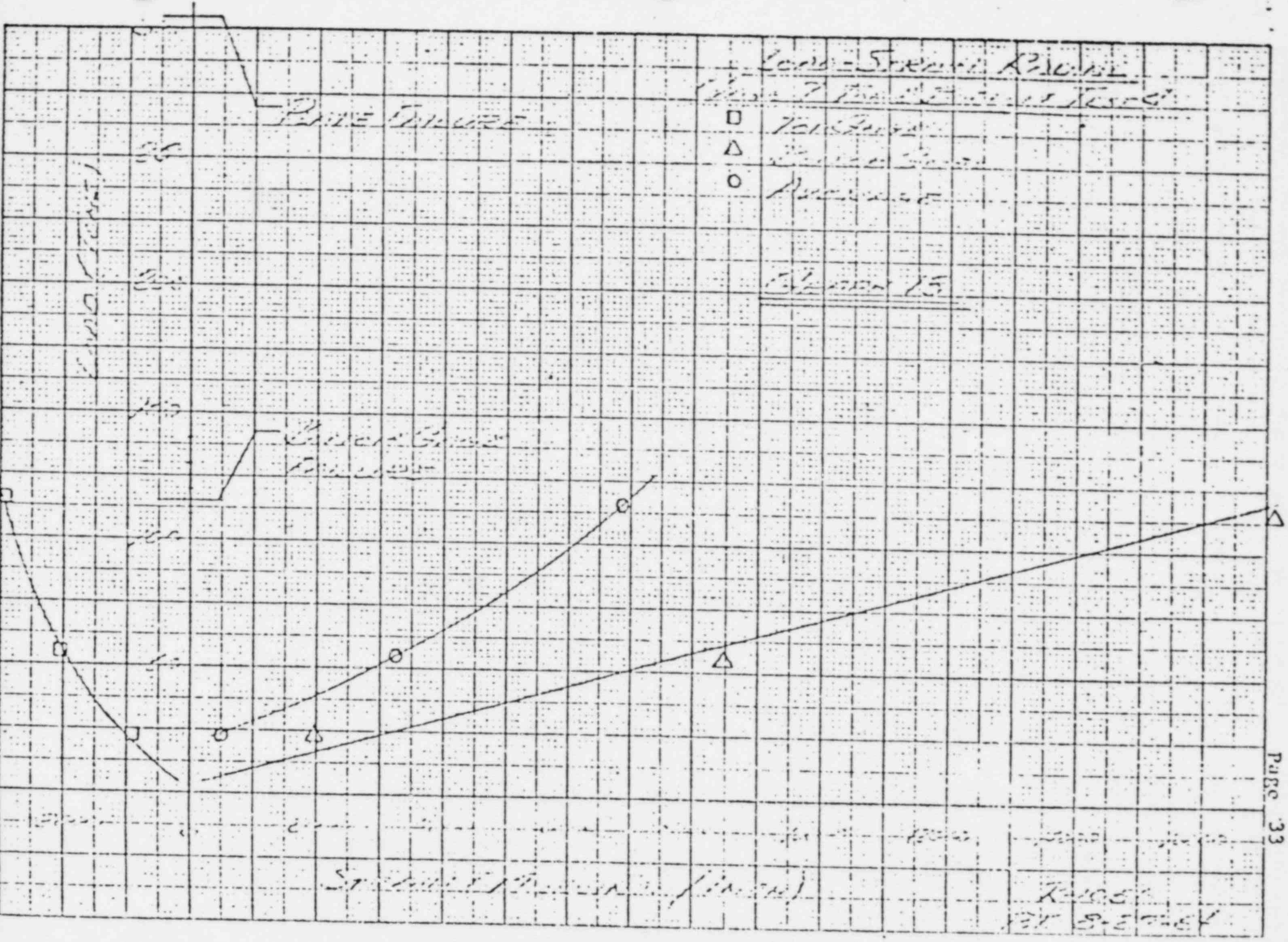
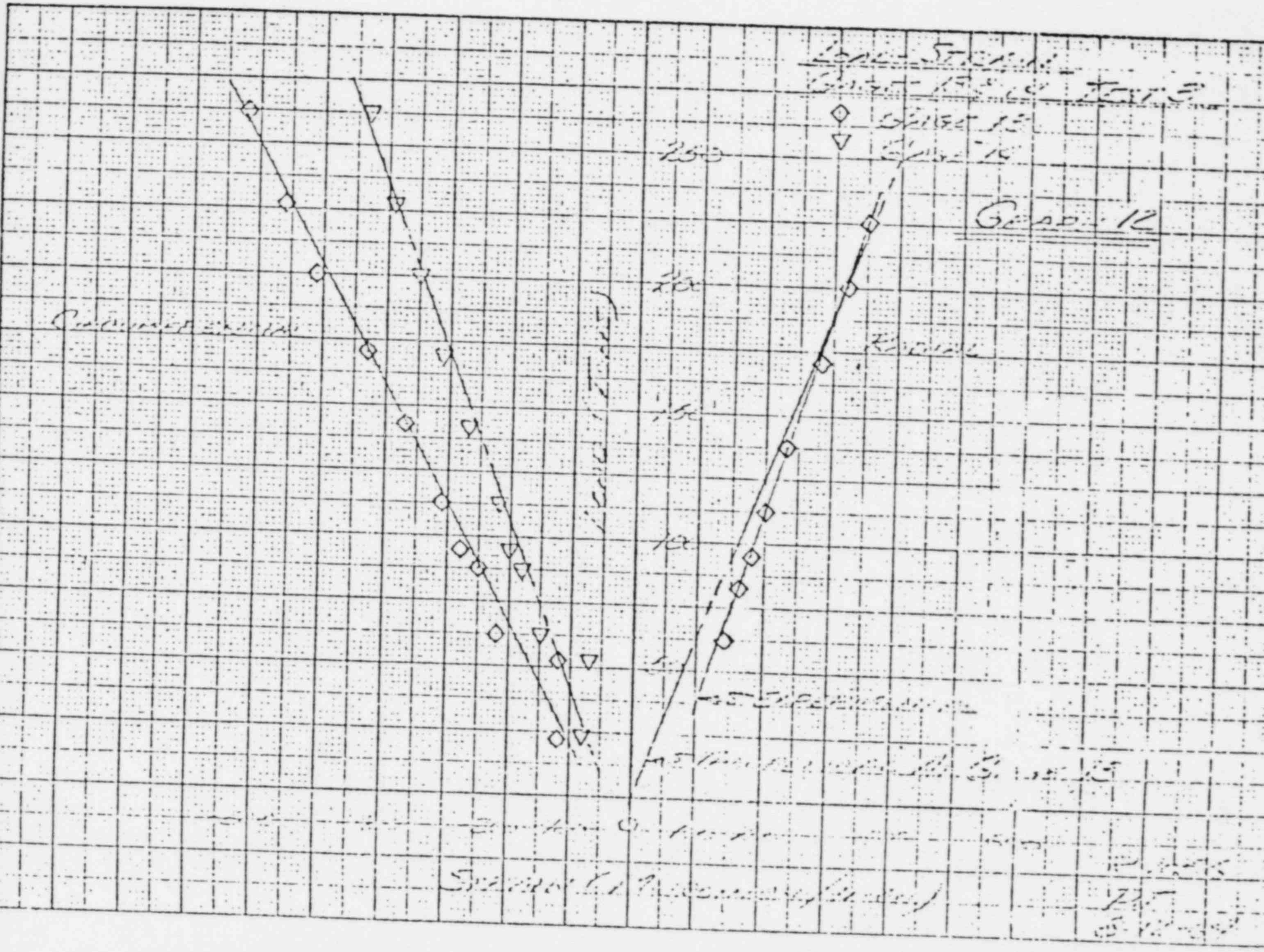


Plate Failure
□
△
○

10 X 10 TO THE ½ INCH 359-11G



APPENDIX F

EVALUATION OF DRYWELL LINER

NORTHEAST UTILITIES SERVICE COMPANY
NUCLEAR ENGINEERING AND OPERATIONS GROUP
GENERATION MECHANICAL ENGINEERING

ASME SECTION III CLASS 2 AND 3
AND ANSI B31.1.0 PIPING ANALYSIS

PROJECT ASSIGNMENT: 78-822

CALCULATION NUMBER: 78-822-147 GP

PLANT: MILLSTONE UNIT NO. 1

TITLE: DRYWELL LINER PLATE
PENETRATION FOR HEPB STUDY

QA CATEGORY 1

REVISION 0

PREPARED BY PJ QUINLAN	DATE 1/30/82	REVIEWED BY R.B. Ray	DATE 2-4-82
REVIEW METHOD FULL REVIEW		APPROVED BY A.F. Mayid	DATE 2-5-82

REVISION 1

PREPARED BY	DATE	REVIEWED BY	DATE
REVIEW METHOD		APPROVED BY	DATE

REVISION 2

PREPARED BY	DATE	REVIEWED BY	DATE
REVIEW METHOD		APPROVED BY	DATE

ED4297 5-80 NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT DRYWELL LINER PLATE PENETRATION FOR HEPB STUDY MILLSTONE UNIT No. 1

BY PJQUINLAN DATE 1/30/82

CHKD. BY RBR DATE 2-4-82

CALC. NO. 78-822.147GP REV. 0

SHEET NO. 2 OF 21

OBJECTIVE:

Verify containment integrity for pipe impact on drywell liner PL for HEPB study.

DISCUSSION:

For piping with nominal size 14" or greater, the Chicago Bridge & Iron report (Appendix E) shows that the containment liner will not rupture when impacted by a whipping pipe. Assuming an impact area equal to the pipe cross sectional area, the study concludes that the liner PL will deform without failure to the point where it comes in contact with the concrete containment. This evaluation was done assuming a 3" air gap between containment and the liner PL. This is conservative due to the fact that the Millstone Unit No. 1 gap between

SUBJECT

BY PJ QUINLAN DATE 1/30/82

CHKD. BY RBK DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 3 OF 21

the liner PL and concrete is a maximum of 2 in. so that the deformation of the PL will be limited to this distance.

For piping less than 14" nominal diameter, analysis is performed below to prove that the liner PL integrity is withheld. The analysis calculates the amount of energy req'd to rupture the liner PL assuming an impact area equal to the cross sectional area of the whipping pipe. This calculation is extracted from Section 3.3 of the attached General Electric report # KAPL-M-6446 entitled 'The Design of Barricades for Hazardous Pressure Systems.' The energy available from the whipping pipe is then compared to the energy needed

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT
BY PJ QUINLAN DATE 1/30/82
CHKD. BY RBR DATE 2-4-82
CALC. NO. 78-822-1476P REV. 0
SHEET NO. 4 OF 21

to rupture the liner PL. If the energy available in the pipe is less than the energy required to penetrate the liner PL, then containment integrity is assured.

The systems which must be analyzed using the energy method include:

- Isolation Condenser
- Cleanup Water
- Feedwater
- Reactor Vent
- Reactor Head Cooling

The worst case for each system will be evaluated.

Conclusion: The systems listed above can not produce sufficient energy to rupture the drywell liner in the event of the worst case break.

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY P.J. QUINLAN DATE 1/30/82
CHKD. BY RBR DATE 2-4-82
CALC. NO. 78·B22·147GP REV. 0
SHEET NO. 5 OF 21

Calculate the energy req'd to penetrate the liner PL for each impact area.

From the attached GE report Section 3.3

$$E = D(U)(0.344T^2 + 0.00806WT)$$

where,

E = energy to penetrate PL ft-lb
D = diameter of impact area in.
U = ultimate tensile strength of PL psi
T = PL thickness in.
W* = width of window in.

* W is the less of either 8D or 100T

100T = 62.5

Liner PL material is A-516 Grade 70 C.S. w/ min. ultimate tensile strength = 70 ksi from ASTM standard.

Min. PL thickness is $\frac{5}{8}$".

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJQuinlan DATE 1/30/82
CHKD. BY RBR DATE 2-4-82
CALC. NO. 78-822-147GP REV. 0
SHEET NO. 6 OF 21

$$E = 70000(D)\left(0.344\left(\tfrac{5}{8}\right)^2 + 0.00806\left(\tfrac{5}{8}\right)W\right)$$

System	O.D.	W	E_{pen}	
IC	10.75	625	338.0	ft kip
CUW	8.625	62.5	271.2	ft kip
FW	12.75	62.5	400.9	ft kip
RV+RHC	2375	19.0	38.3	ft kip

SUBJECT

BY PJ QUINLAN DATE 1/30/82

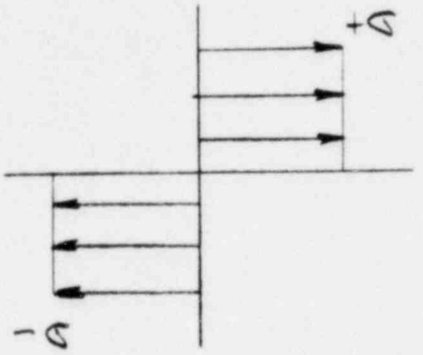
CHKD. BY RBK DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

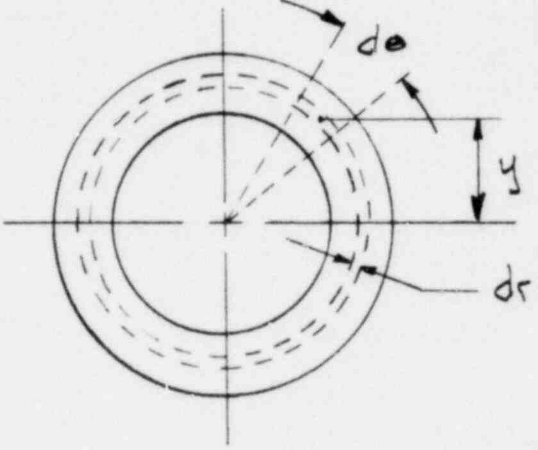
SHEET NO. 7 OF 21

Calculate the minimum moment needed to form a plastic hinge in a pipe.

From Ref. 2



Stress Distribution



$dA = r\,d\theta\,dr$

$y = r\sin\theta$

$$M = \iint \sigma\,dA \cdot y$$

$$M = \iint \sigma\,r\,d\theta\,dr\,r\sin\theta$$

Integrate $\sin\theta$ 2 times from 0 to π

$$M = 2\sigma\int_0^\pi \sin\theta\,d\theta\int_{R_i}^{R_o} r^2\,dr$$

$$M = 2\sigma\int_0^\pi \sin\theta\,d\theta\;\frac{r^3}{3}\Big|_{R_i}^{R_o}$$

$$M = \frac{2\sigma}{3}\int_0^\pi \left(R_o^3 - R_{in}^3\right)\sin\theta\,d\theta$$

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ Quinlan DATE 1/30/82
CHKD. BY RBR DATE 2-4-82
CALC. NO. 78-822-147GP REV. 0
SHEET NO. 8 OF 21

$$M = \tfrac{2}{3}\sigma\left(R_o^3 - R_{IN}^3\right)\left(-\cos\theta\right)\Big|_0^{\pi}$$

$$M = \tfrac{2}{3}\sigma\left(R_o^3 - R_{IN}^3\right)\left[-(-1) - (-1)\right]$$

$$M = \tfrac{4}{3}\sigma\left(R_o^3 - R_{IN}^3\right)$$

This will be used to calculate the moment needed to form a plastic hinge. The value used for σ should be the minimum yield strength of the material to be conservative.

ED4297 5-80

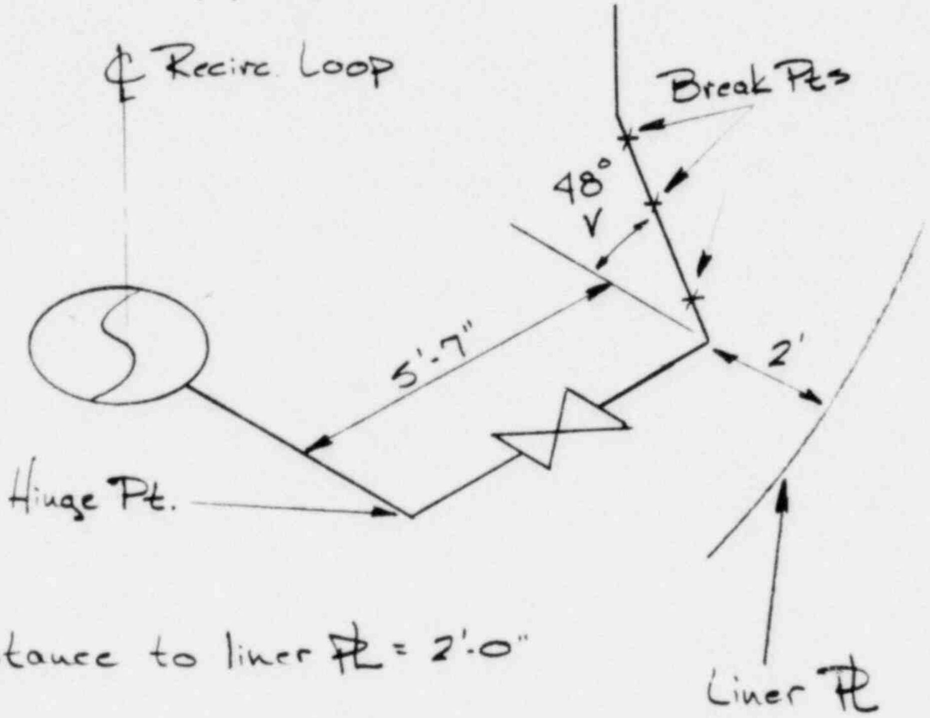
NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY P J QUINLAN DATE 1/30/82
CHKD. BY RBR DATE 2-4-82
CALC. NO. 78-822-1476P REV. 0
SHEET NO. 9 OF 21

Isolation Condenser

The only interaction with the drywell liner and IC piping is due to D.P.'s 7, 8, and 9.



Distance to liner ℄ = 2'-0"

I.C. piping A 358 Type 304 S.S.

10" Sch 80
O.D. = 10.75"
I.D. = 9.564"
A = 71.8"
P = 1250 psi

Min. Yield $S_y = 30$ ksi

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ QUINLAN DATE 1/30/82

CHKD. BY RBR DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 10 OF 21

Force applied

$$F_A = PA = 1250(71.8)$$

$$F_A = 89750 \ \#$$

Moment to develop hinge

$$M_H = 4/3 \, \sigma_y \left(R_o^3 - R_{in}^3\right)$$

$$M_H = 4/3(30000)\left[\left(10.75/2\right)^3 - \left(9.564/2\right)^3\right]$$

$$M_H = 1.837(10^6) \text{ in } \#$$

Moment applied by break

$$M_A = F_A \, d_{\text{arm to hinge}}$$

$$M_A = 89750 \, (67)$$

$$M_A = 6.013 \, (10^6) \text{ in } \#$$

$$M_A > M_H \quad \therefore \text{ Hinge will form}$$

Calculate the resisting force in pipe

$$F_R = \frac{M_H}{d_{arm}} = \frac{1.837(10^6)}{67}$$

$$F_R = 27400 \ \#$$

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT ______

BY PJ QUINLAN DATE 1/30/82

CHKD. BY RBR DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 11 OF 21

Calculate energy in direction of pipe whip

$$E_W = (F_A - F_R) D_{\text{distance to ℄}}$$

$$E_W = (89750 - 27400)\, 2$$

$$E_W = 124.7 \text{ ft kip.}$$

Energy to penetrate liner ℄

$$E_p = 338.0 \text{ ft kip}$$

$$\text{Ratio} = \frac{124.7}{338.0} = .37$$

Pipe develops 37% of energy req'd to penetrate. ∴ Penetration not possible. ✓

ED-297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJQUINLAN DATE 1/30/82

CHKD. BY BAK DATE 2-4-82

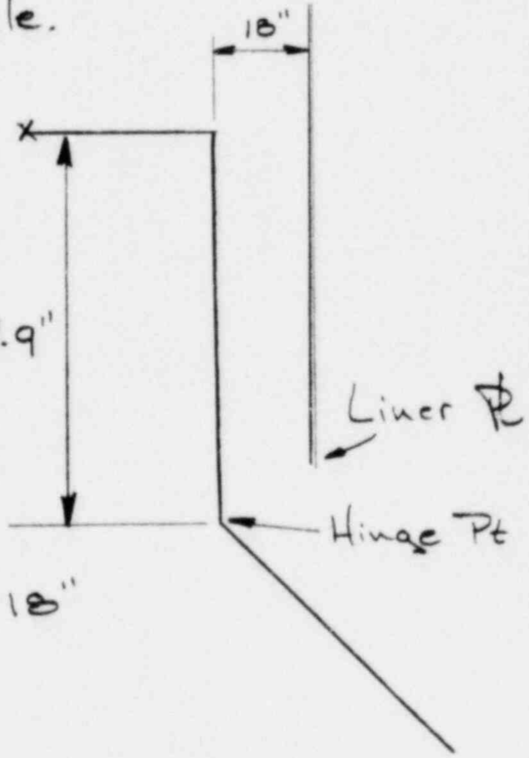
CALC. NO. 78-822-197G REV. 0

SHEET NO. 12 OF 21

Feedwater

Interactions between feedwater lines A and B and the drywell liner PL are typical ∴ only one line will be evaluated.

The worst possible break occurs at the reactor vessel nozzle.



Distance to liner PL = 18"

FW piping material

12" sch 100 A-106 Gr.B C.S.

$S_y = 35.0$ ksi

O.D. = 12.75 in. I.D. = 11.064 in

$A = 96.1 \text{ in}^2$ P = 1250 psi

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ QUINLAN DATE 1/30/82
CHKD. BY RBR DATE 2-4-82
CALC. NO. 78-822-1471GP REV. 0
SHEET NO. 13 OF 21

Force applied due to break

$$F_A = PA = 1250\,(96.1)$$

$$F_A = 120125\ \#$$

Moment req'd to develop hinge

$$M_H = \tfrac{4}{3}\,\sigma_y\left(R_o^3 - R_{in}^3\right)$$

$$M_H = \tfrac{4}{3}\,(35000)\left[\left(\tfrac{12.75}{2}\right)^3 - \left(\tfrac{11.064}{2}\right)^3\right]$$

$$M_H = 4.19\,(10^6)\ \text{in}\ \#$$

Moment applied by break

$$M_A = F_A\, d_{\text{arm to hinge}}$$

$$M_A = 120125\,(22.75)(12)$$

$$M_A = 32.79\,(10^6)\ \text{in}\ \#$$

$M_A > M_H$ $\therefore$ Hinge will form

Calculate resisting force of pipe

$$F_R = \frac{M_R}{d_{arm}} = \frac{4.19\,(10^6)}{22.75\,(12)}$$

$$F_R = 15348\ \#$$

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ QUINLAN DATE 1/30/82

CHKD. BY RBR DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 14 OF 21

Calculate energy in direction of pipe whip

$$E_T = (F_A - F_R) D_{\text{Distance to PL}}$$

$$E_T = (120125 - 15348)\ 1.5$$

$$E_T = 157.1 \text{ ft kip}$$

Energy req'd to penetrate PL

$$E_p = 338.0$$

$$\text{Ratio } \frac{E_T}{E_p} = \frac{157.1}{338.0} = 0.46$$

Pipe develops 46 % of energy req'd to penetrate liner PL

∴ Penetration not possible ✓

SUBJECT

BY PJ QUINLAN DATE 1/30/82

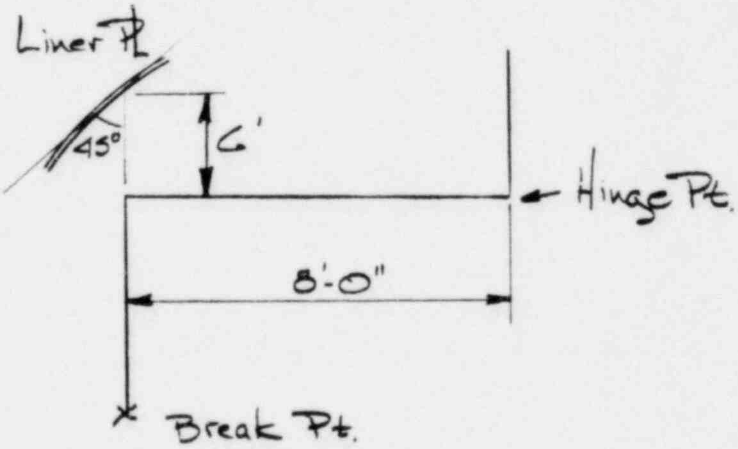
CHKD. BY RBR DATE 2-4-82

CALC. NO. 78.822.147GP REV. 0

SHEET NO. 15 OF 21

Cleanup Water

The worst case interaction between the CUW line and the liner PL occurs at the attachment to the FW piping



Distance to liner PL = 6'-0"

CUW piping A 358 Type 304 SS

$S_y = 30$ ksi

O.D. = 8.625

I.D. = 7.625

$A = 45.7\ in^2$

$P = 1250$ psi

Force applied

$$F_4 = PA = 1250\,(45.7)$$

$$F_4 = 57125\ \#$$

Moment req'd to develop hinge

$$M_H = 4/_3\,\sigma_y\left(R_o^3 - R_{in}^3\right)$$

$$M_H = 4/_3(30000)\left[\left(8.625/_2\right)^3 - \left(7.625/_2\right)^3\right]$$

$$M_H = 0.991(10^6)\ \text{in}\#$$

Moment applied by break

$$M_A = F_A\, d_{\text{arm to hinge}}$$

$$M_A = 57125(8)(12)$$

$$M_A = 5.484\,(10^6)\ \text{in}\#$$

$M_A > M_H$ ∴ Hinge will develop

Calculate the resisting force in pipe

$$F_R = \frac{M_H}{d_{arm}} = \frac{0.991(10^6)}{8\,(12)}$$

$$F_R = 10{,}300\ \#$$

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJQuinlan DATE 1/30/82

CHKD. BY RBR DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 17 OF 21

Calculate the force applied ⊥ to liner ℄

$$F_{A_\perp} = F_A \sin 45° = 57125\,(.707) = 40393$$

$$F_{R_\perp} = F_R \sin 45° = 10300\,(.707) = 7283$$

Energy due to impact

$$E_T = (F_{A_\perp} - F_{R_\perp})\, D_{\text{Distance to ℄}}$$

$$E_T = (40393 - 7283)\, 6$$

$$E_T = 198.6 \text{ ft kip.}$$

Calculate the component of velocity ⊥ to ℄ and use this to find the energy needed to penetrate on the 45° impact angle.

Since $E \sim V^2$

$$E_p = \frac{E_\perp V^2}{(V \sin 45°)^2} = \frac{271.2\, \cancel{V^2}}{(.707)^2\, \cancel{V^2}}$$

$$E_p = 542.4 \text{ ft kip}$$

$$\text{Ratio} = \frac{198.6}{542.4} = .36$$

Pipe develops 36% of energy req'd to penetrate ∴ Penetration not possible ✓

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ QUINLAN DATE 1/30/82

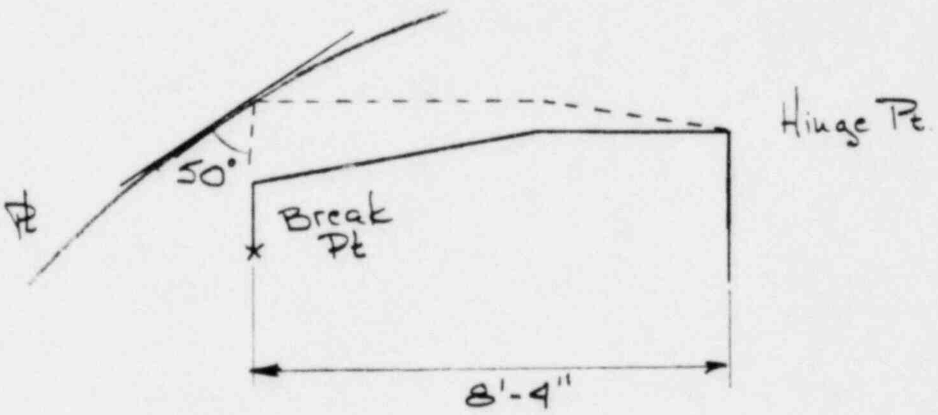
CHKD. BY RBR DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 18 OF 21

Reactor Head Cooling

The worst case interaction between the RHC piping and the liner PL occurs at a break on the top of the head.



Distance to liner PL = 2'-6"

Piping is Stainless Steel assume $S_y = 25.0$ ksi

2" Sch 80

OD = 2.375 in.

ID = 1.939 in.

A = 2.953 in^2

P = 1250 psi

ED4297 5-80

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY P.J.QUINLAN DATE 1/30/82

CHKD. BY DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 19 OF 21

Force applied

$$F_A = PA = 1250(2.953)$$

$$F_A = 3691\ \#$$

Moment to develop hinge

$$M_H = \tfrac{4}{3}\,\sigma_y \left(R_o^3 - R_{in}^3\right)$$

$$M_H = \tfrac{4}{3}(25000)\left[\left(\tfrac{2.375}{2}\right)^3 - \left(\tfrac{1.939}{2}\right)^3\right]$$

$$M_H = 25400\ \text{in}\#$$

Moment applied by break

$$M_A = F_A\, d_{\text{arm to hinge}}$$

$$M_A = 3691(100)$$

$$M_A = 369100\ \text{in}\ \#$$

$M_A > M_H$ ∴ Hinge will develop

Resisting force of pipe

$$F_R = \frac{M_H}{d_{arm}} = \frac{25400}{100}$$

$$F_R = 254\ \#$$

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NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ QUINLAN DATE 1/30/82

CHKD. BY RBR DATE 2-4-82

CALC. NO. 78.822-1476P REV. 0

SHEET NO. 20 OF 21

Force ⊥ to liner

$$F_{A\perp} = F_A \sin 50° = 3691\,(0.766) = 2827$$

$$F_{R\perp} = F_R \sin 50° = 254\,(0.766) = 195$$

Total force

$$F_T = F_{A\perp} - F_{R\perp} = 2827 - 195$$

$$F_T = 2632 \;\#$$

$$E_T = F_T\, D_{\text{Distance to ℄}}$$

$$E_T = 2632\,(2.5)$$

$$E_T = 6.58 \text{ ft kip}$$

$$E_{pen} = 38.3$$

$$\text{Ratio } \frac{6.58}{38.3} = .17$$

Pipe develops 17 % of energy req'd to penetrate liner ℄ ∴ Penetration not possible.

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NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT ______

BY PJQUINLAN DATE 1/30/82

CHKD. BY RAR DATE 2-4-82

CALC. NO. 78-822-147GP REV. 0

SHEET NO. 21 OF 21

Reactor Vent

The reactor vent interaction is basically the same as the RHC interaction with the drywell liner ⅊. The only difference is that the distance traveled to the liner ⅊ is 3'-0".

Neglecting the resisting force of the pipe

$F_A = 3691$ # from RHC

$E_T = F_A D = 3691(3.0)$

$E_T = 11.1$ ft kip

$E_P = 38.3$

$\text{Ratio} = \frac{11.1}{38.3} = 0.29$

Pipe develops 29 % of energy req'd to penetrate the liner ⅊ ∴ Penetration not possible.

KAPL-M-6446

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KAPL-M-6446
(CVM-24)

UC-38 Engineering & Equipment

THE DESIGN OF BARRICADES FOR HAZARDOUS PRESSURE SYSTEMS

C. V. Moore

February 5, 1965

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THE PUBLIC IS APPROVED. PROCEDURES
ARE ON FILE IN THE RECEIVING SECTION.

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United States Atomic Energy Commission
Contract No. W-31-109 Eng-52

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CONTENTS (Cont'd)

ILLUSTRATIONS

ABSTRACT

Procedures are given for the rational design of barricades for hazardous pressure systems. Methods are given for estimating the initial velocities of missiles produced by exploding pressure vessels, and for determining the penetrating effects of these missiles on materials normally used for barricade construction. Methods are also given for estimating effective blast pressures produced by the explosion of pressure vessels. Charts and diagrams to assist in performance of the calculations are included. Some checks of the design methods against experimental data are presented.

THE DESIGN OF BARRICADES FOR HAZARDOUS PRESSURE SYSTEMS

C. V. Moore

1. INTRODUCTION

1.1 Use of Barricades

It is sometimes necessary to operate experimental pressure containing equipment which present hazards not accounted for by existing industrial pressure vessel codes. (An example is a test section used for investigating heat transfer phenomena in which fission heat is simulated by passing electric current through the pressure retaining walls.)

In such cases, personnel hazards can be reduced to the level provided by industrial codes by interposing suitable barricades between the pressure retaining walls and personnel. Such barricades must, of course, be adequate for the purpose or they may, in fact, increase hazards by becoming missiles themselves.

1.2 General Barricade Design Method

The design method outlined in this report is that one first determines what one is barricading against (including the methods by which failure is anticipated), and then evaluates a proposed design of barricade to determine its adequacy.

The evaluation process is something of a trial and error operation since the first proposed design may either be inadequate or excessive.

The trial and error process could be eliminated by restricting consideration to only certain types of barricades (e.g., steel plates). It is felt, however, that to do so would be unduly restrictive.

The evaluation of the adequacy of a barricade is divided into two phases; resistance to penetration or perforation by missiles produced by an exploding pressure vessel, and resistance to the blast effects produced by release of the pressurized fluid inside the pressure vessel. (Complications due to release of flammable fluids are not treated in this report but should be considered, when applicable.) The evaluation of missile resistance is given first since, in most cases, barricades which will be adequate for missile resistance will be more than adequate for blast resistance.

2. RUPTURE CONDITIONS

The methods given below for evaluation of barricade adequacy require consideration of the amount of energy released during the pressure vessel rupture. This amount of energy is a function of the mode of failure assumed for the pressure vessel.

For example, if a rapid chemical reaction is anticipated which is expected to be too fast to be relieved by normal pressure relief devices, one might expect an explosion in which the temperature and pressure of the fluid builds up at a rate which is too fast to transfer heat to the walls of the pressure vessel. Thus the walls of the pressure vessel will remain essentially at the initial temperature and failure will occur when the pressure is high enough to equal the rupture pressure of the vessel at the initial temperature. If the initial temperature is the design temperature for the vessel then, for ASME Code vessels, the rupture pressure will normally be about four times the design pressure.

As another example, consider a vessel for which no mechanism is available by which the pressure can be raised above the design pressure - but which is subjected to severe thermal cycling stresses so that failure by fatigue is feared. It is thus assumed that the vessel ruptures suddenly at design temperature and pressure. The energy released is then assumed to be that released by isentropic expansion of the contained fluid from design conditions to one atmosphere.

As another example, consider a vessel with electrically heated walls where failure by overheating of the walls is anticipated. Pressures are limited to design pressures by pressure relief devices, but the wall is weakened by increased temperature (resulting, say, from loss of flow of internal fluid or low liquid level) until rupture occurs at a temperature at which the tensile strength of the wall material equals the pressure stress. This temperature would be determined by consulting data for the high temperature short-time tensile properties of the wall material, and the initial energy content of the fluid would be obtained at this temperature and design pressure from steam charts or from other thermodynamic data.

3. MISSILE RESISTANCE OF BARRICADES

3.1 Estimation of Initial Missile Velocities

a. Energy Method. An expression derived from energy relationships for the initial velocities of fragments of exploding casings filled with explosives which has been found by experiment to be reasonably accurate is (from Gurney, reference 8.1.2 and Sterne, reference 8.1.4):

$$V_o = \sqrt{2ER} \qquad (1)$$

where, for cylinders

$$R = \frac{C/N}{1 + C/2N} \qquad (2)$$

for spheres

$$R = \frac{C/N}{1 + 3C/5N} \qquad (3)$$

and, for "sandwiches"

$$R = \frac{C/N}{1 + C/3N} \qquad (4)$$

where $\sqrt{2E}$ = Energy function = 6900 ft/sec for TNT
C = Explosive weight
N = Case weight (both sides, for "sandwiches")
V_o = Initial velocity, ft/sec

In deriving this expression, it was assumed that, for a given explosive, a constant fraction of the energy released on detonation of the explosive is converted to kinetic energy - which is imparted to the fragments and to the expanding fluid. For TNT this fraction was found to be about 60 per cent of the calculated energy which would be released by isentropic expansion of the fluid to one atmosphere.

This expression may be used to estimate the velocities of fragments of exploding pressure vessels by assuming that the same fraction of available energy is transformed into kinetic energy for fluids other than those resulting from the detonation of high explosives. This assumption is believed to be conservative. (See Appendix A for some checks of the accuracy of this assumption against published data for pressure vessel explosions.)

The expression then becomes

$$V_o = 1.092 \sqrt{E_f R} \qquad \text{ft/sec} \qquad (5)$$

where E_f = Available energy released by isentropic expansion of pressurized fluid to one atmosphere on per-unit mass basis, ft-lb/slug (see Figure 1, Curve A, for saturated water).

In the event a portion of the interior of the pressure vessel is occupied by an inert material, such as steel, the energy, E_f, and the "explosive" weight, C, should be reduced proportionally.

b. Initial Velocities of Fragments of Cylindrical Pressure Vessels Containing Saturated Water. The initial velocities of fragments of long cylindrical pressure vessels constructed of steel (or material with a similar density to steel, 490 lbs/cu ft) filled with saturated water at various temperatures have been determined from Equation (5), and are presented on Figure 2 as a function of the ratio of the inside diameter of the vessel to its wall thickness.

✓

For subcooled water (water which is pressurized up to 1000 psi above the saturation pressure corresponding to its temperature), Figure 2 can be used with only a few per cent error by using the curve corresponding to the temperature of the subcooled water.

c. Autoclave Heads. For autoclave heads, a simple method of estimating the head kinetic energy which is believed to be conservative is to assume that the full rupture pressure acts on the bottom surface of the head during motion of the head from its initial position for a distance equal to the diameter of the opening generated by its removal.

Making these assumptions, the kinetic energy of the head is given by

$$E_K = 0.0654 \, D^3 P \qquad \text{ft-lb} \qquad (6)$$

where D = Diameter of opening - inches
P = Pressure in system at time of rupture - psig

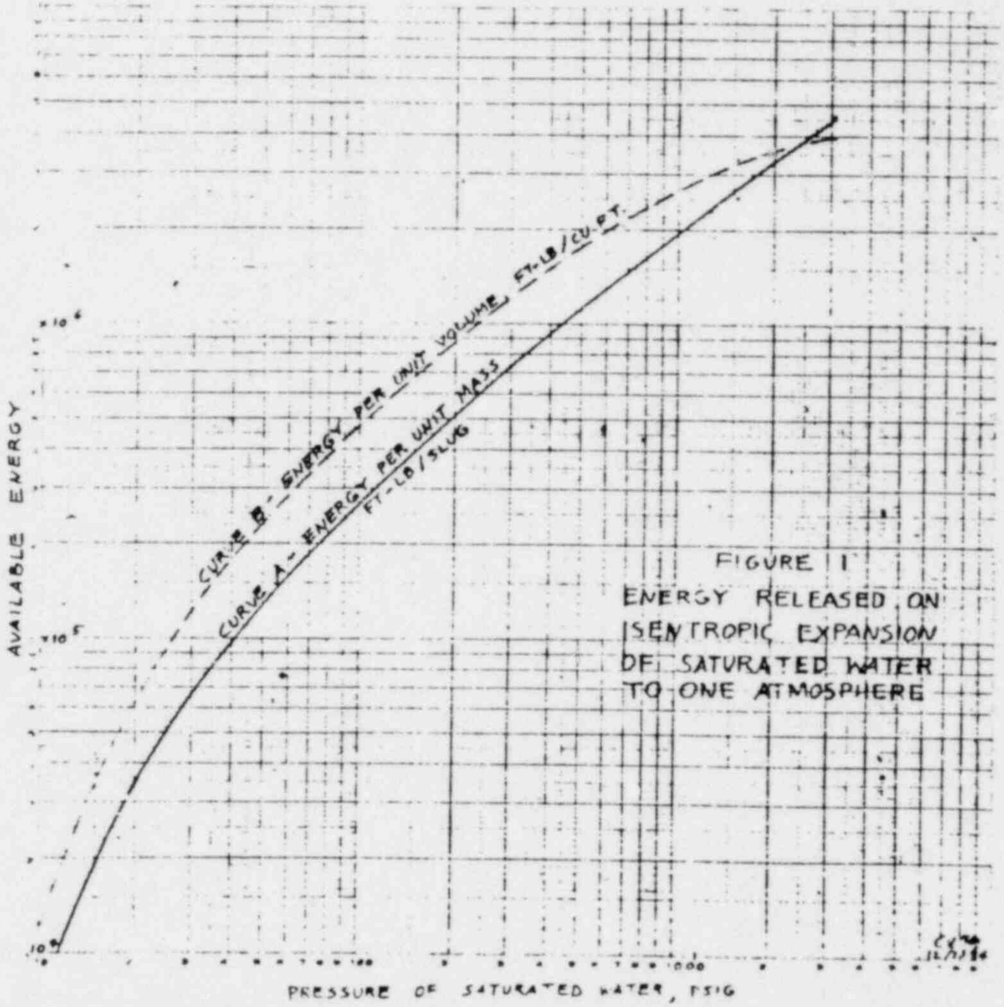
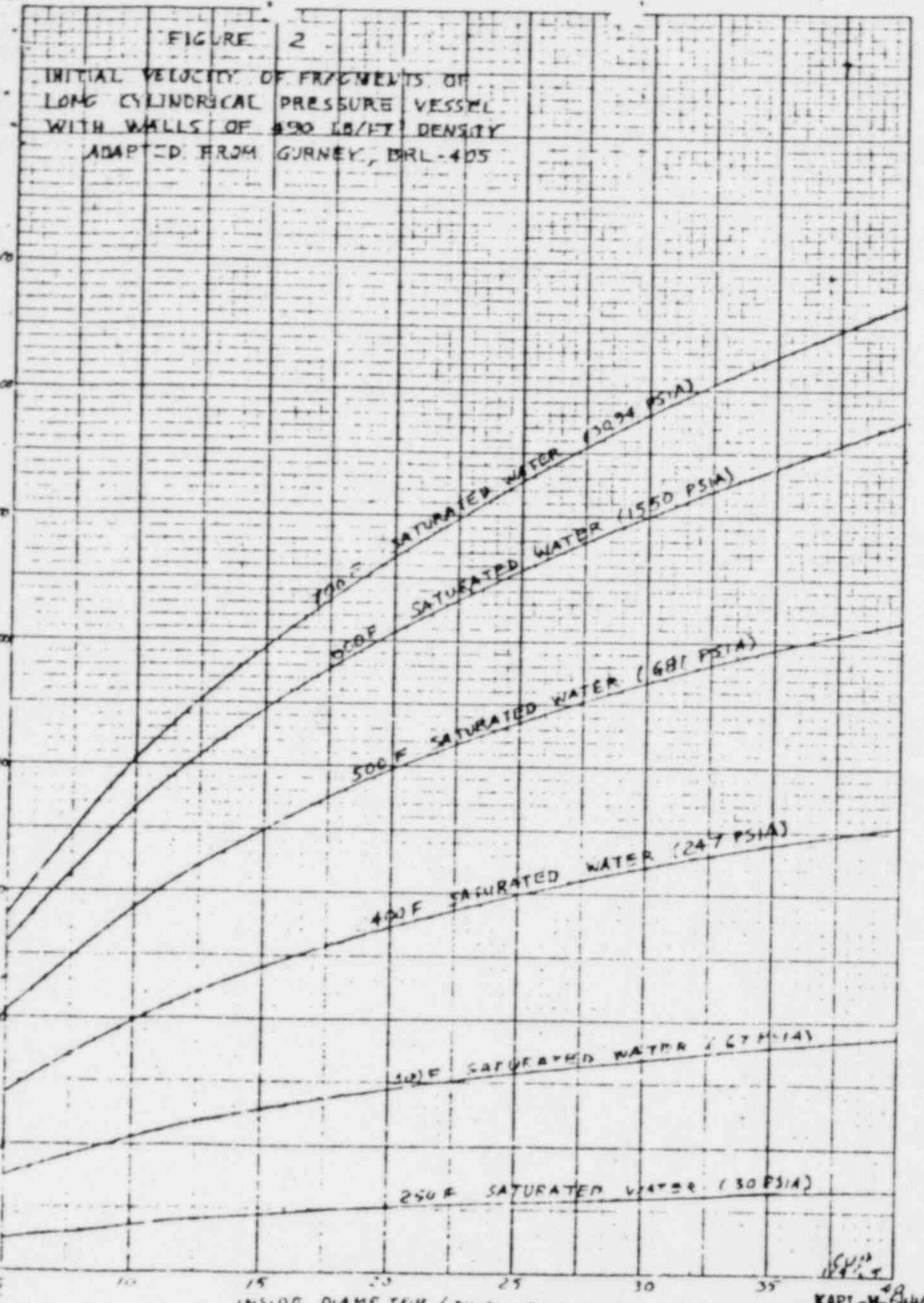


FIGURE 1
ENERGY RELEASED ON ISENTROPIC EXPANSION OF SATURATED WATER TO ONE ATMOSPHERE

FIGURE 2

INITIAL VELOCITY OF FRAGMENTS OF LONG CYLINDRICAL PRESSURE VESSEL WITH WALLS OF 490 LB/FT³ DENSITY

ADAPTED FROM GURNEY, BRL-405



The associated velocity is

$$V_o = 2.05\sqrt{\frac{PD^3}{W}} \qquad \text{ft/sec} \qquad (7)$$

where W = Weight of autoclave head - lbs

d. Attachments. If a piece of equipment such as a pressure gage or thermocouple well becomes dislodged, it will be accelerated by a jet of expanding fluid from the resultant opening in the vessel.

Procedures for predicting the velocities of such missiles are given in reference 8.1.13.

Predicted velocities of such missiles of various sizes and weights propelled from vessels filled with saturated water at 2000 psia are shown on Figure 3 (taken from reference 8.1.13).

e. Rocket Type Missiles. Rocket type missiles are those which discharge fluid while flying through the air. An example of such a missile would be a length of pipe closed at one end and open at the other which is initially filled with a pressurized fluid. The fluid discharges from the open end, accelerating the pipe.

The kinetic energy of such missiles may be conservatively estimated by assuming that the initial available energy of the fluid (taken, for water, from Curve B of Figure 1) is the final kinetic energy of the missile.

That is

$$E_K = v\ E_v \qquad \text{ft-lbs} \qquad (8)$$

where E_K = Kinetic energy of rocket type missile - ft-lbs
v = Volume of water which produces the jet - cu ft
E_v = Available energy per unit volume from Figure 1, Curve B - ft-lb/cu ft

The corresponding velocity of the missile is

$$V_o = \sqrt{\frac{2\ g E_K}{W}} \qquad \text{ft/sec} \qquad (9)$$

where g = Acceleration of gravity - ft/sec^2
W = Weight of missile after discharge of water - lbs

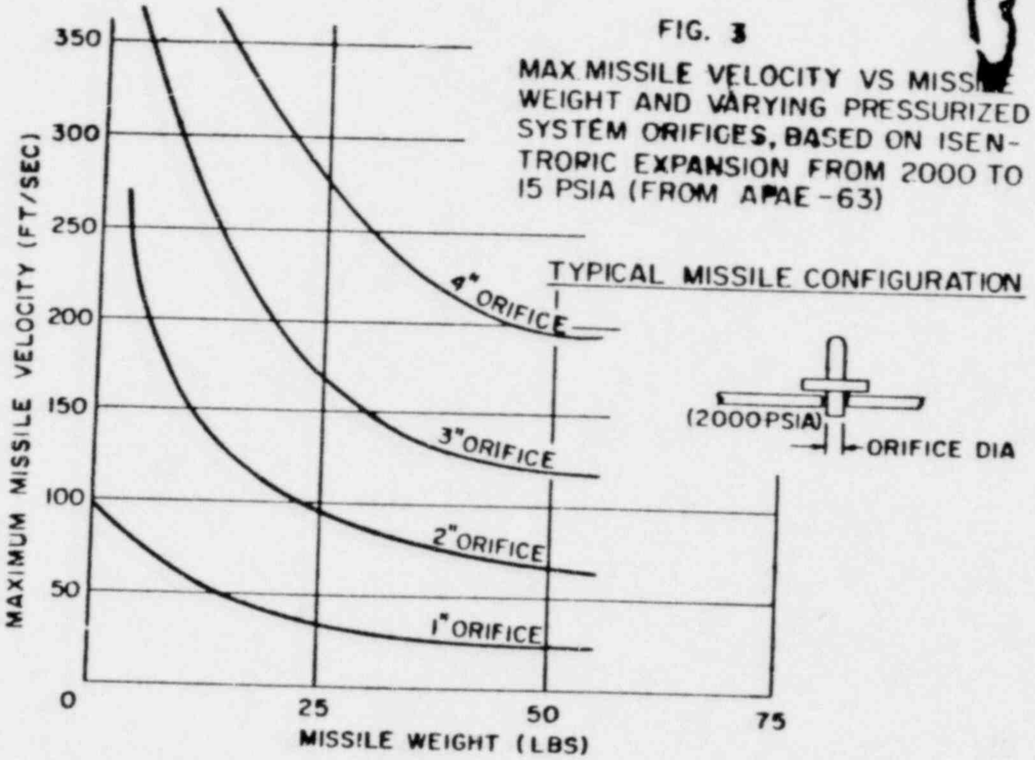


FIG. 3

MAX MISSILE VELOCITY VS MISSILE WEIGHT AND VARYING PRESSURIZED SYSTEM ORIFICES, BASED ON ISENTROPIC EXPANSION FROM 2000 TO 15 PSIA (FROM APAE-63)

A somewhat more sophisticated analysis by Porzel may be found in reference 8.2.3.

Missiles of this type can acquire such high velocities that it is impractical, in many cases, to design barricades to withstand them. Fortunately, in most cases, the probabilities of such missiles occurring can be economically reduced to acceptable levels by suitably anchoring the potential missiles. Such anchors should be capable of withstanding forces equal to the cross-sectional areas of the missiles multiplied by the expected pressures at rupture.

f. General Method. The methods of missile velocity estimation described above are believed to give generally conservative results. In the event the barricades necessary to restrain these missiles are uneconomically massive, more elaborate and less conservative calculations may be desirable. Some examples of such calculations are given in references 8.1.13, 8.2.3, 8.3.a.1, 8.3.a.3, 8.3.a.4, 8.3.a.6, and 8.3.a.15.

In most of these examples a set of differential equations is prepared relating the forces acting on the missiles during expansion of the vessel contents to the pressures occurring during some assumed thermodynamic sequence of events. Normally, a digital computer is required for solution of the equations.

3.2 Missile Shapes

In some cases, the shapes of missiles produced by exploding pressure vessels will be obvious (such as autoclave heads). In other cases, however, (such as fragments of a cylindrical shell) the shapes and sizes of the missiles will not be obvious.

In this latter situation, the recommended procedure is to assume that missiles having the greatest penetrating effect are produced. They will normally be the largest missiles which can be generated.

In the case of cylindrical shells constructed of ductile materials, the worst configuration is normally that generated by a longitudinal split of the shell followed by a flattening out of the cylinder into a flat plate (which is not a bad approximation of configurations produced in many accidents). The missile should be assumed to rotate in flight (if there is sufficient space available inside the barricade for such rotation) and to strike the barricade with a velocity parallel to the plane of the missile.

3.3 Perforation of Steel Plates

a. Missiles of Circular Cross-Section. References 8.1.9 through 8.1.11, and 8.1.14, 8.1.16, 8.1.18, and 8.1.20 report the results of an extensive series of tests conducted by the Stanford Research Institute in which rod shaped missiles traveling at velocities characteristic of missiles produced by pressure vessel explosions were impacted against square steel plates with edges clamped in relatively rigid frames (or "windows").

The results of these tests have been summarized in reference 8.3.a.17 which gives the following expression for the minimum energy per unit diameter of missile required for perforation of a steel plate:

$$\frac{E}{D} = U\,(0.344\,T^2 + 0.00806\,WT) \qquad (10)$$

+ .032 T

where E = Critical kinetic energy required for penetration - ft-lb

D = Diameter of missile - inches

U = Ultimate tensile strength of target plate - psi

T = Plate thickness - inches

W = Width of window - inches

This expression has been tested for validity within the following range of variables:

$$\begin{array}{llll} 0.1 < T/D < 0.8 & (a) & & \\ 0.002 < T/L < 0.05 & (b) & & \\ 10 < L/D < 50 & (c) & & \\ 5 < W/D < 8 & (d) & & (11) \\ 8 < W/T < 100 & (e) & & \\ 0.2 < W/L < 1.0 & (f) & & \\ 70 \text{ fps} < V_c < 400 \text{ fps} & (g) & & \end{array}$$

where L = Missile length - inches

Vc = Missile velocity - fps

It should be used with caution if any of the variables fall outside the ranges given.

The limitations on width of window (which can be taken as the distance between parallel supports or stiffening members) will often be restrictive with common construction practice for spacing of structural members or when a membrane type of construction is used - as, for

example, a cylindrical or spherical container without stiffening members, which possesses no obvious analog to window width.

In these cases, when the upper limits of window size are exceeded or when the window size is unknown, it is recommended that the smallest of the upper limits for W given by (11)d, (11)e, and (11)f be used in equation (10). That is, use the smallest of

$$\begin{array}{lll} W = 8D & (a) & \\ W = 100T & (b) & (12) \\ W = L & (c) & \end{array}$$

If, as is usually the case, the required thickness is unknown and the other factors in equation (10) are known, then a more convenient form for this equation is

$$T = -0.0118W + \sqrt{1.38 \times 10^{-4}W^2 + 2.90\,\frac{E}{DU}} \qquad (13)$$

b. Missiles of Non-Circular Cross-Section. The Stanford reports do not give rules for missiles of other than circular cross-section. It is believed, however, that it is reasonable to use the results obtained for circular cross-section missiles by converting non-circular missiles to "equivalent" circular missiles having the same ratio of length of perimeter to cross-sectional area.

For flat plate hitting edgewise having widths (perpendicular to the direction of velocity) which are large compared to the missile plate thickness, this conversion can be made by assuming that the plate has a penetrating effect the same as a rod having the same velocity and length (measured parallel to the rod velocity), and a diameter twice the thickness of the plate.

Making this conversion, then, and expressing the energy in terms of velocity, the above expression for E/D may be rewritten

$$T = -0.0118W + \sqrt{1.38 \times 10^{-4}W^2 + 0.0706\,\rho t L V_p^2/U} \qquad (14)$$

where T = Plate thickness at which perforation barely takes place - inches
ρ = Density of missile - lbs/cu in
t = Thickness of missile plate - inches
L = Length of missile plate measured parallel to velocity - inches
V_p = Velocity of missile - ft/sec

c. Considerations Other Than Perforation. Even though a missile does not perforate a steel barricade, it may produce considerable rapid deformation in the vicinity of the area of impact. Such deformation may dislodge gauges, fasteners, or other materials mounted on the operators' side of the barricade and convert them into missiles. It is, therefore, recommended that the operators' side of steel plate barricades be kept free of any such attachments, and that operators' stations be kept back at least several inches from the surface of the barricade.

3.4 Penetration and Perforation of Concrete, Masonry and Sand

Penetration depth is the distance into a barricade which a non-perforating missile penetrates before coming to rest.

This distance is given (Amirikian, reference 8.1.5) by the modified Petry formula:

$$D' = KAV'R \qquad (15)$$

where D' = Depth of penetration in slab of thickness T - ft
K = Material property constant from Table 1 - ft^3/lb
A = Sectional mass, weight of missile per unit cross-sectional area - lb/ft^2
V' = Velocity factor, from Figure 4
R = Thickness ratio, from Figure 5

For depths of penetration greater than two-thirds of the total slab thickness, scabbing (that is, expulsion of slab material from the operator side of the slab) may be anticipated. Thus, unless the barricade is made more than 1-1/2 times the predicted penetration depth, a steel plate should be anchored to the operator side of the barricade to prevent scabbing.

Nomograms by means of which the penetration of cylindrical missiles into concrete and soil may be estimated for missile velocities above 500 ft/sec are given in reference 8.1.3.

TABLE 1. VALUES OF PENETRATION COEFFICIENT (K) FOR VARIOUS MATERIALS

Material	$Ft^3\ lb^{-1}$
Limestone	5.36×10^{-3}
Concrete[1]	7.99×10^{-3}
Reinforced concrete[2]	4.76×10^{-3}
Specially-reinforced concrete[3]	2.82×10^{-3}
Stone masonry	11.72×10^{-3}
Brickwork	20.48×10^{-3}
Sandy soil	36.7×10^{-3}
Soil with vegetation	48.2×10^{-3}
Soft soil	73.2×10^{-3}

[1] Mass concrete with a crushing strength of 2,200 pounds per square inch.

[2] Normal reinforced concrete with a crushing strength of 3,200 pounds per square inch and 1.4 per cent of reinforcement.

[3] Specially-reinforced concrete with a crushing strength of 5,700 pounds per square inch and 1.4 per cent of reinforcement.

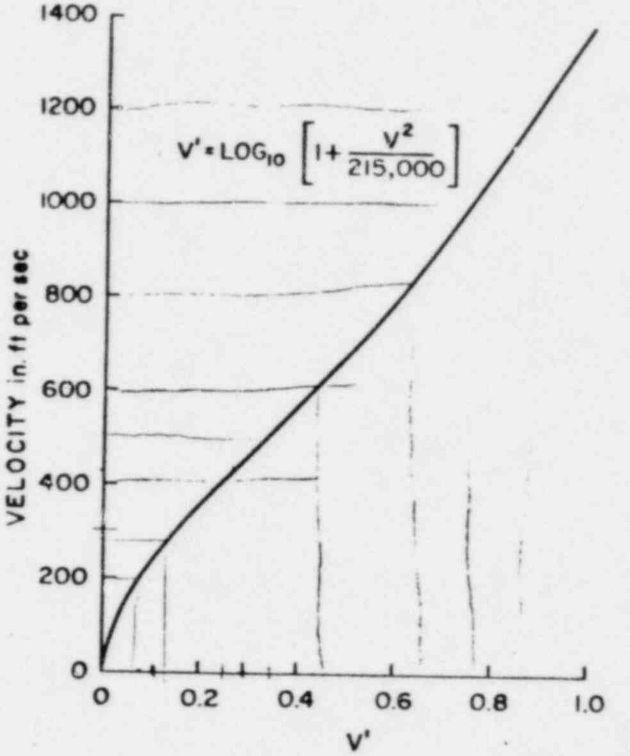


FIG. 4 VELOCITY FACTOR (V') FOR IMPACT PENETRATION

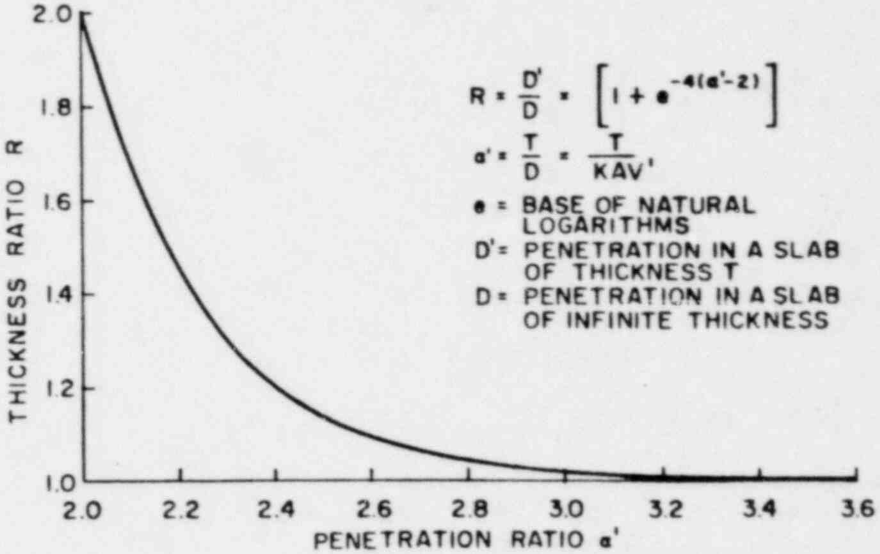


FIG. 5 RELATION OF RELATIVE SLAB THICKNESS TO PENETRATION

$\log_{10}(1.18604)$ .074085

$\log_{10}(48.12)$ 2.682326

3.5 Use of Blast Mats

Woven mats of steel cable or manila rope are commonly used during blasting operations in connection with construction work to prevent rocks from being thrown outside of the blasting area. They have also been used as barricades for hazardous pressure vessels to stop missiles.

Unfortunately, there are no rational methods for quantitatively estimating the effectiveness of blast mats known to the author.

However, one organization with considerable experience in their use for protection of pressure vessels reports that blast mats made of 3/8 - 1/2" steel cable should stop missiles of not more than 1 lb in size provided the mats are separated from the pressure vessel by at least 3 feet and are flexibly supported (such as by ropes) to permit them to deform readily and thereby absorb energy.

3.6 Analysis of Complex Structures

a. Grids. The results of a series of low velocity perforation tests on steel plates reinforced by lattice-work are reported in reference 8.1.17.

b. Dynamic Analysis. Williamson and Alvy (reference 8.1.7) present a dynamic method of analysis for missile penetration similar to that of Newmark (reference 8.2.4) for blast loadings. In this method of analysis, an equivalent static load is obtained which is then used to evaluate the strength of the barricade. The method requires an evaluation of the natural period of vibration of the barricade and its ductility ratio (the ratio of elastic deflection to the deflection at failure) and knowledge of the missile size and velocity. Curves are presented to aid in the computations.

c. General Methods of Analysis. Available analytical techniques for evaluation of impact are given or reviewed by Goldsmith in references 8.1.15 and 8.1.19 and may be of use in certain cases. However, as Goldsmith states in the conclusion of reference 8.1.19, the available theoretical tools cannot handle most of the collisions encountered in actual practice.

3.7 Use of Lining and Packing Materials

Some test cells constructed in the past have been lined with an inch or two of wood, whose purpose is to absorb energy from impacting fragments, thus providing some protection to the primary barricade and reducing ricochet effects.

It seems reasonable to expect that such linings would have such beneficial effects. However, no method is known to the author for quantitatively evaluating this effectiveness.

If the space between the pressure vessel and the barricade can be completely filled with a cushioning material (such as sand or plaster of Paris) impact loadings can be avoided completely and the barricade can be designed primarily on the basis of blast loadings alone.

3.8 Perforation of Transparent Barricades

Viewing ports, windows, and other transparent barricades or portions of barricades present special problems since operating personnel are likely to be located near to them. Also, most transparent materials from which viewing ports are made are relatively brittle - so it is difficult to predict their behavior under concentrated impact loading such as is produced by missiles.

As a result, where missile hazards are unusually severe it is recommended that alternate methods of viewing be provided, such as periscopes, mirrors, and closed circuit television.

Some recommended thicknesses of laminated bullet resisting glass are presented in Table 2 (from reference 8.3.c.4). These thicknesses are given in terms of the kinetic energy of the missile.

No similar data could be located by the author for transparent plastic viewing ports. In general, however, it is believed (from the test results reported in reference 8.3.c.3) that slightly greater thicknesses of Plexiglas and similar acrylics are required to produce equivalent protection.

The properties of the polycarbonate resins (high impact strength and elongation) are such that they should provide relatively good missile resistance. No data suitable for design purposes could, however, be located by the author.

The use of glass for viewing ports which has been neither laminated nor tempered to prevent shattering under impact is, of course, to be avoided in all cases due to the sharp fragments which are formed on fracture. (Glass used for shielding purposes is thus normally unsuitable for use in barricades.)

TABLE 2. MINIMUM REQUIRED THICKNESSES OF LAMINATED BULLET RESISTING GLASS TO PREVENT PENETRATION BY MISSILES

Missile Kinetic Energy ft-lbs	Required Thickness of Bullet Resisting Glass
490	1 3/16
804	1 9/16
2400	2

3.9 Sample Calculations

a. Steel Plate Barricade. Consider a long cylindrical tube with an inside diameter, d, of 2" and a wall thickness, t, of 0.1" which ruptures due to fatigue while containing saturated water at 600°F.

The wall material is carbon steel having a density of 0.234 lbs/cu in (490 lbs/cu ft).

The ratio of inside diameter to wall thickness is

$$d/t = \frac{2.0}{0.1} = 20$$

From Figure 2, the initial velocity of the missile produced is about 1010 ft/sec.

We shall assume that the tube splits longitudinally and opens flat. Thus, the lengthwise dimension of the missile is the circumference of the tube or

$$L = \pi d = \pi(2) = 6.28 \text{ inches}$$

Let us construct the barricade of ASTM A-7 carbon steel plate having a specified minimum tensile strength of 60,000 psi.

From equation (14), the thickness of plate which will barely retain this missile is given by

$$T = -.0118W + \sqrt{1.38 \times 10^{-4}W^2 + 0.0706\ \rho tLV_p^2/U}$$

From Section 3.3.b, the "equivalent diameter" of the missile is

$$D = 2t = (2)(0.1) = 0.2 \text{ inches}$$

Then, from equation (12)a, let us assume an effective window opening of

$$W = 8D = (8)(0.2) = 1.6 \text{ inches}$$

This is smaller than: (a) any likely spacing of supports, or (b) the opening size given by equation (12)b with any reasonable barricade thickness, or (c) the length, L, per equation (12)c. Thus, the value of 1.6 inches from (12)a will be used. Then, putting in numbers

$$T = -0.0118(1.6) + \sqrt{1.38 \times 10^{-4}(1.6)^2 + \frac{(0.0706)(0.284)(0.1)(6.28)(1010)^2}{60{,}000}}$$

$$= 0.445 \text{ inches}$$

or rounding off, say, 1/2 inch.

In some cases, a greater thickness may be desirable to provide a greater factor of safety. In this case, however, greater thicknesses are not considered necessary due to the following conservative factors which entered into the calculations:

(1) The tube was assumed to open up flat and to strike the barricade both with its velocity normal to the barricade and with the plane of the missile normal to the barricade at the instant of contact. Both of these conditions are rather unlikely.

(2) The tube was assumed to open out completely flat so that its characteristics on impact would be similar to those of a cylindrical rod. Actually there would probably be some

residual curvature which would lower the buckling characteristics of the missile and thus reduce its penetrating ability.

b. Reinforced Concrete Barricade. Determine the adequacy of a one foot thick slab of normal reinforced concrete to stop the missile of 3.9.a.

From 3.4 the penetration distance will be

$$D' = KAV'R$$

From Table 1, for "normal" reinforced concrete

$$K = 4.76 \times 10^{-3} \ ft^3/lb$$

The sectional mass is

$$\begin{aligned} A &= \rho b \\ &= (0.284 \ lb/in^3)(6.28 \ in)(144 \ in^2/ft^2) \\ &= 256 \ lb/ft^2 \end{aligned}$$

The velocity factor is, from Figure 4

$$V' = 0.75$$

The penetration ratio is, from Figure 5

$$\begin{aligned} a' &= \frac{T}{KAV'} \\ &= \frac{1}{(4.76 \times 10^{-3})(256)(0.75)} = \frac{1}{0.914} \\ &= 1.10 \end{aligned}$$

The thickness ratio is off scale to the left on Figure 5, thus indicating that the penetration depth is greater than the thickness of the slab.

To barely stop the missile, then, the slab must have a thickness of

$$\begin{aligned} T_M &= 2(KAV') \\ &= (2)(1.10) = 2.20 \ ft \end{aligned}$$

Let us try a thickness of 3.0 ft. Then

$$a' = \frac{3.0}{1.10} = 2.73$$

From Figure 5, the thickness ratio is

$$R = 1.06$$

The depth of penetration in this slab will then be

$$D' = (0.914)(1.06) = 0.97 \ ft$$

The slab thickness of 3.0 ft is more than 1-1/2 times this depth, so no anti-scabbing plate is needed.

4. BLAST RESISTANCE OF BARRICADES

4.1 Conditions Requiring Evaluation

Blast effects will be produced whenever high pressure fluids are suddenly released to atmosphere. These effects are often (perhaps usually) more destructive than the effects of missiles - which act over much smaller areas. It is thus felt that blast effects should be evaluated unless experience has shown that for credible modes of failure, blast effects will be negligible.

4.2 Physiological Effects of Blast

This report is concerned primarily with evaluation of structural effects and the structural adequacy of barricades. It is felt that a barricade which is structurally adequate to resist blast and which provides line of sight protection for personnel will normally also provide adequate physiological protection.

However, when determining the need for a blast barricade or for evaluating possible effects on personnel who might be inside a barricade at the wrong time, some consideration of physiological effects may be of interest.

Table 3 (adapted from Glasstone, reference 8.3.a.12) gives values for the peak overpressures at which various physiological effects are anticipated. These values were obtained largely in connection with the

TABLE 3. PHYSIOLOGICAL EFFECTS OF BLAST PRESSURES

Peak Overpressure psi	Physiological Effect
1	Knock Personnel Over
5	Threshold for Eardrum Rupture
15	Threshold of Lung Damage
35	Threshold for Fatalities
65	Fatalities 99% Probable

effects of atomic weapons - which are characterized by unusually long period blast waves. With the shorter period blast waves which are expected from pressure vessel explosions, these values are felt to be conservative.

In order for this table to have any predictive value, it is necessary, of course, to obtain an estimate of peak overpressure in a given incident.

Rigorous calculations of blast wave pressures can be very complex (see references 8.2.3, 8.2.5, and 8.2.18). However, it is believed that a rough estimate for the purposes described above may be obtained by multiplying the static pressures obtained by the methods of 4.3.a by a factor of 6. (This factor was obtained by comparing predicted static pressures from 4.3.a with those obtained by Porzel in reference 8.2.3.)

In addition to physiological effects resulting from pressure load, effects may also be produced by the high temperatures which frequently accompany blasts, such as by scalding by steam. Protection should be provided against such hazards when present.

4.3 Effective Static Pressure

a. Static Analysis. The effective static overpressure for structural evaluation purposes may be estimated from the following expression (adapted from Loving, reference 8.2.9):

$$P = 5.75 \frac{V_p}{V_c} E_v \qquad (16)$$

where P = Effective static overpressure - psig

V_p = Volume of pressure vessel - cu in

V_c = Volume of chamber into which fluid is released on explosion of pressure vessel - cu ft

E_v = Energy released due to expansion of fluid or chemical reaction (if present) per unit volume of pressure vessel - Btu/cu in

This expression may be rearranged in the form

$$\frac{P}{V_p/V_c} = 5.75 E_v$$

which is given by Figure 6 for saturated water as a function of water temperature and pressure.

For nonreacting fluids, the available energy E_v should be obtained by determining the amount of energy released by isentropic expansion of the fluid from rupture conditions to one atmosphere.

For reactions of certain explosive compounds, see reference 8.2.9.

The above expressions were obtained for chambers having a maximum dimension no greater than twice the minimum dimension. Thus, for long, narrow chambers (such as pipes) an effective volume should be used for V_c equal to the volume of a space having its maximum dimension twice that of the minimum dimension of the chamber.

The pressure is used by conventional static structural techniques to determine barricade adequacy.

b. Dynamic Analysis. Examples of calculations in which transient pressures during pressure vessel incidents were calculated are given by references 8.2.2, 8.2.3, 8.2.5, 8.2.18, 8.3.a.1, and 8.3.a.6.

Newmark, in reference 8.2.4, gives a method for evaluating the effects of blast loading in terms of an equivalent static pressure. This method requires an evaluation of the natural frequency of vibration of the structure, its ratio of elastic deflection to deflection at failure, and a knowledge of the duration and magnitude of the blast loading.

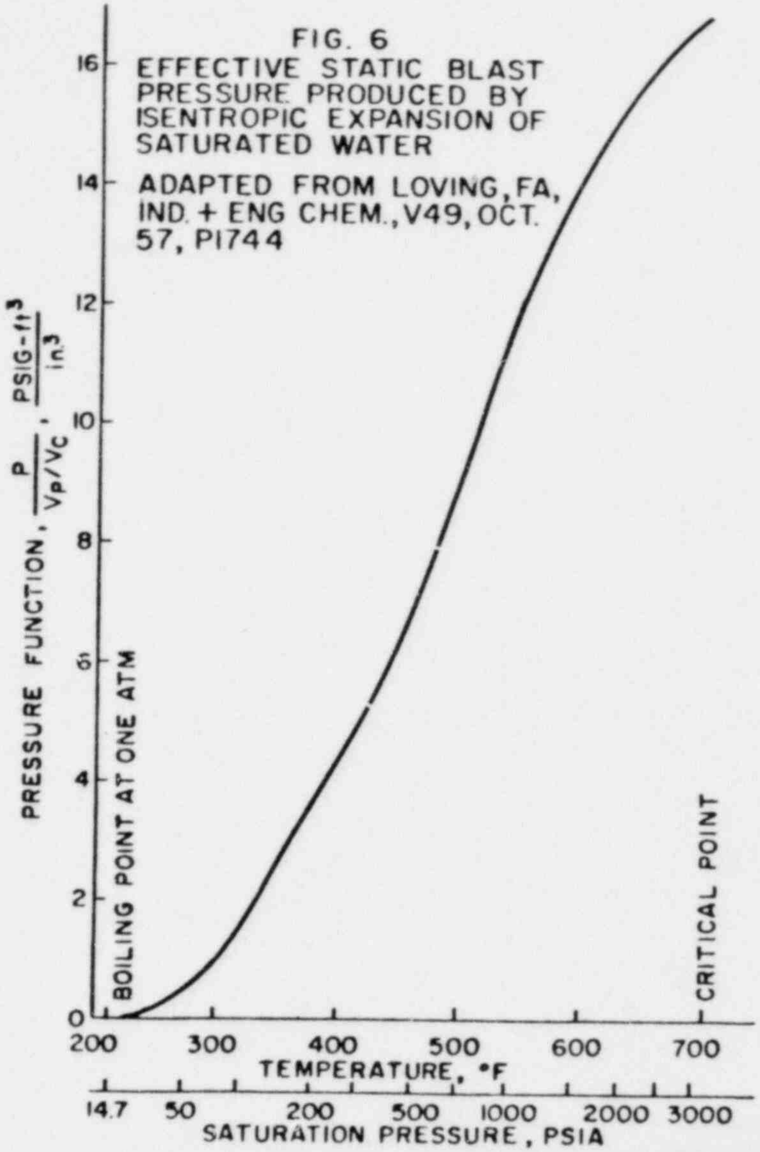


FIG. 6
EFFECTIVE STATIC BLAST PRESSURE PRODUCED BY ISENTROPIC EXPANSION OF SATURATED WATER

ADAPTED FROM LOVING, FA, IND. + ENG CHEM., V49, OCT. 57, P1744

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Methods for the design of specially constructed masonry walls to resist blast loading are given by McKee and Monk in references 8.2.6, 8.2.7, and 8.2.15.

4.4 Blast Energy Absorption by Deformation

Methods which may be used for the evaluation of blast resistance of cylindrical containment structures in terms of their energy absorption abilities are given by Wise in references 8.2.8 and 8.2.14.

The use of crushable materials such as wood and celotex is discussed by Porzel (references 8.2.5 and 8.2.12), Hanna and Ewing (reference 8.2.20), Monson (reference 8.3.a.7) and Zaker and his associates at Armour Research Foundation (now IITRI) (reference 8.2.19 and subsequent periodic reports). As yet, however, no simple, generally applicable design techniques are known.

Absorption of blast energy from steam and water pipes ruptured under water is discussed by Luken and Leeman (reference 8.2.21).

4.5 Sample Calculation

Let us determine the adequacy for blast resistance of the barricade selected in 3.9.a. A 1/2 inch steel plate was selected as adequate for missile resistance.

We will assume that the barricade is in the form of a nominal 10 inch diameter Schedule 60 pipe having a nominal wall thickness of 1/2 inch, the same length as the pressure vessel, and constructed of ASTM-SA-106B material.

From Figure 6, the blast pressure function developed by rupture of the pressure vessel containing 600° water is

$$\frac{P}{V_p/V_c} = 14.1 \quad \frac{\text{psig - ft}^3}{\text{in}^3}$$

The volume of the chamber will be

$$V_c = \frac{\pi}{4} D^2 L$$

where D = Inside diameter of barricade - ft
L = Length of barricade - ft (taken as unit length or 1 ft)

The inside diameter of 10-inch Schedule 60 pipe is 9.75 inches. Thus

$$V_c = \frac{\pi}{4} \left(\frac{9.75}{12}\right)^2 (1) = 0.518 \text{ ft}^3$$

Similarly, the inside volume of the exploding pipe is

$$V_p = \frac{\pi}{4} d^2 L$$

$$= \frac{\pi}{4} (2)^2 (12)$$

$$= 37.7 \text{ in}^3$$

Then the effective static pressure produced is

$$P = (14.1) \frac{V_p}{V_c} = (14.1) \left(\frac{37.7}{0.518}\right) = 1025 \text{ psig}$$

From paragraph UG-27 of Section VIII of the ASME Boiler Code, the thickness required to withstand this pressure is given by

$$t = \frac{PR}{SE-0.6P}$$

where S = Maximum stress allowable by Code (equals 15,000 psi for this material)
E = Joint efficiency (equals 1 for seamless pipe)
R = Inside radius - inches

Putting in these values we obtain

$$t = \frac{(1025)(4.875)}{(15{,}000)(1) - (0.6)(1025)}$$

$$= 0.348 \text{ in}$$

This is less than the 1/2 inch required for missile resistance. Thus the blast resistance is satisfactory.

4.6 Evaluation of Barricades by Test

The ASME Boiler Code provides standard overload proof tests by means of which pressure vessels having geometries whose adequacy cannot be reliably evaluated by analysis can be shown to be adequate.

Unfortunately, similar proof tests for barricades are likely to be prohibitively expensive and should be considered only when no other means for evaluation exist.

A program to develop and evaluate scaling laws for tests of model barricades using explosive charges is described in references 8.2.10, 8.2.16, 8.2.17, 8.2.22, and 8.2.23. The application of these laws to tests of a 1/4 scale model of a nuclear reactor barricade is described in references 8.2.13 and 8.2.17.

The design of a laboratory cell and tests of a full scale mockup of the cell using up to 50 lb charges of TNT are described in references 8.3.b.11 and 8.3.b.12.

Tests conducted on a full scale portable barricade are described in reference 8.3.b.13.

4.7 Blast Resistance of Transparent Barricades

Circular glass viewing ports with manufacturer's static pressure ratings may be purchased in sizes up to 17 inch diameter (reference 8.3.c.1 and 8.3.c.5). These are considered generally preferable to "homemade" designs due to the difficulties of providing edge supports which develop the full strength of the glass.

If, however, a special design is desired, the following equation may be used for estimating the required thickness (from Shand, reference 8.3.c.2) of solid glass or plastic ports

$$t = d \sqrt{\frac{K_1 P}{\sigma}} \quad \text{inches} \qquad (17)$$

where d = Diameter of circular port or smaller dimension (width) of rectangular port - inches
P = Effective static pressure due to blast - psi
σ = Allowable working stress of port material - psi
K_1 = Stress factor. For circular ports $K_1 = 0.3025$. For rectangular ports K_1 is a function of the ratio of length to width and is given by Table 4.

Recommended working stresses are 1500 psi for tempered glass and 1100 psi for Plexiglas G .

TABLE 4. STRESS FACTORS FOR RECTANGULAR VIEWING PORTS
(Shand, ref. 8.3.c.2)

Length/Width Ratio	Stress Factor K_1
1	0.29
1.5	0.48
2	0.61
2.5	0.67
3	0.71
4	0.74
Over 5	0.75

4.8 Effectiveness of Venting for Blast Protection

Laboratory test cells are normally constructed with one wall either open or of lightweight construction to act as an explosion vent. Such vents are of considerable value for minimizing the effects of relatively slow explosions such as occur if the test cell is filled with a hydrocarbon or combustible dust mixture and ignition occurs (see reference 8.2.11).

When pressure vessels explode, however, the resultant blast wave is projected outwards from the vessel at the velocity of sound. Thus portions of the surroundings which are acted upon by one portion of the blast wave will be relatively unaffected by what is happening elsewhere to the blast wave. As a result, little reliance can be placed on the beneficial effects of venting for the types of explosions considered here.

This lack of effectiveness of venting has been demonstrated when pressure vessels have exploded out of doors (under "ideal" venting conditions) with extensive blast damage resulting.

5. DESIGN OF LABORATORY TEST CELLS

Laboratory test cells consist, in general, of three reinforced walls constructed of concrete or similar materials and a fourth wall of lightweight blowout construction pointed in a safe direction. The designs of a number of such test cells are described in references 8.3.b.1 through 8.3.b.12 and 8.3.b.14 and 8.3.b.15.

6. ADDITIVE MISSILE AND BLAST EFFECTS

Usually a barricade will have a considerably greater margin of strength for blast resistance than for missile resistance. Thus exposure of the barricade to blast effects will not affect its subsequent resistance to missiles. (Blast waves usually travel faster than the missiles and thus act upon the barricade first.)

If, however, the blast and missile resistance of a barricade are about equal, the blast effects could conceivably cause weakening or dislodgement of the barricade so that barricade failure subsequently occurs due to missile impact - where such failure would not be expected for either of the effects acting singly. Thus the possibility of additive effects should be considered when the required thicknesses for blast and missile resistance are about the same.

7. ACKNOWLEDGMENT

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APPENDIX A. CHECK OF MISSILE VELOCITY ESTIMATE

The expression given by Equation (5) for the estimation of the velocities of fragments of exploding pressure vessels is an extrapolation from the Gurney equation (Equation 1) - which has been verified by experiment for explosions of high explosives in cylindrical geometries over a wide range of diameters and thicknesses of cylinders.

Its use in the form given by Equation (5) for the much slower and lower pressure explosions characteristic of pressure vessels is, of course, without sound theoretical foundation. Thus an attempt was made to correlate predicted velocities obtained from Equation (5) with some calculated from the distances of travel of fragments of exploded pressure vessels reported in the literature (references 8.4.1 thru 8.4.8).

The literature references give, in general, the distances traveled by fragments of the pressure vessel shells, the pressures at which the explosions occurred, the dimensions of the pressure vessels prior to the explosions and, in the cases of the fire tube boilers studied, usually some indication of the water level at the time of the explosion. All of the explosions studied except one (reference 8.4.7) were fire tube boilers.

It was assumed in predicting the velocities by Equation (5), that the fire tube boilers were filled to the equivalent of fifty per cent of their internal volume with water; the remainder of the space being the normal steam space in the boiler and the space occupied by the fire tubes.

The minimum initial velocities calculated from the range of the fragments were calculated by the method suggested by Wood (reference 8.3.a.1) with an additional correction factor taken from ordnance data to account for air resistance. This method implies that the missile was fired at a forty-five degree angle (or elevation) to the horizontal. Thus the computed velocity is the maximum which could have occurred and may be considerably less than the actual initial velocity.

The results of this comparison are summarized in Figure 7 - in which the minimum velocity computed from the range of the fragments is plotted on the vertical scale, and the velocity predicted by Equation (5) is plotted on the horizontal scale. The dotted line represents an exact correlation. The numbers next to the points refer to reference numbers given in 8.4.

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All of the points fall below the dotted line, thus indicating that Equation (5) gives results which appear to be conservative - which is reassuring.

The scatter in the vertical direction of the predicted velocity may be explained on the basis of the random elevations of the fragments. If this is, in fact, a true explanation then the upper points most accurately represent the true initial velocities. Using these points, the velocities predicted by Equation (5) are high by about forty or fifty per cent of the "true" velocities.

Some caution should, however, be observed before jumping to the conclusion that Equation (5) is, in fact, this conservative - since the apparent conservatism may also be explained by the following factors:

a. A relatively small number of cases of explosions were studied; thus there is a significant probability that none of the fragments came off at close to the forty-five degree elevation required to produce maximum range.

b. In the fire tube boiler explosions studied, considerable kinetic energy may have been absorbed in accelerating the tubes - many of which were thrown considerable distances. No allocation of energy was made to the tubes, however, in estimating the velocities of the fragments. Thus vessels which do not contain comparable internal structures might be expected to produce higher shell fragment velocities.

c. The data for the explosions was of rather poor quality by laboratory standards. Most of it was taken by untrained observers, some of whom were probably biased by personal considerations.

d. All the explosions studied occurred at relatively low pressures; the highest being 100 psig. What sort of correlation would be obtained at higher pressures can only be speculated. It seems reasonable, however, to expect better agreement - since vessels exploded at higher pressure would seem to approach more nearly the conditions occurring during detonation of high explosives.

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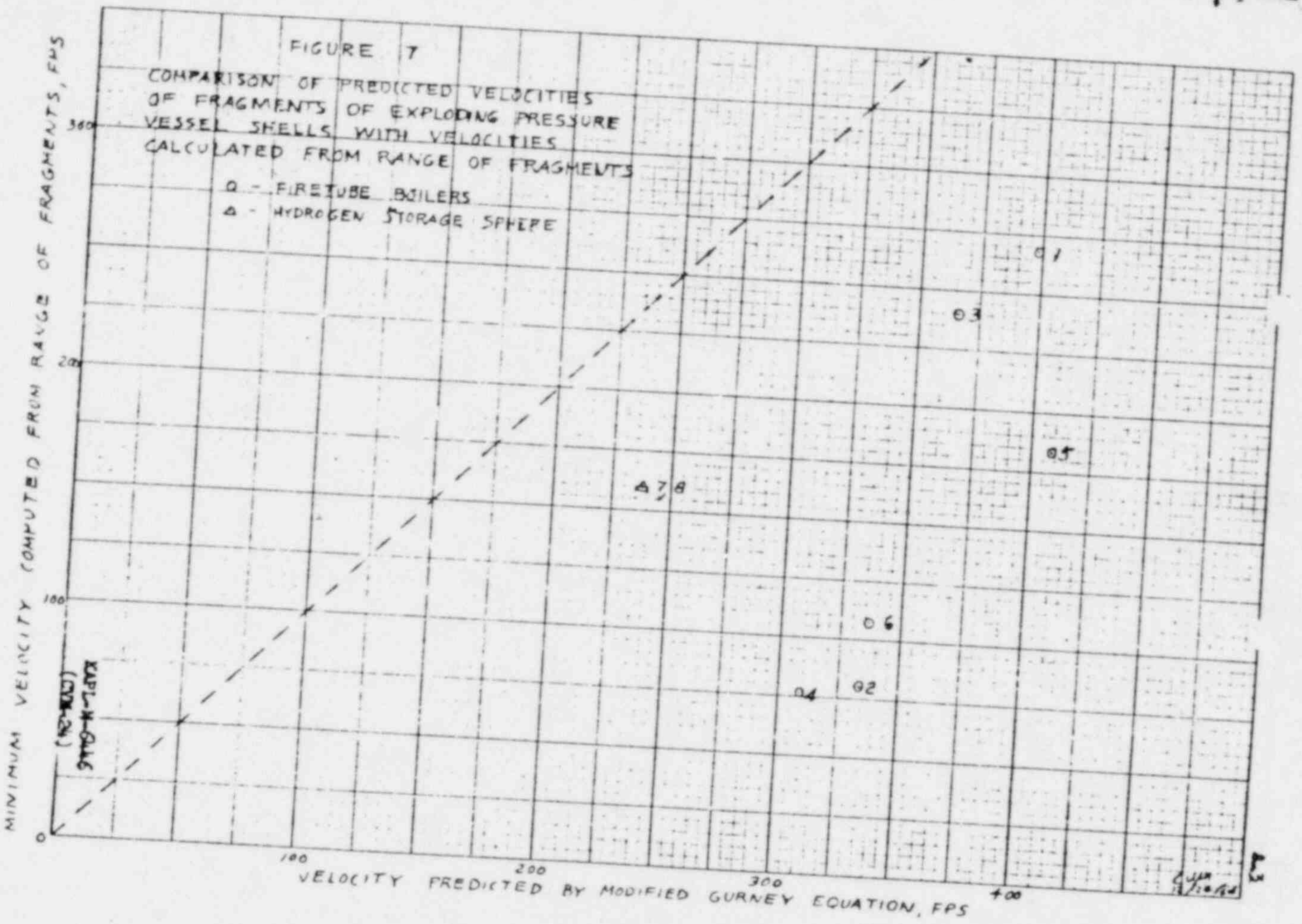

FIGURE 7

COMPARISON OF PREDICTED VELOCITIES OF FRAGMENTS OF EXPLODING PRESSURE VESSEL SHELLS WITH VELOCITIES CALCULATED FROM RANGE OF FRAGMENTS

○ - FIRETUBE BOILERS

△ - HYDROGEN STORAGE SPHERE

KAPL-M-GAHG (CSM-24)

APPENDIX B. CHECK OF EQUIVALENT STATIC OVER-PRESSURE ESTIMATE

Hanna and Ewing (reference 8.2.23) have reported data for a series of experiments in which charges of 50/50 pentolite were exploded while suspended on the center lines of cylindrical steel pressure vessels of various sizes. The pressure vessels were instrumented with strain gauges whose readings were recorded with high speed instrumentation during the explosions.

From the strain gauge readings, an effective over-pressure during the explosion can be derived. (That is, the static internal pressure which would be required to produce the same strain.) With strains in the elastic range such an over-pressure would seem to be equivalent to the effective static over-pressure discussed in 4.3.a. Such a pressure was calculated for round 221 (reference 8.2.23) - giving a value of 155 psi.

Loving's equation (reference 8.2.9) from which Equation (16) was derived is

$$P = K \frac{W}{V_c} \qquad (18)$$

where P = Over-pressure in lbs per sq inch gauge
W = Weight of material exploded in lbs
V_c = Chamber volume in cubic feet
K = 15,000 for PETN

The value of K given was based on an available energy release of 1450 calories per gram (reference 8.4.9). Loving does not give a value of K for 50/50 pentolite, however, one can be extrapolated from the value of K given for PETN by assuming that K is directly proportional to the available energy release and using the value of 1220 calories per gram reported in reference 8.2.23.

Making this extrapolation, an equivalent static over-pressure of 113 psi is obtained from Equation (18). This value compares reasonably well with the 155 psi derived from the strain gauge data.

A number of experiments have been reported in the literature in which pipes or vessels containing pressurized water have been discharged into larger vessels initially filled with air - following the breaking of rupture discs or the opening of quick opening valves. (for example, references 8.2.19, 8.2.21, and 8.4.10)

In most of these, either no blast pressures have been measured or very small pressures have been measured. In all cases with which the author is familiar, however, the sizes of the suddenly produced openings have been relatively small compared to the volume of pressurized water. (That is, the area of the opening has been very, very small compared to the area of cross-section of a sphere having a volume equal to the volume of the pressurized water.) Thus the conditions of the experiments have been relatively mild compared to those which apparently occurred during many recorded explosions of pressure vessels - judging from the damage produced and the configurations of the pressure vessel remains.

The most severe (by this standard) tests known to the author are those reported by Kolflat (reference 8.4.10). In these tests a drum, 42 inches in diameter by 23 feet long, filled with various quantities of saturated water at pressures up to 600 psig was discharged through a 12 inch rupture disc into an outer vessel having an inside diameter of 14 feet and a height of 32 feet.

The effective over-pressure predicted by Equation (16) for Kolflat's test number 11 was 328 psi. The first pulse of measured pressure reported by Kolflat was 86 psi. The large difference between the predicted and measured pressures is believed to be due primarily to the relatively small size of the opening - which had an area only 1/12 of the cross-sectional area of the drum. A contributing factor might also have been a lack of adequate speed of response of the pressure measuring and recording equipment which would tend to cause an under estimation of very rapid pressure transients.

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END

APPENDIX G

MAIN STEAM PIPING STRESS ANALYSIS

NORTHEAST UTILITIES SERVICE COMPANY
NUCLEAR ENGINEERING AND OPERATIONS GROUP
GENERATION MECHANICAL ENGINEERING

ASME SECTION III CLASS 2 AND 3 AND ANSI B31.1.0 PIPING ANALYSIS

PROJECT ASSIGNMENT: 78-822

CALCULATION NUMBER: 78-822-146-GP

PLANT: MILLSTONE UNIT No. 1

TITLE: MAIN STEAM LINE STRESS ANALYSIS FOR HEPB STUDY

QA CATEGORY 1

REVISION 0

PREPARED BY PJ QUINLAN	DATE 1/30/82	REVIEWED BY Frank J Mello	DATE 2/4/82
REVIEW METHOD FULL REVIEW		APPROVED BY Majid	DATE 2/4/82

REVISION 1

PREPARED BY	DATE	REVIEWED BY	DATE
REVIEW METHOD		APPROVED BY	DATE

REVISION 2

PREPARED BY	DATE	REVIEWED BY	DATE
REVIEW METHOD		APPROVED BY	DATE

SUBJECT Appendix G
Main Steam Line Stress
Analysis for HEPB Study
Millstone Unit No. 1

BY PJQUINLAN DATE 1/30/82
CHKD. BY FJ MEZZO DATE 2/2/82
CALC. NO. 78-872-146GP REV. 0
SHEET NO. 2 OF 7

By utilizing a simple mechanistic approach, a pipe rupture is postulated at each weld in the piping system. However, when stress analysis information is available, it can be used in a mechanistic evaluation as follows. Pipe ruptures are postulated at the following locations:

1.) At the terminal ends of each pipe run.

2.) At all locations in the piping run where the stress as calculated by the sum of equations (9) and (10) of ASME NC-3652 exceeds $0.8(1.2 S_h + S_A)$. At least two intermediate points of highest stress must be chosen.

These rules are documented in Standard Review Plan 3.6.2 and apply to Class 2 piping analysis.

NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ QUINLAN DATE 1/30/82
CHKD. BY FJ MEZZO DATE 2/2/82
CALC. NO. 78-822-146GP REV. 0
SHEET NO. 3 OF 7

The approach outlined above may be used for all piping inside the drywell which was analyzed under Class 2 rules.

PROBLEM

In several cases in the analysis of high energy pipe break inside containment for Millstone Unit No. 1 there were found interactions due to postulated pipe ruptures which are considered to be unacceptable. However, if it can be shown that the pipe break locations which are responsible for the unacceptable consequences are in fact, not included in the group of locations as choosen by the criteria above, then there will not be any interaction at all since the pipe rupture will not have to be postulated.

SUBJECT

BY P J QUINLAN DATE 1/30/82

CHKD. BY FJ Mello DATE 2/2/82

CALC. NO. 78-822-146GP REV. 0

SHEET NO. 4 OF 7

CASE I.

Main Steam line B points 11 and 12 on isometric BMZ072-IC9 have unacceptable interaction with the CRD withdraw lines.

Using the EBASCO stress analysis, calculation number 262, the following is calculated.

EBASCO Case 71 - Combines stresses due to thermal expansion and seismic anchor displacements.

EBASCO case 51 or 52 - Represents worst combination of deadweight, pressure and OBE seismic stresses.

Material is A-106 Carbon Steel

ASME allowables $S_h = 12.5$ ksi $S_c = 12.5$ ksi

$$\sigma_A = 0.8\left(1.2\,S_h + S_A\right)$$

$$S_A = f\left(1.25\,S_c + 0.25\,S_h\right)$$

$$f = 1.0$$

$$\therefore\ S_A = 1.25(12.5) + 0.25(12.5) = 18.75 \text{ ksi}$$

$$\sigma_A = 0.8\left[1.2(12.5) + 18.75\right]$$

$$\sigma_A = 27.0 \text{ ksi}$$

SUBJECT

BY PJ QUINLAN DATE 1/30/82
CHKD. BY FJ MEZZA DATE 2/2/82
CALC. NO. 78-822-14GGP REV. 0
SHEET NO. 5 OF 7

All locations with stress greater than 27 ksi must be considered pipe rupture locations.

D.P.	EBASCO D.P.	CASE 51 or 52	CASE 71	TOTAL
11	12	6438	4762	11200 psi
12	1200	6117	5806	11923 psi

The total stress values for points 11 and 12 are well below the pipe rupture location criterion of 27 ksi. However it must be shown that at least two locations have higher total stress than locations 11 and 12.

EBASCO D.P.	CASE 51 or 52	CASE 71	TOTAL
2	7819	5710	13529 psi
20	5966	11698	17664 psi

Since locations 2 and 20 (EBASCO designations) have higher total stress values than locations 11 and 12, pipe ruptures need not be postulated for locations 11 and 12.

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NORTHEAST UTILITIES SERVICE COMPANY

SUBJECT

BY PJ QUINLAN DATE 1/30/82

CHKD. BY FJ Mello DATE 2/2/82

CALC. NO. 78-822-1466GP REV. 0

SHEET NO. 6 OF 7

CASE II.

Main Steam line C has much the same problem as Main Steam line B with an interaction with the CRD withdraw lines. The identical approach will be used. Points 11 and 12 on isometric BMR072-IC8 have the unacceptable interaction.

D.P.	EBASCO D.P.	CASE 51 or 52	CASE 71	TOTAL	
11	9	5657	6263	11920	psi
12	11	5955	4495	10450	psi
—	2	7369	6504	13873	psi
—	18	6541	5739	12280	psi

Data points 11 and 12 are well below the 27 ksi value for postulating break locations and are below at least two other data points, EBASCO points 2 and 18. Therefore, they need not be required as break locations.

SUBJECT

BY PJ QUINLAN DATE 1/30/82

CHKD. BY FJ Mezzo DATE 2/2/82

CALC. NO. 78-822-146GP REV. 0

SHEET NO. 7 OF 7

CASE III.

A pipe rupture of Main Steam line B at locations 13 and 14 is postulated to interact with the core spray and LPCI lines of the same ECCS train. This leads to an unacceptable situation when a single active failure is postulated. However, if these locations have lower stresses than points 2 and 20 (EBASCO D.P.) from CASE I, then they need not be considered to be pipe break locations.

D.P.	EBASCO D.P.	CASE 51 or 52	CASE 71	TOTAL
13	13	6467	5435	11902 psi
14	14	6882	5325	12207 psi

Data points 13 and 14 are below stress values for intermediate points 2 and 20 from CASE I. Therefore pipe breaks need not be postulated.