UTILITY PRESENTATION:

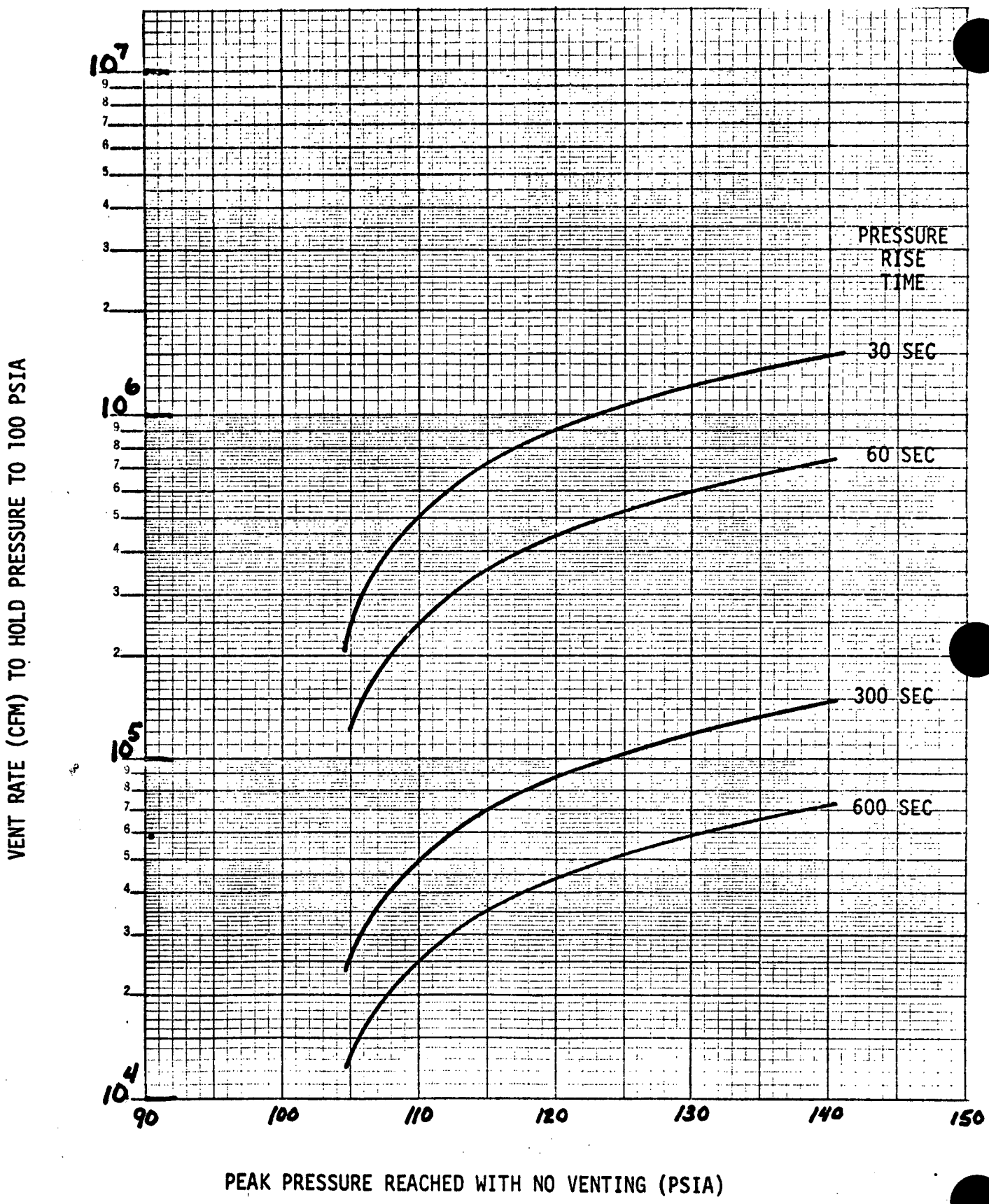
CONTAINMENT OVERPRESSURE

CONTROL CONCEPTS

June 3, 1980

8008060052

ATTACHMENT I



CONTAINMENT VENT SYSTEM
SIXTY DAY STUDY

- FUNCTIONAL REQUIREMENTS
- CONCEPTUAL HARDWARE DESIGN SKETCHES
- ESTABLISH BASIS FOR COMPARING RELATIVE MERITS OF CONCEPTUAL DESIGNS

DESIGN BACKGROUND

- CONCEPTUAL SYSTEMS DESIGNS DONE IN PARALLEL WITH CONTAINMENT TRANSIENT ANALYSES

- BASED ON BEST INFORMATION AVAILABLE

  - BATELLE COLUMBUS NUREG/CR-0138 EFFECT OF CONTAINMENT VENTING ON THE RISK FROM LWR MELTDOWN ACCIDENTS

  - WASH-1400

  - INTERNAL WESTINGHOUSE DATA

  - LITERATURE SOURCES

  - BEST ESTIMATE

FUNCTIONAL REQUIREMENTS

- PASSIVE OPERATION

  - NUREG/CR-0138 TMLB' CONTAINMENT PRESSURE TRANSIENT INDICATES OPERATION REQUIRED WITHIN 30 TO 120 MINUTES

  - LOSS OF ON-SITE POWER ASSUMED FOR 24 HOURS

FUNCTIONAL REQUIREMENTS

- VENT FLOW

  - NUREG/CR-0138 INDICATES CONTAINMENT LEAK RATE OF 1000 PERCENT PER DAY PREVENTS FAILURE BY LONG TERM OVERPRESSURIZATION. FOR A 2.5 MILLION FT^3 CONTAINMENT, 1000 PERCENT PER DAY IS 18000 CFM.

  - 18000 CFM USED AS A BASIS TO ESTABLISH COMPARATIVE MERITS OF SYSTEMS

  - SUBSEQUENT ANALYSES USED TO DETERMINE ADEQUACY OF 18000 CFM VENT FOR SHORT TERM EVENTS INVOLVING HYDROGEN BURN AND STEAM GENERATION.

- PRESSURE

  - ACTUATE AT CONTAINMENT DESIGN PRESSURE (60 PSIA)

  - TERMINATE AT 40 PSIA

  - FUTURE CONTAINMENT RUPTURE ANALYSES MAY WARRANT USING HIGHER PRESSURES

- TEMPERATURE

  - $400^{o}F$, ABOUT $1000^{o}F$ HIGHER THAN MOST SEVERE LOCA

FUNCTIONAL REQUIREMENTS

- VENT GAS STEAM CONTENT

  - PRESSURIZING CONTAINMENT AIR FROM 100°F AND 14.7 PSIA TO 400°F AND 60 PSIA BY STEAM INJECTION REQUIRES 60 VOLUME PERCENT STEAM AT FINAL CONDITIONS

- HEAT REMOVAL RATE

  - ESTIMATED 80 MILLION BTU/HR REMOVED TO COOL 18000 CFM OF 60 VOLUME PERCENT STEAM, 40 COLUME PERCENT AIR MIX FROM 400°F AND 60 PSIA TO 180°F AND 14.7 PSIA VALUE ROUNDED UPWARD TO 100 MILLION BTU/HR FOR DESIGN PEAK HEAT REMOVAL RATE.

- HEAT ABSORPTION CAPABILITY

  - 2 BILLION BTU BASED ON INPUTS FROM DECAY HEAT FOR 100 HOURS AND BURNING HYDROGEN FROM ZIRCONIUM-WATER REACTION, AND ASSUMING CREDIT WILL BE TAKEN FOR CONTAINMENT HEAT SINKS AVAILABLE WITHIN ACCIDENT MODEL

FUNCTIONAL REQUIREMENTS

- VENT GAS FISSION PRODUCTS
  - BASED ON WASH-1400 SOURCE TERMS
  - ASSUMES CORE MELT WITH VAPORIZATION OF FISSION PRODUCTS
  - ASSUMES NO STEAM EXPLOSION

- VENT GAS PARTICULATES
  - THREE STEP DERIVATION OF DATA
  - WASH-1400 INDICATES 1% OF CORE URANIUM DIOXIDE ENTERS ATMOSPHERE FOLLOWING VESSEL MELT-THROUGH
  - SANDIA REPORT 79-1918C, MELT CONCRETE INTERACTION, PROVIDES ATMOSPHERE COMPOSITION DURING MOLTEN CORE REACTION WITH A CONCRETE PAD.
  - NUCLEAR TECHNOLOGY VOL 46, RELEASE OF FISSION AND ACTIVATION PRODUCTS DURING LWR CORE MELTDOWN INDICATES 10% OF PARTICLES REMAIN SUSPENDED, 90% SETTLE OUT

FUNCTIONAL REQUIREMENTS

- NON-CONDENSIBLE GAS GENERATION

  - 1000 LB MOLS OF HYDROGEN FROM ZIRCONIUM-WATER GENERATED BETWEEN 40 AND 100 MINUTES

  - 500 LB MOLS OF HYDROGEN GENERATED AT CONSTANT RATE THROUGH BALANCE OF FIRST DAY

  - GENERATION OF OTHER NON-CONDENSIBLE GASES NOT CONSIDERED AT THIS TIME

FUNCTIONAL REQUIREMENTS

- OTHER REQUIREMENTS

  - CONTINUOUS OPERATION FOR 100 DAYS REQUIRED AT ANY TIME IN PLANT LIFE

  - STRUCTURAL INTEGRITY REQUIRED FOR TWO YEARS FOLLOWING OPERATION

  - MUST NOT COMPROMISE CONTAINMENT, CONTAINMENT ISOLATION SYSTEM, OR OTHER SAFEGUARDS SYSTEMS

  - MUST REMOVE 90% OF IODINE AND PARTICULATE FISSION PRODUCTS

  - NO PROVISION TO REMOVE NOBLE GASES

  - NO COMPONENTS INSIDE CONTAINMENT EXCEPT POSSIBLY FIRST CONTAINMENT ISOLATION

  - CONTROL PANEL MUST BE ACCESSIBLE DURING OPERATION

  - OPERATION INITIATES AT 60 PSIA AND TERMINATES AT 40 PSIA. NUMBER OF START-STOP CYCLES IS TEN.

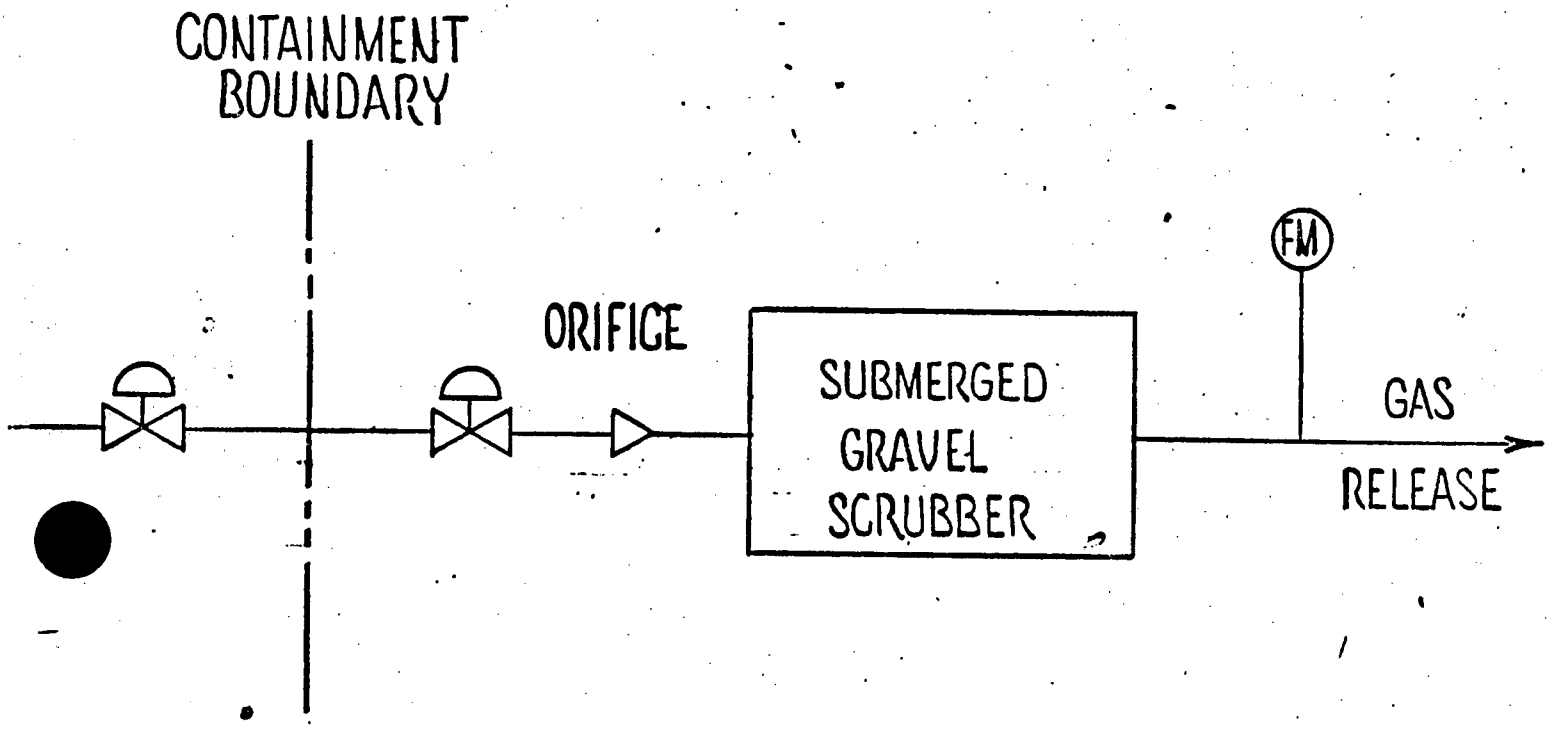
FUNCTIONAL REQUIREMENTS

- OTHER REQUIREMENTS
  - MUST ACCOMMODATE OR ALLEVIATE VACUUMS RESULTING FROM STEAM CONDENSATION AFTER SYSTEM SHUTDOWN
  - MUST NOT INTERFERE WITH NORMAL POWER GENERATION
  - PERIODIC MAINTENANCE WILL BE PERFORMED
  - MUST REMAIN OPERABLE AFTER A HYDROGEN BURN IN CONTAINMENT
  - MANUAL ISOLATION OF VENT SYSTEM REQUIRED TO ASSURE TERMINATION OF OPERATION
  - SYSTEM SHALL NOT SIGNIFICANTLY INCREASE THE CHANCE OF RADIATION RELEASE FROM NON-CORE MELT ACCIDENTS

CONCEPTUAL DESIGNS

- ONCE-THROUGH VENT TO ATMOSPHERE
  - SUBMERGED GRAVEL SCRUBBER
  - SPARGER CONDENSER
  - SAND AND GRAVEL BED PLUS CHARCOAL FILTER
  - SPARGER CONDENSER PLUS HEAT EXCHANGER
  - SPARGER CONDENSER PLUS CHARCOAL FILTER
- RECIRCULATING WITH BLEED TO ATMOSPHERE
  - TURBINE DRIVEN SIDE ARM COOLER
  - RECIRCULATING VENT FILTER

SUBMERGED GRAVEL SCRUBBER



SUBMERGED GRAVEL SCRUBBER SYSTEM
COMPONENT DESIGN PARAMETERS

Scrubber Tank

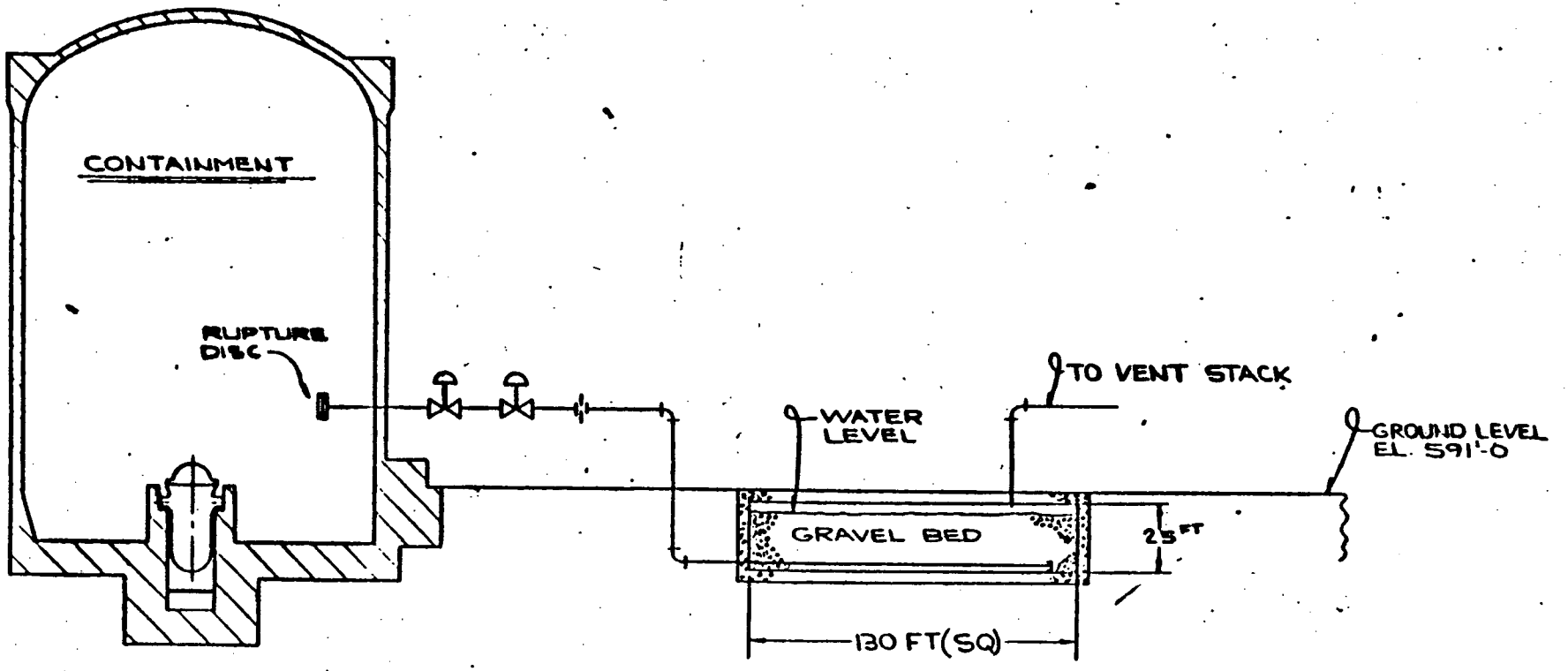
Number	1
Usable Volume, Ft^3	425,000
Design Pressure, psia	30
Design Temperature, °F	212
Material	Steel or Concrete
Initial Operating Temperature, °F	50
Final Operating Temperature, °F	180
Flow, CFM at 400 °F, 40 psia	27,000
Design Heat Absorption Rate, BTU/Hr	100×10^6
Total Heat Absorption Capacity, BTU	2×10^9
Inlet Fluid Pressure, psia	40
Inlet Fluid Temperature, °F	400
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A(1)
Particulates	Appendix B(1)
Design Decontamination Factors	
Particulates	100
Molecular Iodines	10
Organic Iodines	1
Noble Gases	1

(1) Functional Specification

SUBMERGED GRAVEL SCRUBBER SYSTEM
COMPONENT DESIGN PARAMETERS

Orifice

Number	1
Design Pressure, psia	100
Design Temperature, °F	500
Design Flow, CFM at 400°F, 60 psia	18,000
Maximum Pressure Loss, psi	20
Inlet Fluid Composition, Volume Percent	
Steam	0-100
Nitrogen	0-30
Oxygen	0-10
Hydrogen	0-7



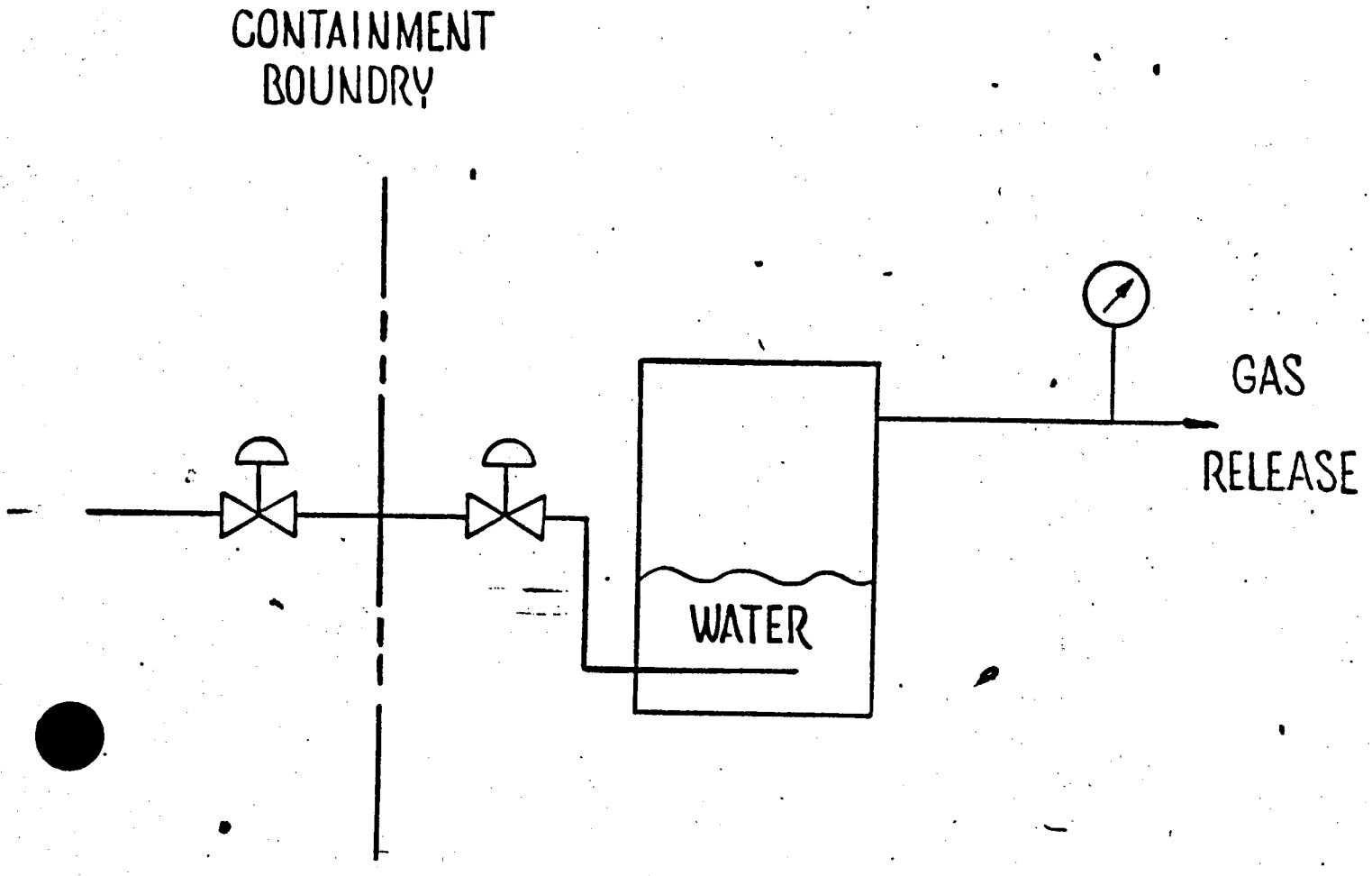
CHANGE

W. VANDRIAK

Westinghouse Electric Corporation

CONTAINMENT OVERPRESSURE VENT SYSTEM-SUBMERGED GRAVEL BED SCRUBBER

6770197-55


CONTAINMENT
BOUNDRY
GAS
RELEASE
WATER

SPARGER CONDENSER AND WATER SCRUBBER SYSTEM
COMPONENT DESIGN PARAMETERS

Sparger Tank

Number	1
Usable Volume, Ft^3	2.5×10^5 ft^3
Type	Vertical
Design Pressure, psia	30
Design Temperature, °F	212
Material	Steel or Concrete
Initial Operating Temperature, °F	50
Final Operating Temperature, °F	180
Sparger Flow, CFM at 400°F, 25 psia	43,200
Design Heat Absorption Rate, BTU/hr	100×10^6
Total Heat Absorption Capacity, BTU	2×10^9
Inlet Fluid Pressure, psia	25
Inlet Fluid Temperature, °F	400
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A(1)
Particulates,	Appendix B(1)
Design Decontamination Factor	
Particulates	100
Molecular Iodines	10
Organic Iodines	1
Noble Gases	1

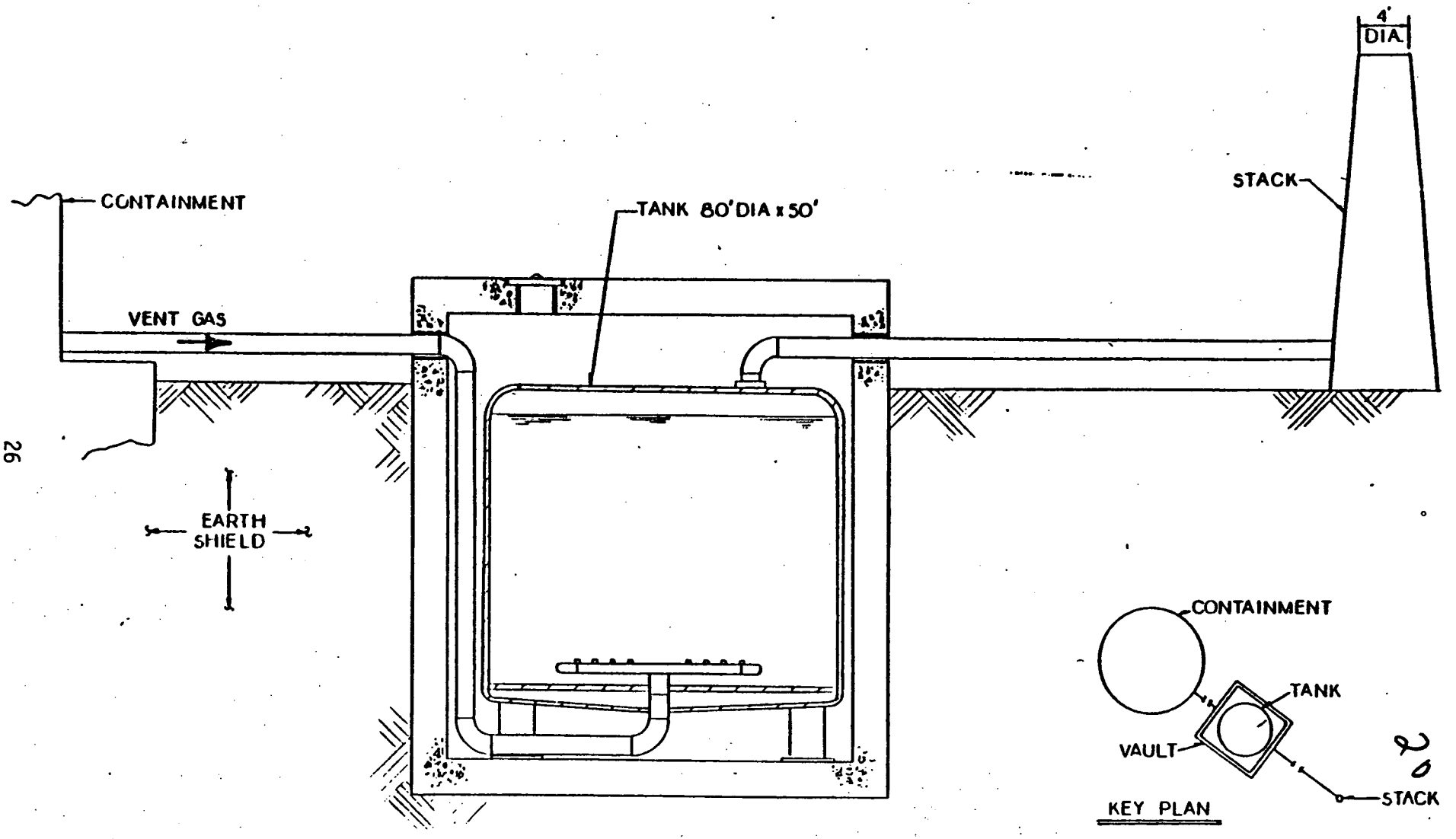
(1) Functional Specification

SPARGER CONDENSER AND WATER SCRUBBER SYSTEM
COMPONENT DESIGN PARAMETERS

Orifice

Number	1
Design Pressure, psia	100
Design Temperature, °F	500
Design Flow, CFM at 400°F, 60 psia	18,000
Maximum Pressure Loss, psi	35
Inlet Fluid Composition, volume %	
Steam	0-100
Nitrogen	0-30
Oxygen	0-10
Hydrogen	0-7

977019 L-47



26

1	CHANGE		

C. Bollinger

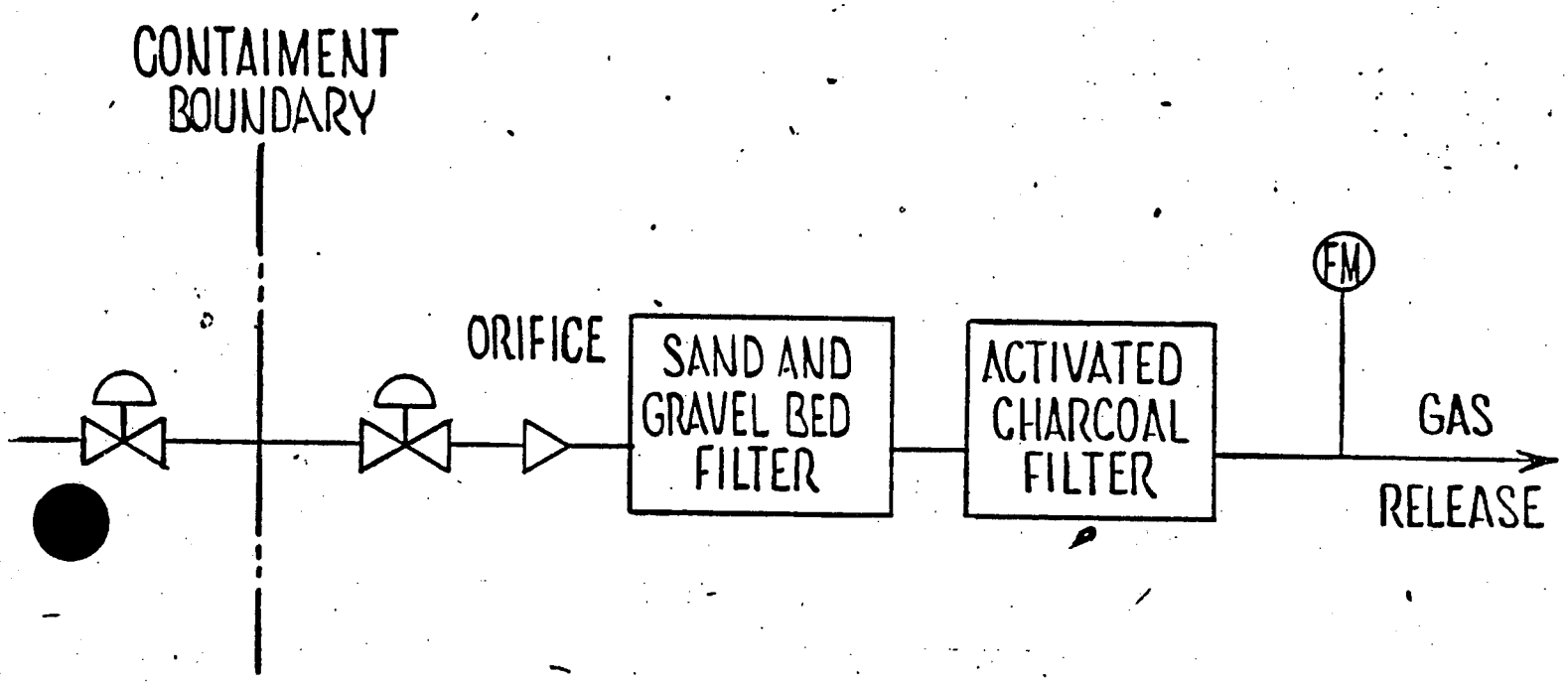
Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.

TITLE CONTAINMENT
OVER PRESSURE VENT SYSTEM
SPARGER CONDENSER & WATER
SCRUBBER

977019 L-4

DO NOT SCALE

SAND AND GRAVEL BED PLUS CHARCOAL FILTER



22

SAND AND GRAVEL BED PLUS CHARCOAL FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Sand and Gravel Bed

Number	1
Usable Volume, Ft^3	660,000
Design Pressure, psia	20
Design Temperature, °F	212
Material	Carbon Steel & Concrete
Initial Operating Temperature, °F	50
Final Operating Temperature, °F	180
Sparger Flow, CFM at 400°F, 25 psia	43,200
Design Heat Absorption Rate, Btu/hr	100×10^6
Total Heat Absorption Capacity, BTU	2×10^9
Gravel Bed Depth, Ft	15
Inlet Fluid Pressure, psia	25
Inlet Fluid Temperature, °F	400
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A(1)
Particulates	Appendix B(1)
Design Decontamination Factors	
Particulates	100
Molecular Iodines	10
Organic Iodines	1
Noble Gases	1

(1) Functional Specification

SAND AND GRAVEL BED PLUS CHARCOAL FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

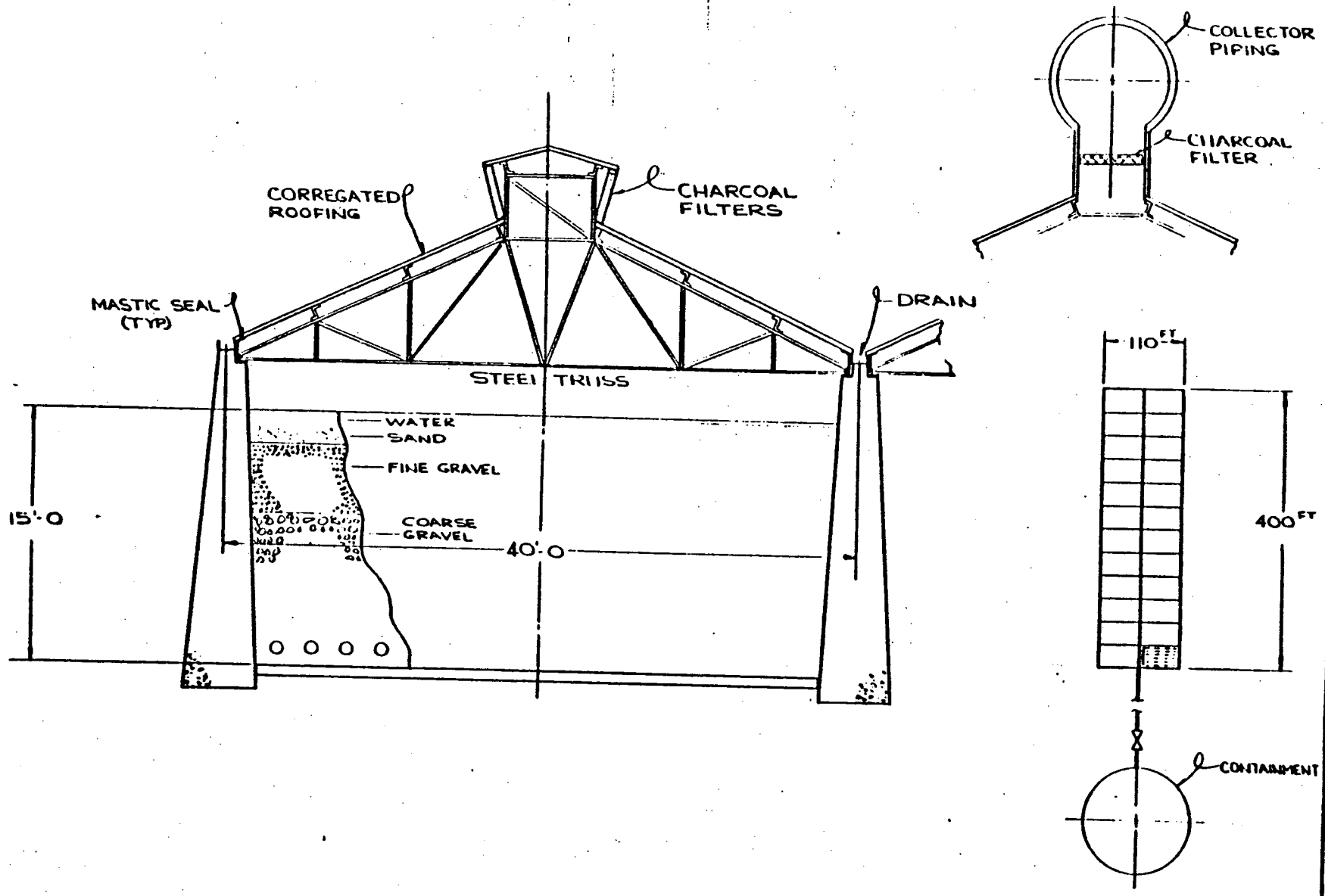
Charcoal Filter

Number	1
Design Pressure, psia	20
Design Temperature, °F	200
Material, Framework	Carbon Steel
Maximum Operating Temperature	180
Design Flow, CFM at 180°F, 15 psia	40,000
Design Face Velocity, Ft/sec	0.3
Inlet Fluid Pressure, psia	15
Allowable Pressure Loss, in. water	1
Inlet Fluid Composition	
Water Vapor, Volume %	3-100
Nitrogen, Volume %	0-62
Oxygen, Volume %	0-21
Hydrogen, Volume %	0-14
Fission Products, μc/cc	Appendix A
Particulates, lb/ft^3	Appendix B
Design Decontamination Factors	
Particulates	100
Molecular Iodine	10
Organic Iodines	10
Noble Gases	1
Filter Medium	Potassium Iodine Treated Charcoal

SAND AND GRAVEL BED PLUS CHARCOAL FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Orifice

Design Pressure, psia	100
Design Temperature, °F	500
Design Flow, CFM at 400°F, 60 psia	18,000
Maximum Pressure Loss, psi	35
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7



CHANGE

W. VANDRIAK

Westinghouse Electric Corporation

NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.

CONTAINMENT OVERPRESSURE VENT SYSTEM- SAND & GRAVEL BED

9770191

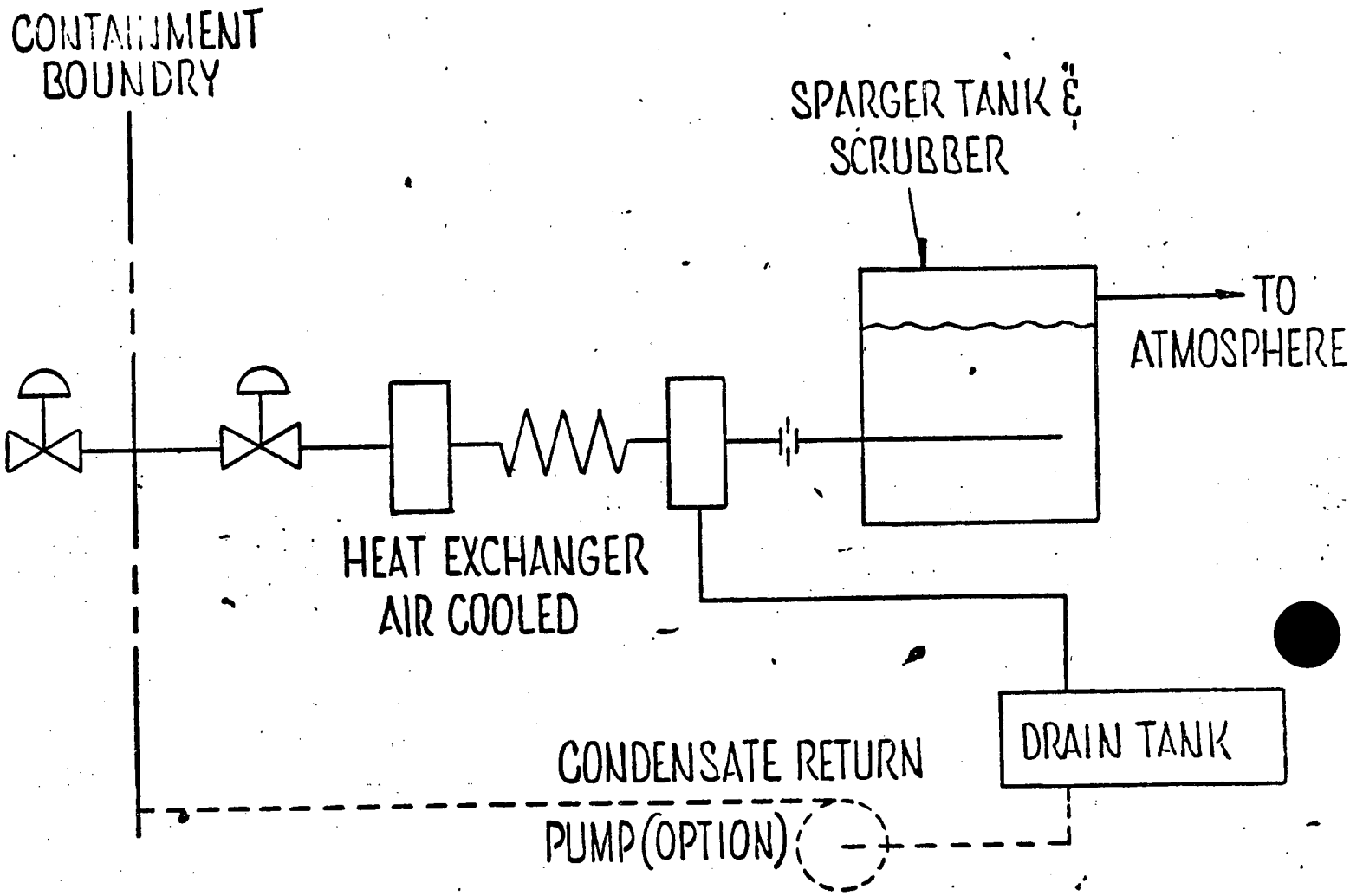
SCALE

DIMENSIONS IN INCHES

DO NOT SCALE

26

SPARGER TANK PLUS HEAT EXCHANGER



977019-L03

SPARGER CONDENSER PLUS HEAT EXCHANGER SYSTEM
COMPONENT DESIGN PARAMETERS

Sparger Tank

Number	1
Usable Volume, ft^3	3×10^4
Type	Vertical
Design Pressure, psia	30
Design Temperature, °F	212
Material	Steel or Concrete
Initial Operating Temperature, °F	80
Final Operating Temperature, °F	160
Sparger Flow, CFM at 180°F, 22 psia	17,000
Design Heat Absorption Rate, BTU/hr	50×10^6
Total Heat Absorption Capacity, BTU	0.5×10^9
Inlet Fluid Pressure, psia	22
Inlet Fluid Temperature, °F	180
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A(1)
Particulates	Appendix B(1)
Design Decontamination Factors	
Particulates	100
Molecular Iodines	10
Organic Iodines	1
Noble Gases	1

(1) Functional Specification

SPARGER CONDENSER PLUS HEAT EXCHANGER SYSTEM
COMPONENT DESIGN PARAMETERS

Heat Exchanger

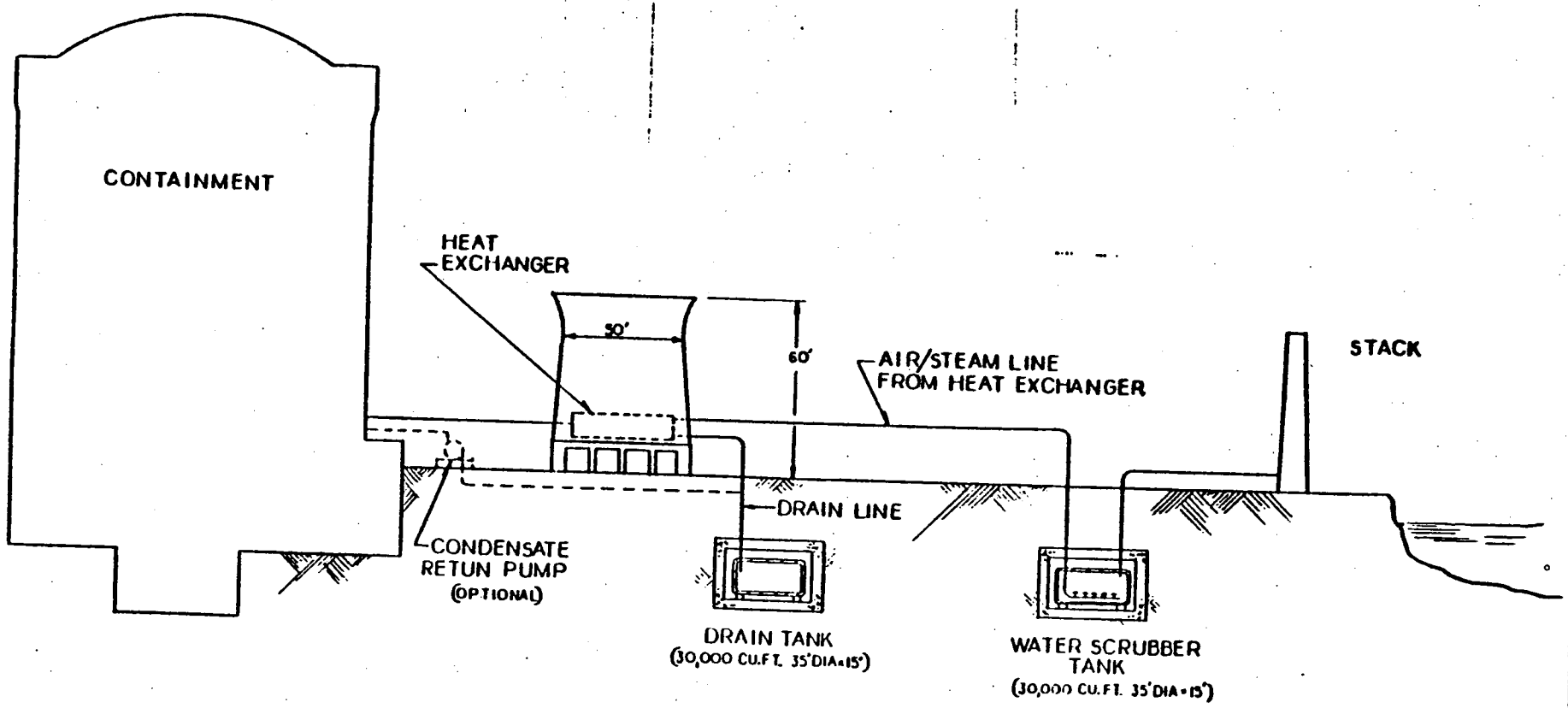
Area (ft^2)	$0.5\text{-}1.0 \times 10^6$
Type	Finned Tube - Natural Circulation
Estimated UA, BTU/hr °F	10^6
Design Pressure, Internal, psia	100
Design Temperature, °F, External	100
Internal	500
Design Flow, CFM at 400°F, 60 psia	Internal 18,000
Temperature in, °F, External	100
Internal	400
Temperature out, °F, External	To be determined
Internal	180
Material	Copper Fins, (Later) Tubes
Tubeside Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	See Appendix A(1)
Particulates	See Appendix B(1)
Cooling Medium	Air

Orifice

Design Pressure, psia	100
Design Temperature, °F	250
Design Flow, CFM at 180°F, 55 psia	9000
Maximum Pressure Loss, psi	35
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7

(1) Functional Specification

15-1610276



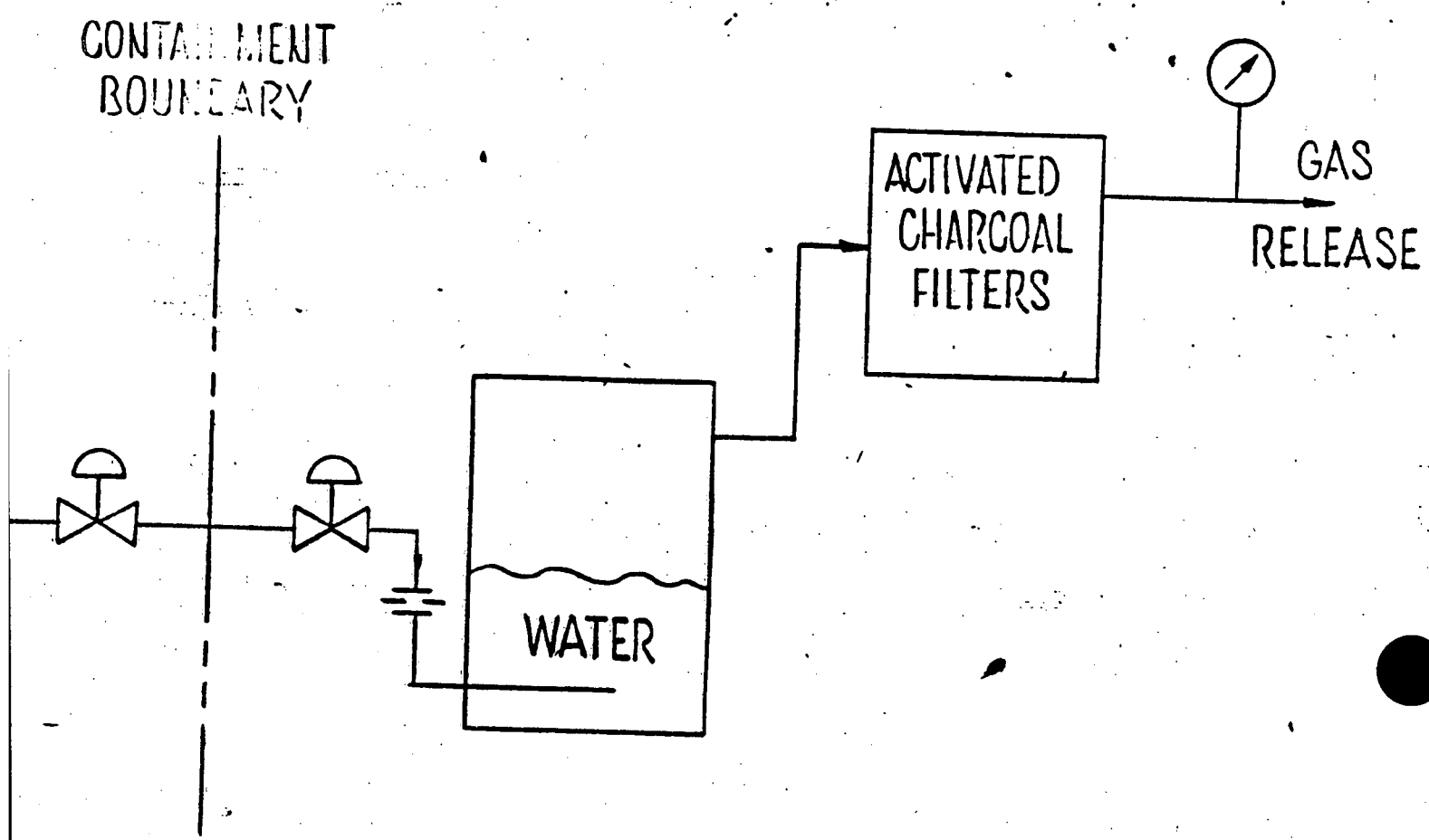
40

29

CHANGE	DRN C. Bollinger		Westinghouse Electric Corporation — NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.
			TITLE CONTAINMENT OVER PRESSURE VENT SYSTEM AIR HEAT EXCHANGER & WATER SCRUBBER
			SCALE N.T.S. — 977019 L-51

SPARGER CONDENSER AND CHARCOAL FILTER

30



SPARGER CONDENSER AND CHARCOAL FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Sparger Tank

Number	1
Usable Volume, Ft^3	2.5×10^5
Type	Vertical Cylindrical
Design Pressure, psia	30
Design Temperature, °F	212
Material	Steel or Concrete
Initial Operating Temperature, °F	50
Final Operating Temperature, °F	180
Sparger Flow, CFM at 400°F, 25 psia	43,200
Design Heat Absorption Rate, BTU/hr	100×10^6
Total Heat Absorption Capacity, BTU	2×10^9
Inlet Fluid Pressure, psia	25
Inlet Fluid Temperature, °F	400
Inlet Fluid Composition	
Steam Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A(1)
Particulates	Appendix B(1)
Design Decontamination Factor	
Particulates	100
Molecular Iodine	10
Organic Iodine	1
Noble Gases	1

(1) Functional Specification

SPARGER CONDENSER AND CHARCOAL FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Charcoal Bed

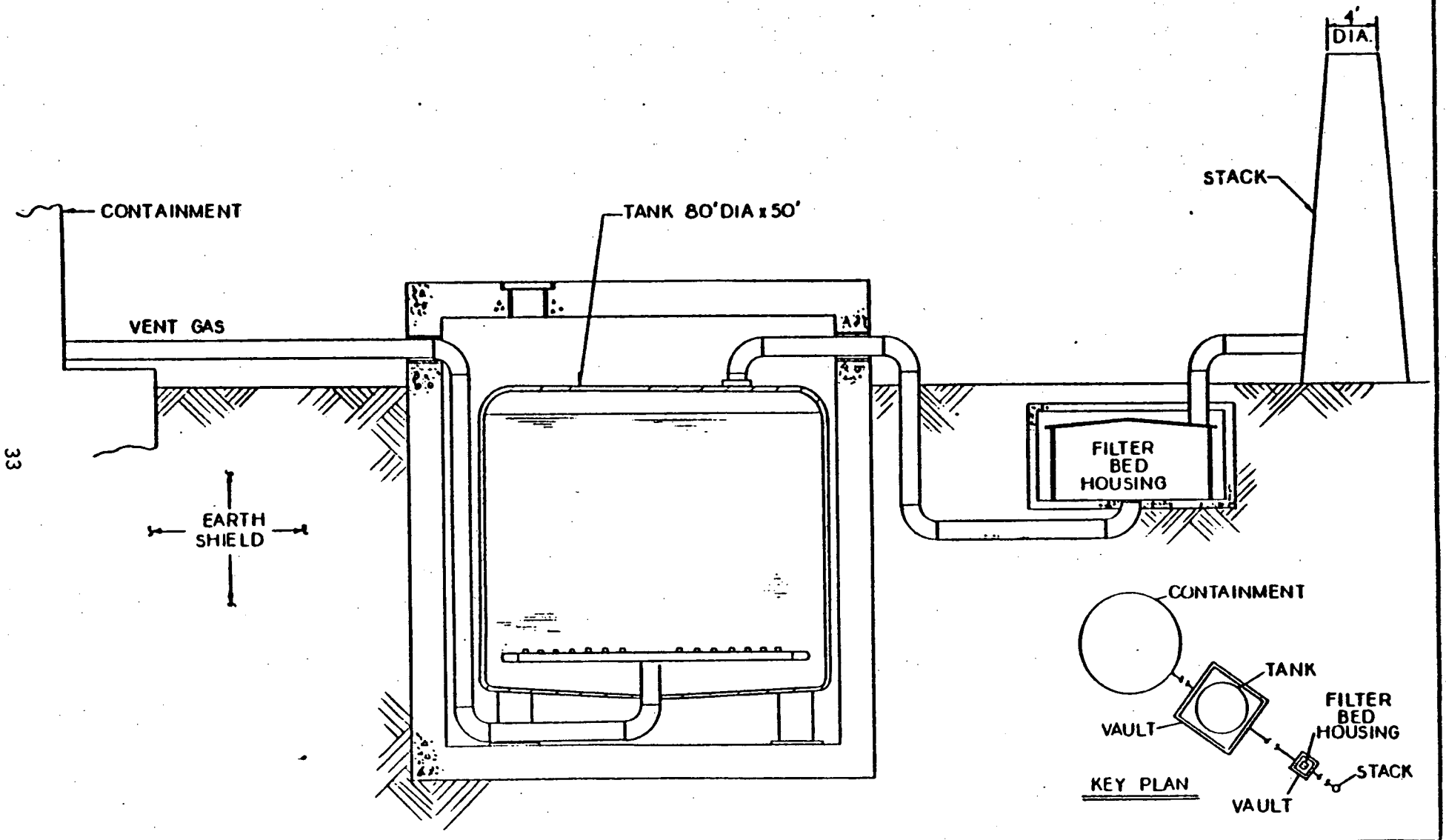
Number	1
Design Pressure, psia	20
Design Temperature °F	200
Material	Carbon Steel
Maximum Operating Temperature	180
Design Flow, CFM at 180°F, 15 psia	40,000
Design Face Velocity, Ft/Sec	0.3
Inlet Fluid Pressure, psia	15
Allowable Pressure Loss, in. water	1
Inlet Fluid Composition	
Water Vapor, Volume %	3-100
Nitrogen, Volume %	0-62
Oxygen, Volume %	0-21
Hydrogen, Volume %	0-14
Fission Products	Appendix A
Particulates	Appendix B
Design Decontamination Factors	
Particulates	10
Molecular Iodine	10
Organic Iodines	10
Noble Gases	1
Filter Medium	Potassium Iodine Treated Charcoal

SPARGER CONDENSER AND CHARCOAL FILTER SYSTEM

Orifice

Design Pressure, psia	100
Design Temperature, °F	500
Design Flow, CFM at 400°F, 60 psia	18,000
Maximum Pressure Loss, psi	35
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7

05-7610276



CHANGE

C. Bellinger

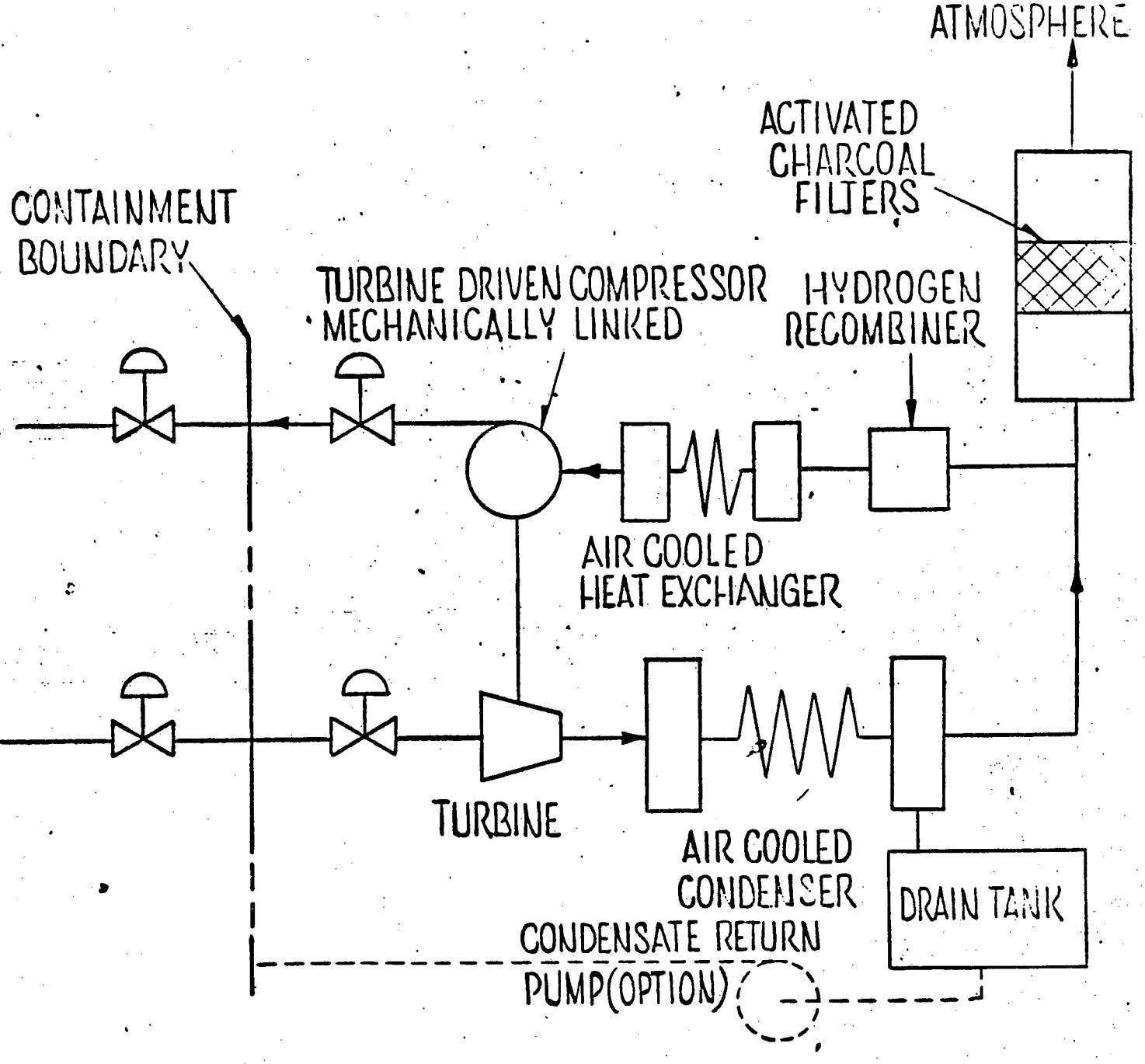
Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.

CONTAINMENT
OVER PRESSURE VENT SYSTEM
SPARGER CONDENSER & WATER SCRUBBER

NTS

977019 L-50

TURBINE DRIVEN SIDEARM COOLER



977019-L05

TURBINE DRIVEN SIDEARM COOLER SYSTEM
COMPONENT DESIGN PARAMETERS

Turbine

Number	1
Design Pressure, psia	100
Design Temperature, °F	500
Material	
Power Rating, HP	600
Inlet Fluid Pressure, psia	60
Inlet Fluid Temperature, °F	400
Exhaust Pressure, psia	45
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A[1]
Particulates	Appendix B[1]

Drain Tank

Number	1
Usable Volume, ft^3	30,000
Type	Horizontal
Design Pressure, psia	100
Design Temperature, °F	212
Material	Steel

[1] Functional Specification

TURBINE DRIVEN SIDEARM COOLER SYSTEM
COMPONENT DESIGN PARAMETERS

Heat Exchanger

Area (ft^2)	$0.5\text{-}1.0 \times 10^6$
Type	Finned Tube-Natural Circulation
Estimated UA, BTU/hr °F	10^6
Design Pressure, Internal, psia	100
Design Temperature, °F, External	100
Internal	500
Design Flow, CFM at 400°F, 45 psia, Internal	24,000
Temperature in, °F, External	100
Internal	400
Temperature Out, °F, External	To be determined
Internal	180
Material	Cooper Fins, (later) Tubes
Tubeside Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A(1)
Particulates	Appendix B(1)
Cooling Medium	

(1) Functional Specification

TURBINE DRIVEN SIDEARM COOLER SYSTEM
COMPONENT DESIGN PARAMETERS

Turbine Driven Compressor

Number	8
Type	Rotary
Design Pressure, psia	100
Design Temperature, °F	500
Design Flow, CFM at 180°F, 45 psia inlet	7500
Design Head, psi	15
Power Rating, HP	250

Hydrogen Recombiner

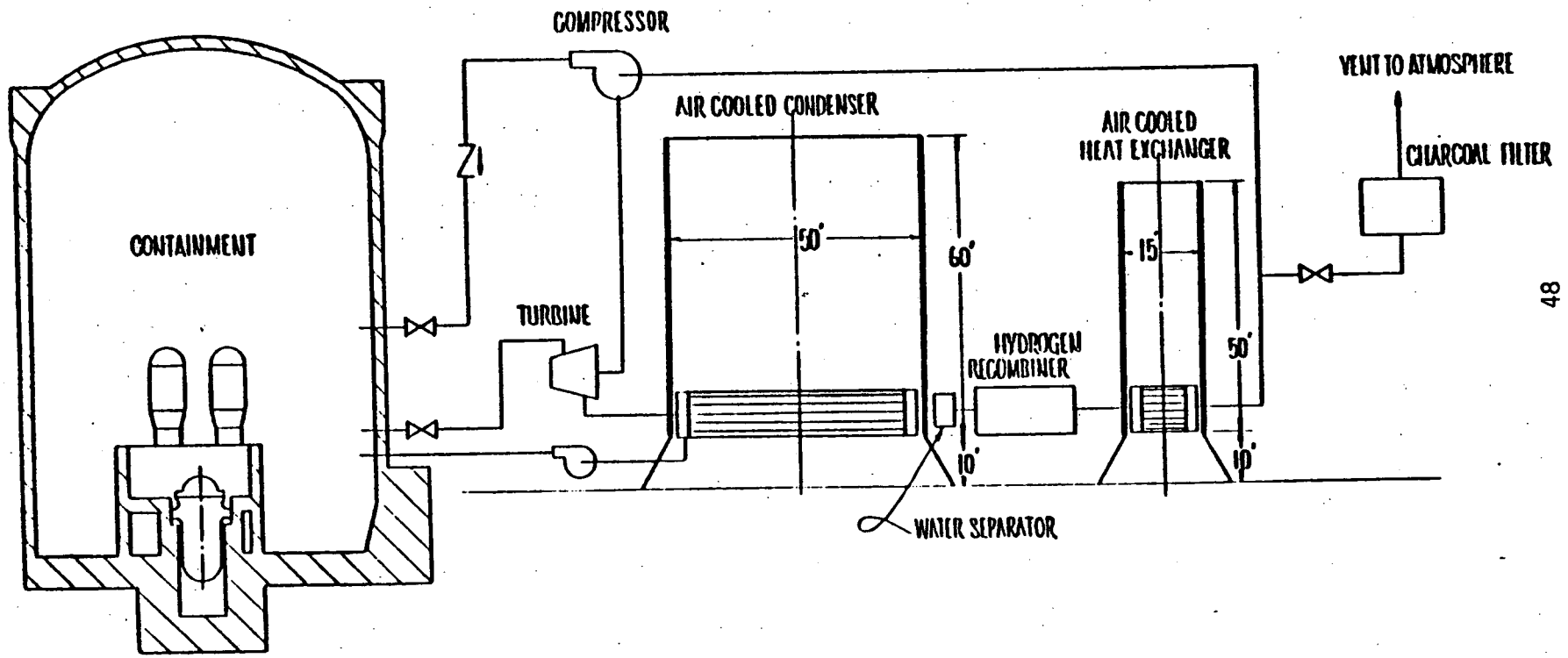
Number	1
Type	Combustion
Design Pressure, psia	100
Design Temperature, °F	200
Design Flow, CFM at 180°F, 45 psia	9000
Inlet Operating Temperature, °F	180
Inlet Operating Pressure, psia	45
Inlet Fluid Composition	
Steam, Volume %	3-100
Nitrogen, Volume %	0-62
Oxygen, Volume %	0-21
Hydrogen, Volume %	0-14
Outlet Hydrogen Content, Max., Volume %	1
Outlet Temperature, °F	180°
Allowable Pressure Loss, psi	23

SPARGER CONDENSER PLUS HEAT EXCHANGER SYSTEM
COMPONENT DESIGN PARAMETERS

Drain Tank

Number	1
Usable Volume, Ft^3	30,000
Type	Horizontal
Design Pressure, psia	100
Design Temperature, °F	212
Material	Steel

TURBINE DRIVEN SIDE ARM COOLER

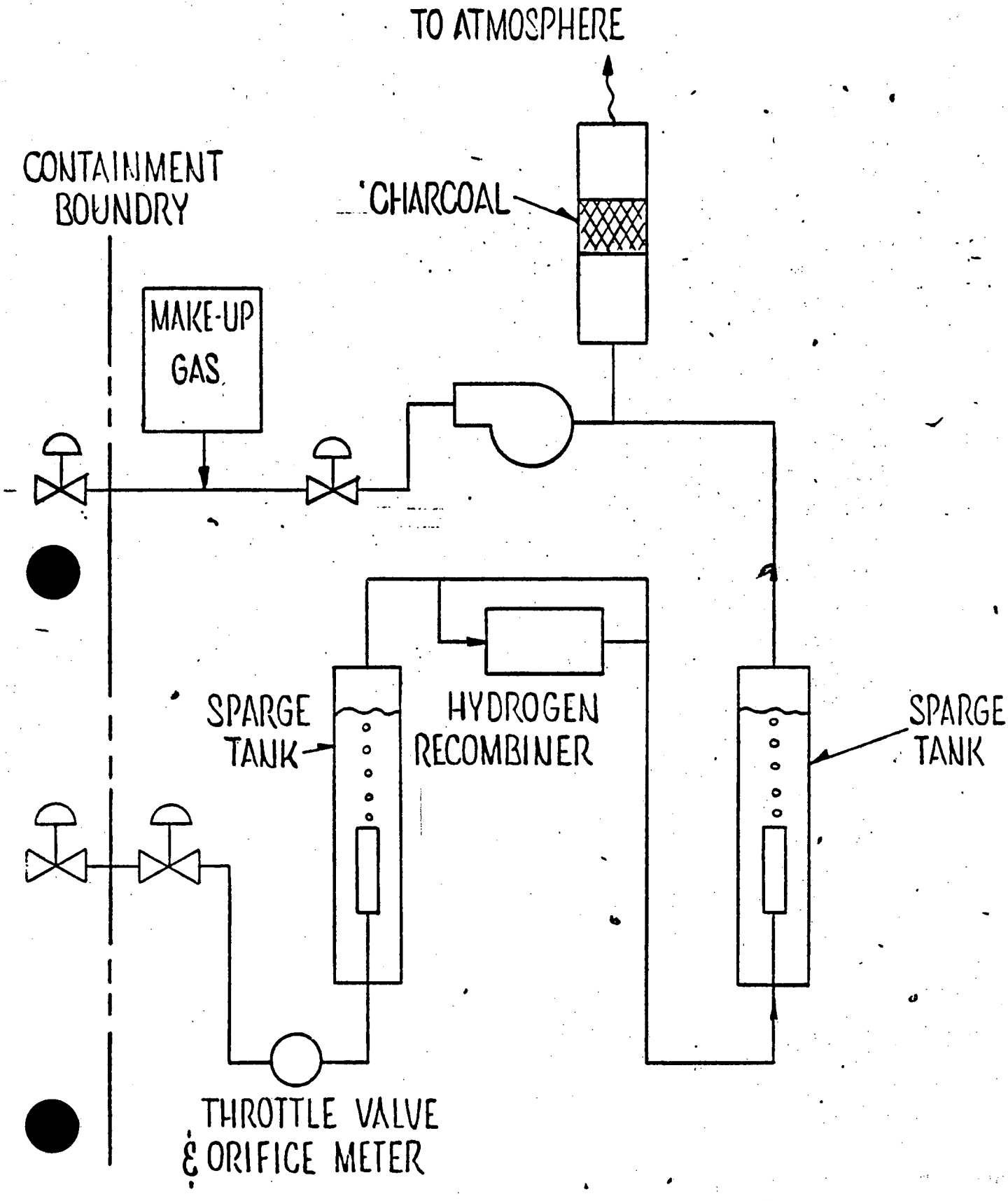


48

CHANGE	DRN R. SHAFFER		Westinghouse Electric Corporation
			TITLE CONTAINMENT OVERPRESSURE VENT SYSTEM - TURBINE DRIVEN SIDE ARM COOLER
			977019-L45
			DO NOT SCALE

40

RECIRCULATING VENT-FILTER SYSTEM



977019-L04

RECIRCULATING VENT FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Sparger Tank No. 1

Number	1
Usable Volume, ft^3	175,000
Type	Vertical
Design Pressure, psia	100
Design Temperature, °F	500
Material	Carbon Steel
Initial Operating Temperature, °F	80
Final Operating Temperature, °F	180
Sparger Flow, CFM at 400°F, 60 psia	18,000
Design Heat Absorption Rate, BTU/Hr.	100×10^6
Total Heat Absorption Capacity, BTU	1.1×10^9
Inlet Fluid Pressure, psia	50
Inlet Flud Temperature, °F	400
Inlet Fluid Composition	
Steam, Volume %	0-100
Nitrogen, Volume %	0-30
Oxygen, Volume %	0-10
Hydrogen, Volume %	0-7
Fission Products	Appendix A(1)
Particulates	Appendix B(1)
Design Decontamination Factor	
Particulates	100
Molecular Iodine	10
Organic Iodine	1
Noble Gases	1

(1) Functional Specification

RECIRCULATING VENT FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Sparger Tank No. 2

Usable Volume, Ft^3	175,000
Type	Vertical Cylindrical
Design Pressure, psia	60
Design Temperature, °F	200
Material	Carbon Steel
Initial Operating Temperature, °F	80
Final Operating Temperature, °F	180
Total Heat Absorption Capacity, BTU	1.1×10^9
Inlet Fluid Pressure, psia	42
Inlet Fluid Temperature, °F	2500

RECIRCULATING VENT FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Compressor

Number	8
Type	Rotary
Design Pressure, psia	100
Design Temperature, °F	200
Design Flow, CFM at 80°F, 15 psia inlet	12,000
Design Head, psi	45

RECIRCULATING VENT-FILTER SYSTEM
COMPONENT DESIGN PARAMETERS (cont.)

Hydrogen Recombiner

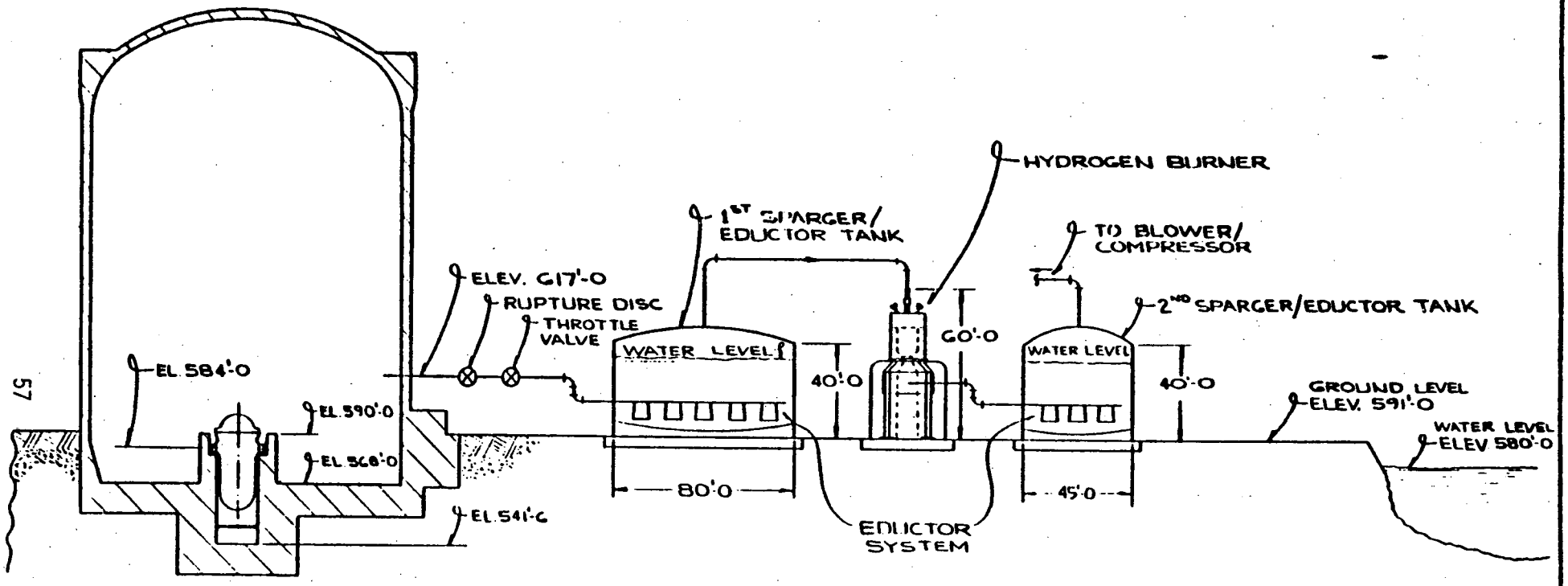
Number	1
Type	Combustion
Design Pressure, psia	100
Design Temperature, °F	200
Design Flow, CFM at 180°F, 45 psia	9000
Inlet Operating Temperature, °F	180
Inlet Operating Pressure, psia	45
Inlet Fluid Composition	
Steam, Volume %	3-100
Nitrogen, Volume %	0-62
Oxygen, Volume %	0-21
Hydrogen, Volume %	0-14
Outlet Hydrogen Content, Max., Volume %	1
Outlet Temperature, °F	2500
Allowable Pressure Loss, psi	3

46

RECIRCULATING VENT FILTER SYSTEM
COMPONENT DESIGN PARAMETERS

Charcoal Bed

Number	1
Design Pressure, psia	20
Design Temperature	200
Material	Carbon Steel
Maximum Operating Temperature	180
Design Flow, CFM at 180°F, 15 psia	40,000
Design Face Velocity, Ft/sec	0.3
Inlet Fluid Pressure, psia	15
Allowable Pressure Loss, in. water	1
Inlet Fluid Composition	
Water Vapor, Volume %	3-100
Nitrogen	0-62
Oxygen, Volume %	0-21
Hydrogen, Volume %	0-14
Fission Products	(Later)
Particulates	(Later)
Design Decontamination Factors	
Particulates	100
Molecular Iodine	10
Organic Iodines	10
Noble Gases	1
Filter Medium	Potassium Iodine Treated Charcoal



57

CHANGE				
1				
0				

DRWN W. VANDRIAK

Westinghouse Electric Corporation

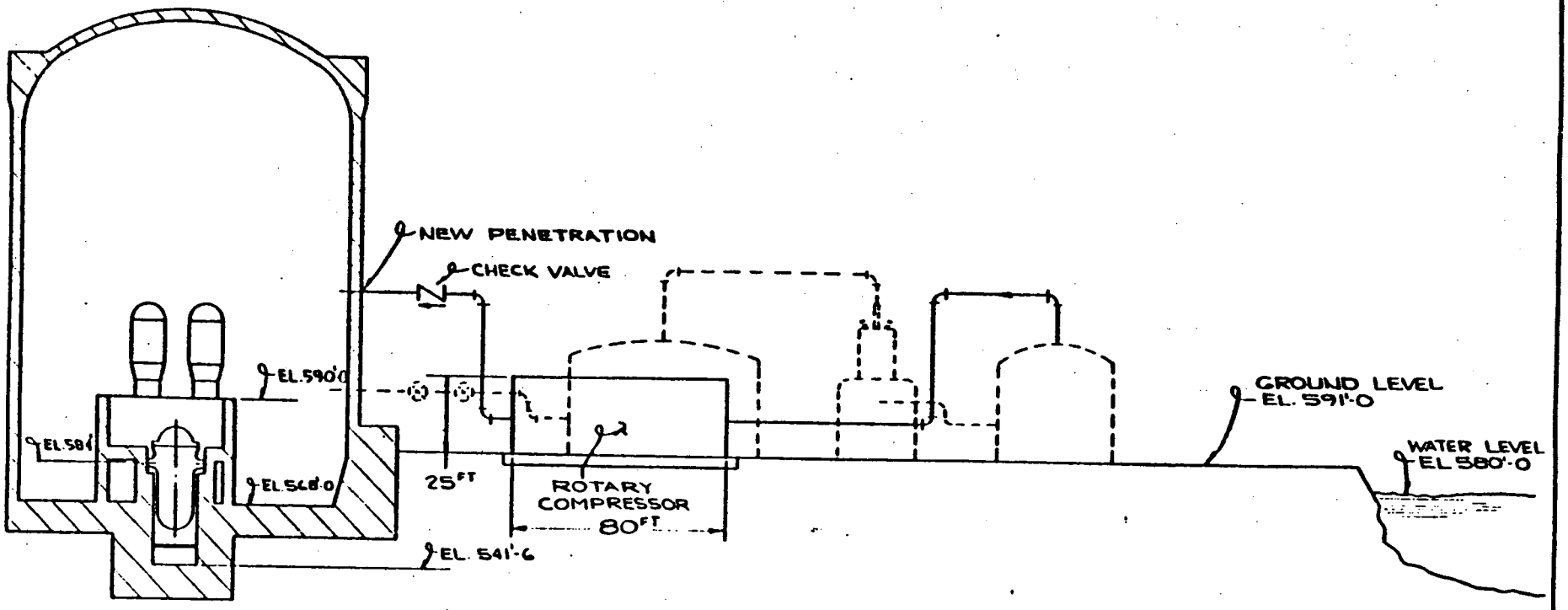
NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.

CONTAINMENT OVERPRESSURE VENT SYSTEM - RECIRCULATING VENT-FILTER SYSTEM

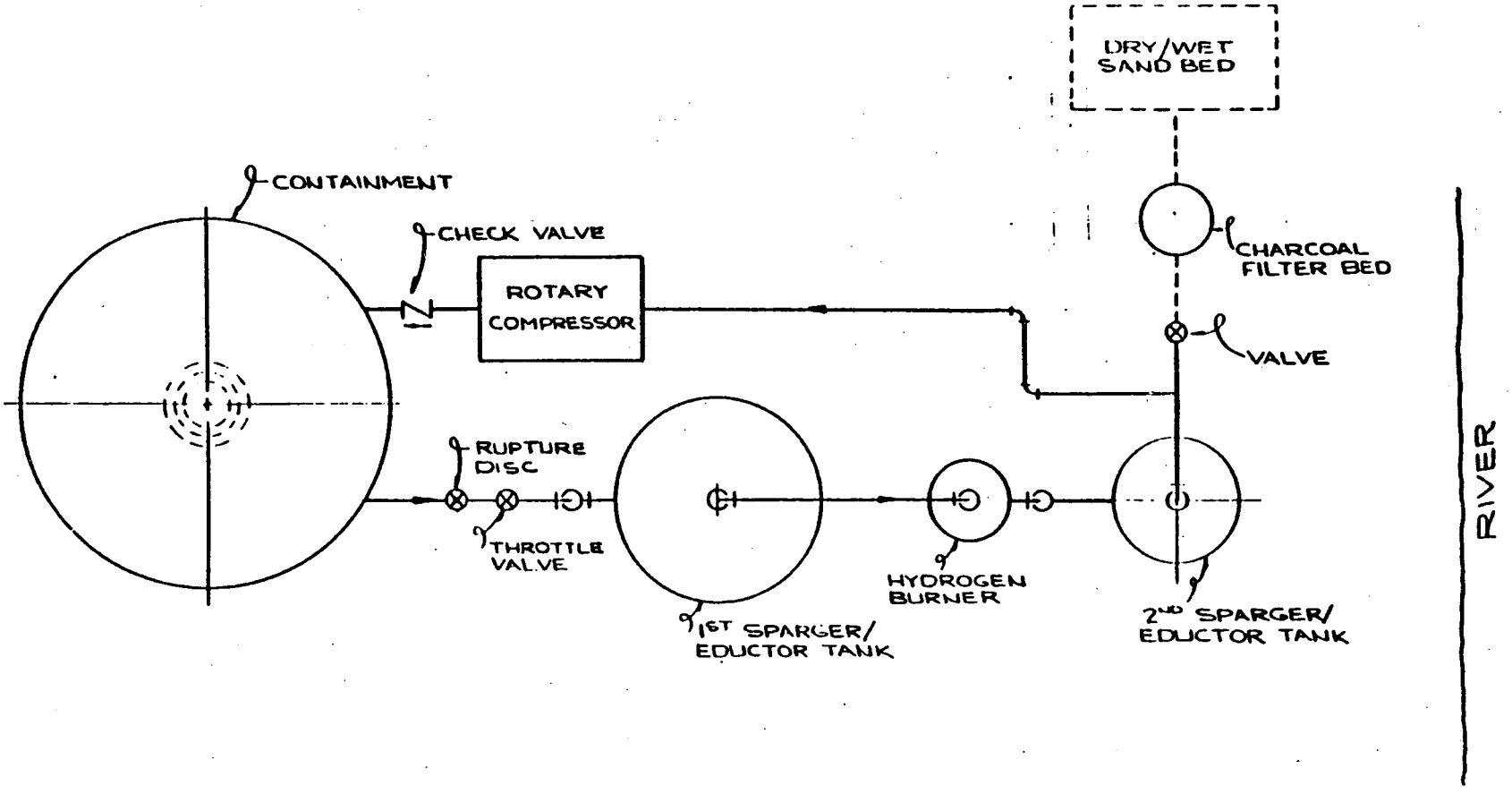
977019-L21

DO NOT SCALE

47



CHANGE	W. VANDRIAK	1-22-66	Westinghouse Electric Corporation NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.
			CONTAINMENT OVERPRESSURE VENT SYSTEM - RECIRCULATING VENT/FILTER SYSTEM
			977019-L29



1	CHANGE		

W. VANDRIAK

Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS PITTSBURGH PA. U.S.A.

CONTAINMENT OVERPRESSURE VENT SYSTEM - RECIRCULATING VENT/FILTER SYSTEM (PLAN)

977019-L22

CONSEQUENCE REDUCTION

- COMPARED CORE MELT FOLLOWED BY VENTING TO CORE MELT FOLLOWED BY RUPTURE
- EVALUATION BASED ON HAND MANIPULATION OF BATELLE CRAC CODE OUTPUT
- EARLY CONSEQUENCES

$$0.45\ T_E + 0.37I + 0.01\ XE + 0.17\ OTHER = 1.0$$

TE = TE-132
I = I-131, I - 132, I - 133, I - 135
XE = KR-88
OTHERS = PARTICULATE R_U - 106, S_R - 89, B_A - 140

- LATE CONSEQUENCES

$$0.26\ C_S + 0.53\ R_U + 0.21\ LA = 1.0$$

C_S = C_S - 134, C_S - 137
R_U = R_U - 106
L_A = P_U - 238, C_E - 144

SYSTEMS EVALUATION

- COMPARED
  - PLANT IMPACT
    - MAINTENANCE AND TEST REQUIREMENTS
    - SIZE
    - AREA
  - PUBLIC SAFETY
    - DECONTAMINATION FACTORS
    - CONSEQUENCE REDUCTION
  - SYSTEM SAFETY
    - HYDROGEN REMOVAL
    - FIRE POTENTIAL
    - PASSIVITY
  - MECHANICAL DESIGN
    - DESIGN AND CONSTRUCTION TIME
    - AVAILABILITY OF DESIGN DATA
  - COST
    - EQUIPMENT
    - STRUCTURES AND INSTALLATION
    - DEVELOPMENT AND DESIGN

SYSTEM COMPARISON

- ELIMINATE SAND AND GRAVEL BED PLUS CHARCOAL FILTER
  - DOES NOT PROMISE BETTER PERFORMANCE THAN SMALLER LESS COSTLY SYSTEMS
  - CONTAMINATES LARGE QUANTITIES OF SOLIDS
  - LARGE GAS DISTRIBUTION SYSTEM REQUIRED
- ELIMINATE SPARGER TANK PLUS HEAT EXCHANGER
  - DOES NOT PROMISE BETTER PERFORMANCE THAN OTHER SYSTEMS
  - LONG LEAD TIME FOR HEAT EXCHANGER
  - HIGH COST OF HEAT EXCHANGER
- ELIMINATE RECIRCULATING SYSTEMS
  - PERFORMANCE GAINS DID NOT BALANCE NEGATIVES
  - REQUIRE OPERATOR ACTION
  - INCLUDE LARGE ACTIVE COMPONENTS
  - MIGHT BE INCORPORATED INTO PASSIVE SYSTEMS FOR FLEXIBILITY
- SUBMERGED GRAVEL SCRUBBER AND SPARGER CONDENSER SYSTEMS WERE MOST PROMISING VENT SYSTEM CONCEPTS
  - MAXIMUM PASSIVE DESIGN
  - SHOULD MEET OR EXCEED ASSUMED DECONTAMINATION CAPABILITY
  - MINIMUM DESIGN AND INSTALLATION LEAD TIME
  - CONSIDER ADDING SECOND STAGE CLEAN-UP, BUT CONSIDER IMPACT ON CONSTRUCTION LEAD TIME

CONTAINMENT VENT SYSTEMS QUESTIONS

- CONFLICT BETWEEN ENSURING ABILITY TO VENT DURING A CORE MELT ACCIDENT AND MAINTAINING CONTAINMENT INTEGRITY IN LESSER ACCIDENTS
- SHORT TERM CONTAINMENT OVERPRESSURIZATION - PRESSURE SPIKES
- HYDROGEN REMOVAL BEFORE COOLDOWN
- CONTAINMENT VACUUM FOLLOWING VENTING
- APPLICABILITY TO OTHER DESIGN TRANSIENTS
- GAS DISTRIBUTION
- LARGE RADIATION SOURCES OUTSIDE CONTAINMENT
- LEAKAGE, CHANNELING AND BYPASS FLOW
- START-UP AND SHUTDOWN IMPACT ON COMPONENTS
- RELIABILITY
- TESTING AND MAINTENANCE
- LONG TERM OPERATION

FVCS COMPARISON SUMMARY

- COMPARED 7 CONCEPTS USING 18000 SCFM TO PROVIDE RELATIVE RANKING BASE
- SPARGER CONDENSOR AND SUBMERGED GRAVEL FILTER RANKED HIGH
- ALL SYSTEMS REQUIRE LARGE AREAS AT 18000 SCFM
- NONE OF THE SYSTEMS PROVIDE CAPABILITY TO MITIGATE BOUNDING SEQUENCES WITHIN PRACTICAL COMPONENT LIMITS

MITIGATION SYSTEM SUMMARY

1. SYSTEM DESIGN IS VERY DEPENDENT ON ACCIDENT SENARIO AND TRANSIENT CONDITIONS.

   A. HEAT RELEASE RATES

   B. HYDROGEN RELEASE RATES

   C. HYDROGEN BURN MODELS

   D. CORE MELT MECHANICS

   E. VESSEL FAILURE MODEL

   F. EX-VESSEL PARTICLE SIZE AND STEAM RELEASE RATES

   G. POWER RECOVERY TIME

   H. ARE SPRAYS AND FAN COOLERS ASSUMED TOO INOPERATIVE FOR 2, 4, 6, 8 HOURS OR LONGER?

   I. OTHER SYSTEM TRANSIENT CONDITIONS

2. <u>WILL A FILTER VENT SYSTEM PREVENT OVERPRESSURE AND REDUCE RISK?</u>

A. UNTIL 1 IS DEFINED, THIS CANNOT BE DETERMINED.

B. FOR PRACTICAL VENT SIZES, 12 TO 18 INCHES, PASSIVE VENT SYSTEM IS NOT ADEQUATE TO PREVENT OVERPRESSURE FOR SOME EVENTS.

C. OPERATOR ACTUATED VENT SYSTEM TO ANTICIPATE OVERPRESSURE MAY NOT BE PRACTICAL CONSIDERING PROBLEMS THAT OPERATOR IS INVOLVED IN.

D. IF ONE ASSUMES THAT ACCIDENTS OF THE CLASS 9 EVENTS ALWAYS LEADS TO 100% MELTDOWN THEN VENTING MAY REDUCE CONSEQUENCE; HOWEVER, IF IT IS ASSUMED THAT THE ACCIDENT IS CONTAINED AT 40, 50, OR 80 PERCENT, THEN VENTING MAY INCREASE CONSEQUENCE.

3. <u>IF EXTERNAL POWER IS REQUIRED FOR A MITIGATION SYSTEM, WHAT WOULD BE THE BEST USE OF THIS POWER SOURCE?</u>

   A. SUPPLY WATER TO SPRAYS AND FAN COOLERS

   B. OPERATE SEPARATE SYSTEM TO MITIGATE ACCIDENT

4. <u>BOTTOM LINE</u>

   UNTIL THE EVENTS AND TRANSIENTS ARE DEFINED, THERE IS NO ONE SYSTEM OR ANSWER TO CLASS 9 EVENTS .

ALTERNATIVES TO VENTING

- OXYGEN DEPLETION
  - INSIDE CONTAINMENT
  - OUTSIDE CONTAINMENT
- HYDROGEN BURNING
  - INSIDE CONTAINMENT
  - OUTSIDE CONTAINMENT
- HALON EXPLOSION SUPPRESSION
- HYDROGEN ABSORPTION
- SPRAY MIST
- REACTOR HEAD VENT

OXYGEN DEPLETION (INSIDE CONTAINMENT)

DESCRIPTION: SYSTEM TO REDUCE OXYGEN LEVEL IN CONTAINMENT BY BURNING WITH METHANE OR PROPANE IN ORDER TO PREVENT A HYDROGEN BURN.

FEATURES:

- FINAL OXYGEN CONCENTRATION LESS THAN 8% REQUIRES O_2 SUPPLY TO BURN BELOW 13%
- HIGHLY RELIABLE CONTROL AND IGNITION SYSTEM
- HEAT REJECTION IN EXCESS OF 250 MILLION BTU'S
- FUEL REQUIREMENTS BETWEEN 6 AND 7 TONS LIQUID FUEL
- RAPID DEPLETION WILL REQUIRE 20 TO 30 INDIVIDUAL BURNERS STRATEGICALLY LOCATED
- MAINTENANCE AND TESTING MUST BE PERFORMED INSIDE CONTAINMENT
- CAN BE ACTIVATED EARLY BY EXISTING TRIP OR ALARM FUNCTION TO INSURE ADEQUATE TIME FOR OXYGEN DEPLETION
- SYSTEM SAFEGUARDS PREVENT RELEASE OF CO AND RAW FUEL INTO CONTAINMENT

OXYGEN DEPLETION (OUTSIDE CONTAINMENT)

DESCRIPTION: SYSTEM TO REDUCE OXYGEN LEVEL IN CONTAINMENT BY BURNING WITH METHANE OR PROPANE IN AN EXTERNAL LOOP IN ORDER TO PREVENT A HYDROGEN BURN.

FEATURES:

- FINAL OXYGEN CONCENTRATION LESS THAN 8%
- HIGHLY RELIABLE CONTROL AND IGNITION SYSTEM
- HEAT GENERATED REMOVED BY INLINE HEAT SINKS
- FUEL REQUIRED BETWEEN 6 AND 7 TONS LIQUID FUEL
- TO CONTROL O_2 LEVEL IN 2 HOURS WILL REQUIRE 8,000 TO 10,000 CFM BLOWER AND COMBUSTION CHAMBER
- OXYGEN ADDITION REQUIRED AS INLET CONCENTRATION DECREASES
- MAINTENANCE AND TESTING CAN BE PERFORMED OUTSIDE CONTAINMENT
- MUST MEET CONTAINMENT DESIGN CRITERIA
- CAN BE ACTIVATED EARLY BY EXISTING TRIP OR ALARM FUNCTION TO INSURE ADEQUATE TIME FOR OXYGEN DEPLETION
- SYSTEM SAFEGUARDS TO PREVENT RELEASE OF CO AND RAW FUEL BACK INTO CONTAINMENT
- RECIRCULATION COMPRESSOR REQUIRED

HYDROGEN BURNING (INSIDE CONTAINMENT)

DESCRIPTION: SYSTEM TO BURN OFF GENERATED HYDROGEN IN A SAFE, CONTROLLED MANNER.

FEATURES:

- BURNING BELOW HYDROGEN LEVELS OF 8% IS DIFFICULT IN STEAM ATMOSPHERE
- HIGHLY RELIABLE CONTROL AND IGNITION SYSTEM
- HEAT REJECTION IN EXCESS OF 100 MILLION BTU'S
- ADDITIONAL HYDROGEN AND OXYGEN MAY HAVE TO BE ADDED AT BURNER (PROBABLY 2 TONS OR LESS)
- NUMEROUS BURNERS REQUIRED IN STRATEGIC LOCATIONS
- MAINTENANCE AND TESTING MUST BE PERFORMED INSIDE CONTAINMENT
- BURNERS BECOME ADDITIONAL, EFFECTIVE EXPLOSION IGNITION SOURCES AT HIGH HYDROGEN CONCENTRATIONS

HYDROGEN BURNING (OUTSIDE CONTAINMENT)

DESCRIPTION: SYSTEM TO BURN OFF GENERATED HYDROGEN IN A SAFE, CONTROLLED MANNER VIA AN EXTERNAL LOOP.

FEATURES:

- BURNING BELOW HYDROGEN CONCENTRATIONS OF 8% IS DIFFICULT IN STEAM ENVIRONMEN
- HIGHLY RELIABLE CONTROL AND IGNITION SYSTEM
- HEAT GENERATED REMOVE BY INLINE HEAT SINKS
- ADDITIONAL HYDROGEN AND OXYGEN MAY HAVE TO BE ADDED AT BURNER (PROBABLY 2 TONS OR LESS)
- HIGH TEMPERATURE DESIGN AND MATERIALS ENGINEERING
- MAINTENANCE AND TESTING CAN BE PERFORMED OUTSIDE CONTAINMENT
- MUST MEET CONTAINMENT DESIGN CRITERIA
- RECIRCULATION COMPRESSOR REQUIRED

HALON 1301 EXPLOSION SUPPRESSION

DESCRIPTION: SYSTEM TO INJECT SUFFICIENT VOLUME OF HALON 1301 TO SUPPRESS EXPLOSION OF HYDROGEN IN CONTAINMENT.

FEATURES:

- NFPA-12A REQUIRES 31.4% BY VOLUME TO SUPPRESS HYDROGEN EXPLOSION (THIS IS APPROXIMATELY 10% MARGIN)
- REQUIRES IN EXCESS OF 240,000 LBS OR TWO D.O.T. 105 A600W RAIL TANK CARS ON SITE
- REQUIRES RAPID INJECTION AND VAPORIZATION WITHOUT CAUSING NEGATIVE CONTAINMENT PRESSURE OR EQUIPMENT DAMAGE
- HALON CONCENTRATIONS GREATER THAN 7% ARE HIGHLY TOXIC TO PERSONNEL
- LONG-TERM EFFECTS ON EQUIPMENT HARDWARE AND SEALS UNCLEAR
- HALON 1301 DECOMPOSES TO HF AND HBR ABOVE 900 DEGREES F
- STABILITY OF HALON 1301 IN PRESENCE OF HIGH NEUTRON OR GAMMA FIELDS IS UNKNOWN
- ADDS TO POST ACCIDENT GAS CLEANUP PROBLEM
- HYDROGEN WILL STILL EXIST IN THE CONTAINMENT ATMOSPHERE
- EFFECTS OF SPRAY WATER ARE NOT WELL KNOWN

HYDROGEN ABSORPTION WITH METAL

DESCRIPTION: SYSTEM TO STRIP HYDROGEN FROM STREAM OF CONTAINMENT GASES TO PREVENT HYDROGEN BURN.

FEATURES:

- INTERMETALLIC COMPOUNDS ABSORB HYDROGEN, FORMING HYDROGEN COMPOUNDS THROUGHOUT THE METAL LATTICE
- COULD BE USED ON CONTAINMENT HEAD VENT, PRESSURIZER RELIEF TANK, CONTAINMENT CIRCULATION SYSTEM, OR EXTERNAL RECIRCULATING SYSTEM
- PRESENT TECHNOLOGY LIMITED FOR THIS SPECIFIC APPLICATION
- MATERIAL TO HYDROGEN RATIO APPROXIMATELY 50 TO 1
- EFFECTS OF STEAM AND CONTAMINANTS UNKNOWN
- ONLY A FEW KNOWN CANDIDATE MATERIALS FOR TEMPERATURES AND PRESSURES EXPECTED
- THESE MATERIALS ARE NOT CURRENTLY PRODUCED IN QUANTITY OR FORM NEEDED FOR THIS APPLICATION
- NO COMMERICAL HARDWARE IN EXISTENCE AT THIS TIME

SPRAY MIST SYSTEM

DESCRIPTION: SYSTEM PROVIDES AN ADDITIONAL SEPARATE, DIVERSE SPRAY MIST SYSTEM TO REDUCE STEAM PRESSURE AND SUPPRESS A HYDROGEN BURN FOR A FINITE TIME PERIOD.

FEATURES:

- SEPARATE, INDEPENDENT CONTAINMENT SPRAY
- SUPPLIED BY DIESEL DRIVEL PUMP, FIRE PUMPER, OR PRESSURIZED ACCUMULATORS
- PROVIDES SUPPRESSION OF HYDROGEN BURN PRESSURE AND STEAM PRESSURE EARLY IN ACCIDENT SEQUENCE
- CHEMICALLY SEEDED FOR IODINE REMOVAL AND BORATION
- CONCENTRATION OF HYDROGEN COULD RISE TO EXPLOSIVE LEVELS AS SPRAY DEMINISHES
- DELAYS BUT DOES NOT GUARANTEE AGAINST HYDROGEN BURN AT A LATER TIME

REACTOR HEAD VENT

DESCRIPTION: THERMALLY ACTIVATED DEVICE ON REACTOR HEAD WHICH INSURES CONTROLLED, FIXED HYDROGEN RELEASE THROUGH REACTOR HEAD VENT PENETRATION.

FEATURES:

- MUST PROVIDE RELIABLE HYDROGEN IGNITION
- COMBUSTION HEAT AND STEAM STILL DISCHARGED TO CONTAINMENT
- ISOLATION MUST BE PROVIDED TO PREVENT CONTINUOUS DISCHARGE AFTER HYDROGEN IS PURGED FROM VESSEL.
- INTEGRITY OF DEVICE IS ESSENTIAL DURING NORMAL PLANT OPERATIONS
- COMPLETE COMBUSTION MAY BE DIFFICULT ESPECIALLY IF HEAVILY STEAM DILUTED
- CONTROLLED COMBUSTION MAY BE DIFFICULT OR IMPOSSIBLE
- WOULD NOT BE EFFECTIVE IN LARGE LOCA SCENARIOS
- BACKFIT CAPABILITY MUST BE EVALUATED

NRC PRESENTATION:

FILTERED VENTED

CONTAINMENT SYSTEMS

June 3, 1980

ZION/INDIAN POINT

TECHNICAL EXCHANGE MEETING

BETHESDA, MARYLAND

JUNE 3, 1980

ALLAN S. BENJAMIN

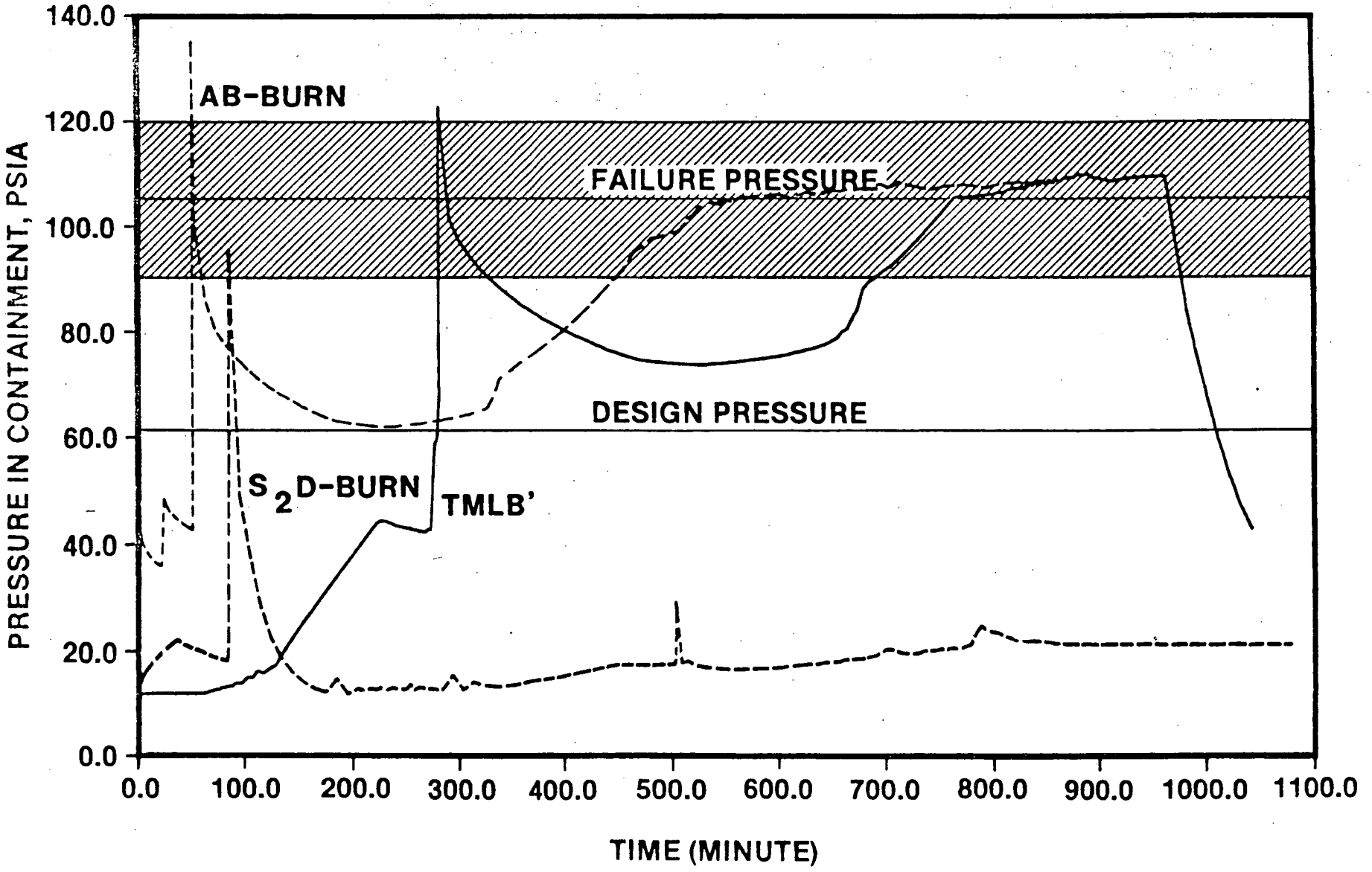
SANDIA NATIONAL LABORATORIES

G8

ACCIDENT SCENARIOS

- TMLB'
  - LOSS OF OFFSITE AND ONSITE AC POWER FOR AN INDEFINITE PERIOD (16 HOURS)
- AB-BURN
  - LARGE LOCA PLUS LOSS OF OFFSITE AND ONSITE AC POWER FOR AN INDEFINITE PERIOD. H_2 EXPLOSION WHEN CORE HITS CONCRETE
- S_2D-BURN
  - SMALL LOCA, FAILURE OF ECCS INJECTION, H_2 EXPLOSION WHEN CORE HITS CONCRETE
- S_2G
  - SMALL LOCA, FAILURE OF CONTAINMENT HEAT SINK
- TMLB"
  - LOSS OF OFFSITE AND ONSITE AC POWER FOR 6 HOURS, FOLLOWED BY ACTIVATION OF CONTAINMENT COOLERS, CONTAINMENT SPRAYS, AND ECCS INJECTION
- A-VENT
  - LARGE LOCA CAUSING ACTUATION OF CONTAINMENT VENTING

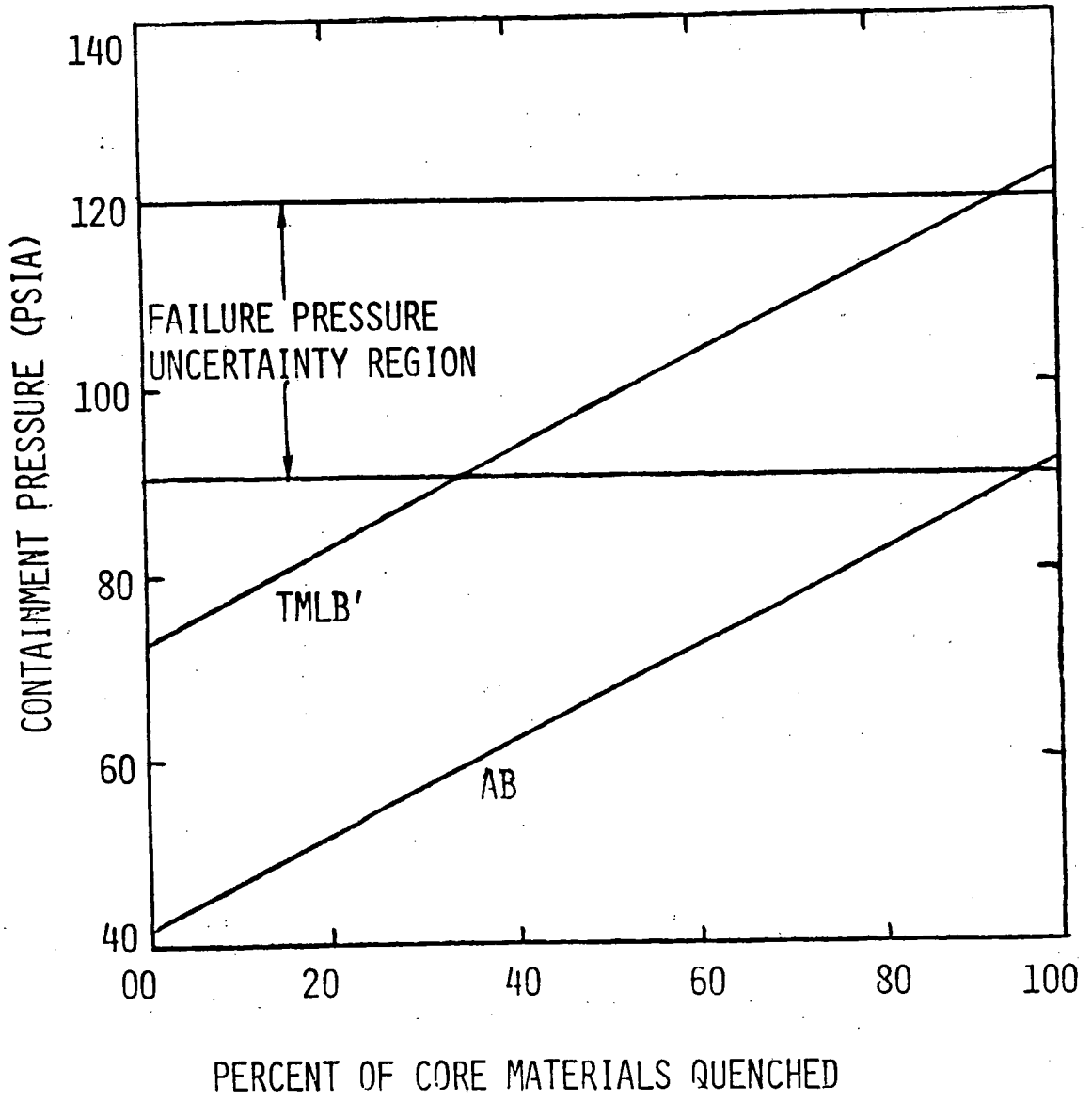
CONTAINMENT PRESSURE VERSUS TIME



CONTRIBUTORS TO PRESSURE SPIKE

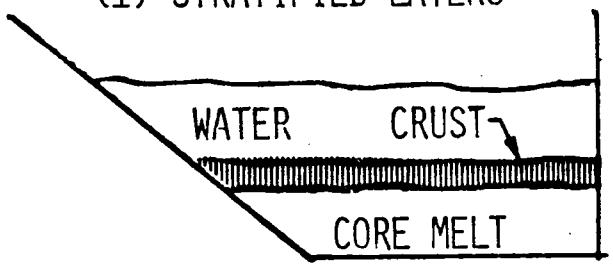
• CORE SLUMPING INTO BOTTOM HEAD	15 psi
• STEAM BLOWDOWN FROM PRIMARY SYSTEM	13 psi
• CORE INTERACTION WITH RESIDUAL PRIMARY SYSTEM WATER IN CAVITY	16 psi
• CORE INTERACTION WITH ACCUMULATOR WATER IN CAVITY	34 psi

CONTAINMENT PRESSURES VERSUS PERCENT OF QUENCHING



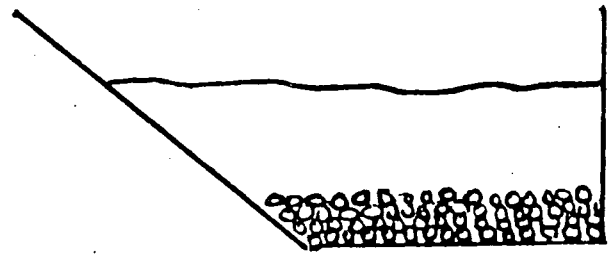
ALTERNATIVE CORE-WATER INTERACTION MODES IN REACTOR CAVITY

(1) STRATIFIED LAYERS



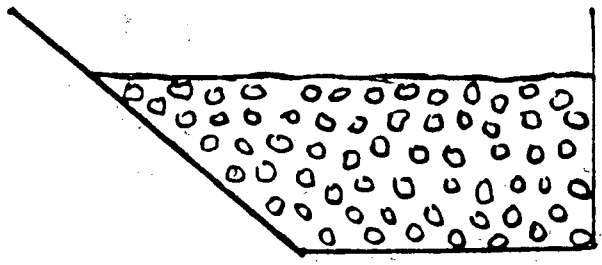
- CRUST FORMATION
- FILM BOILING

(2) DEBRIS BED IN WATER



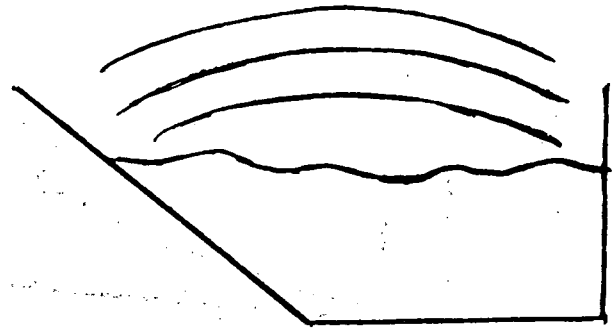
- SETTLING TIME
- DRYOUT HEAT FLUX

(3) FLUIDIZED PARTICLES



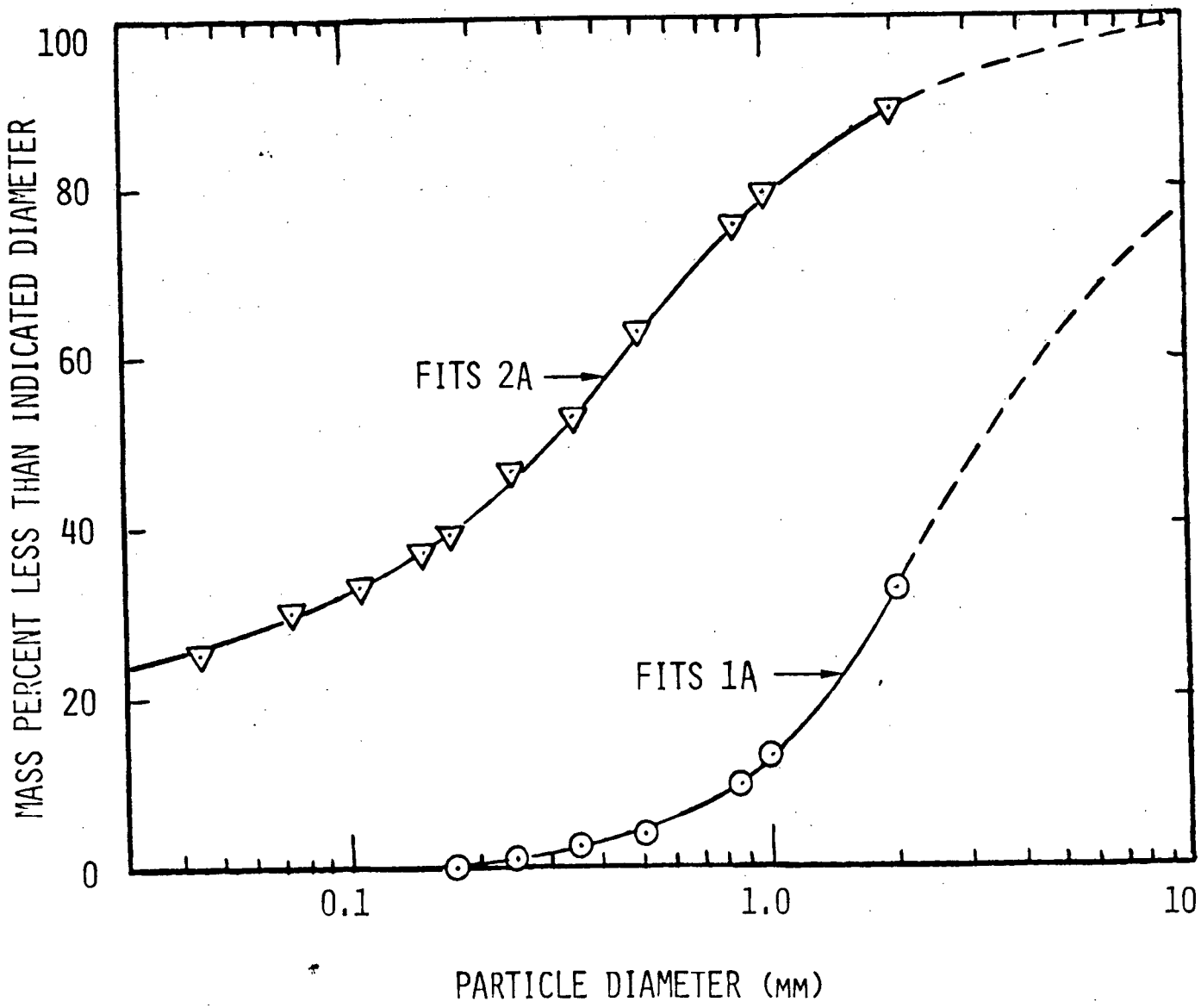
- MINIMUM AND MAXIMUM FLUIDIZATION VELOCITIES

(4) STEAM EXPLOSION

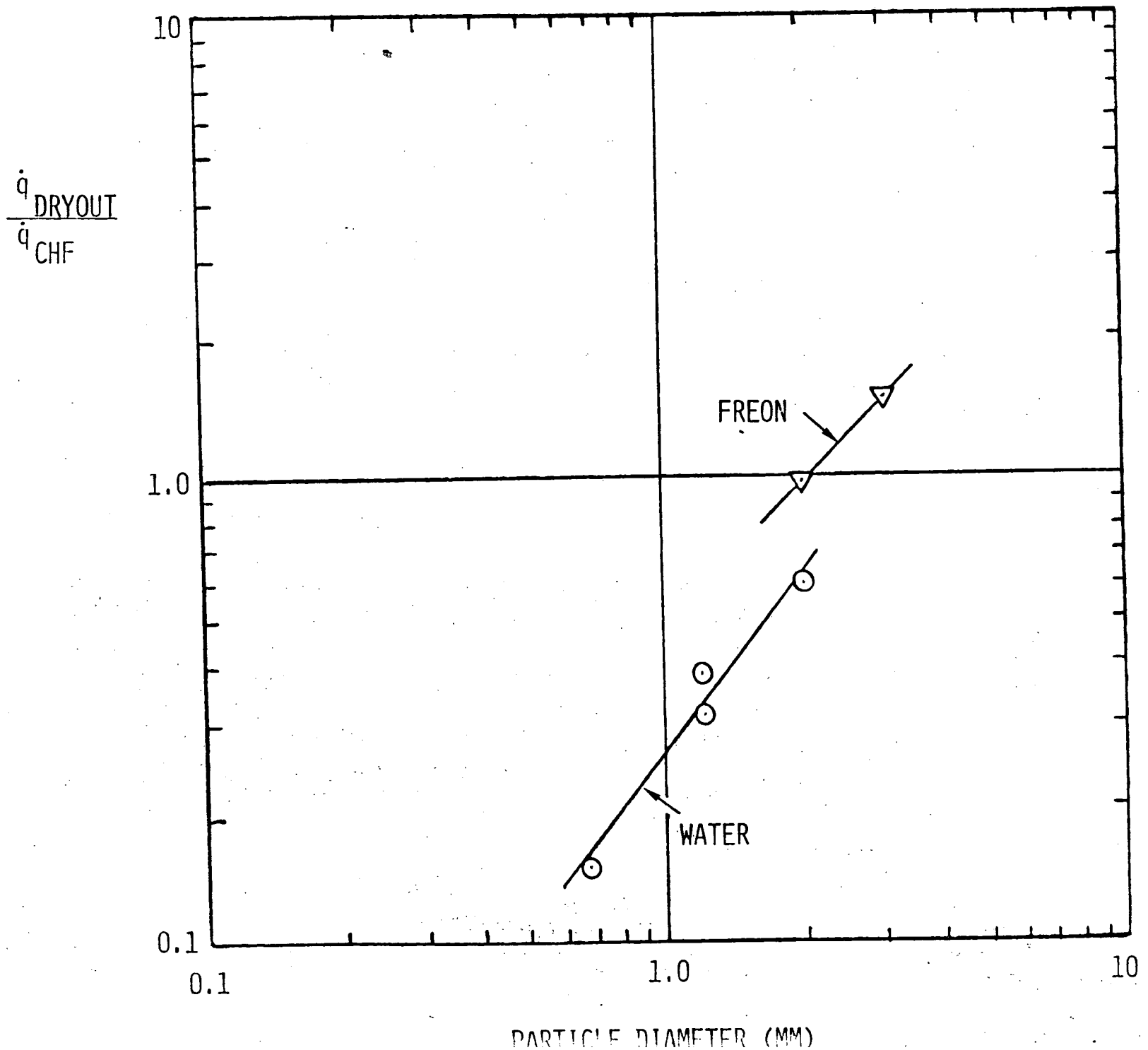


- SHOCKING OF AIR
- STEAM GENERATION
- DEBRIS/WATER DISPERSAL

DEBRIS PARTICLE SIZE DISTRIBUTION



DRYOUT HEAT FLUX RATIO VERSUS PARTICLE DIAMETER



ESTIMATES OF CORE DEBRIS QUENCHING CHARACTERISTICS

	DEBRIS PARTICLE DIAMETER		
	0.3 MM	3.0 MM	30 MM
CORE DEBRIS AND WATER IN REACTOR CAVITY			
DROP TIME OF A PARTICLE (SEC)	12	3	1
QUENCHING TIME OF A PARTICLE IN WATER (SEC)	1	20	300
FRACTION OF UNQUENCHED DEBRIS THAT CAN BE RETAINED IN A DISPERSE STATE WITHOUT BLOWOUT	.001	.25	1.00
MINIMUM TOTAL SETTLING TIME (SEC)	1000	20	300
TIME TO BOIL REMAINDER OF WATER AFTER BED FORMATION (SEC)	NA	3000	1000
MAXIMUM CONTAINMENT PRESSURE INCREMENT FROM INTERACTIONS IN CAVITY (PSI)	25	9	25
CORE DEBRIS DISPERSED IN CONTAINMENT			
QUENCHING TIME IN AIR/STEAM ATMOSPHERE (SEC)	4	40	NA
QUENCHING TIME ON A WATER SATURATED SURFACE (SEC)	1	20	300
MAXIMUM CONTAINMENT PRESSURE INCREMENT FROM TOTAL DEBRIS DISPERSAL INTO CONTAINMENT (PSI)	50	50	40

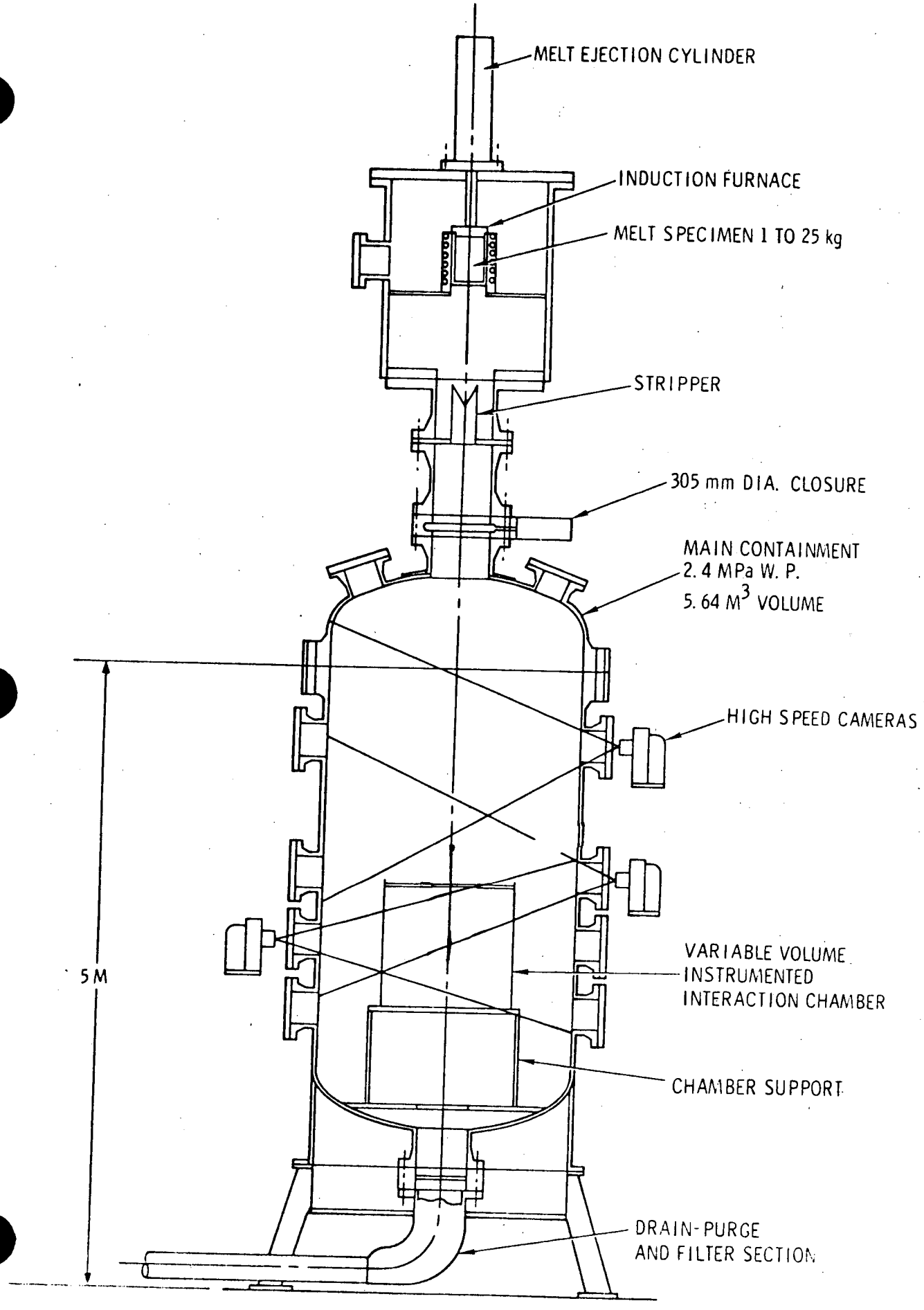
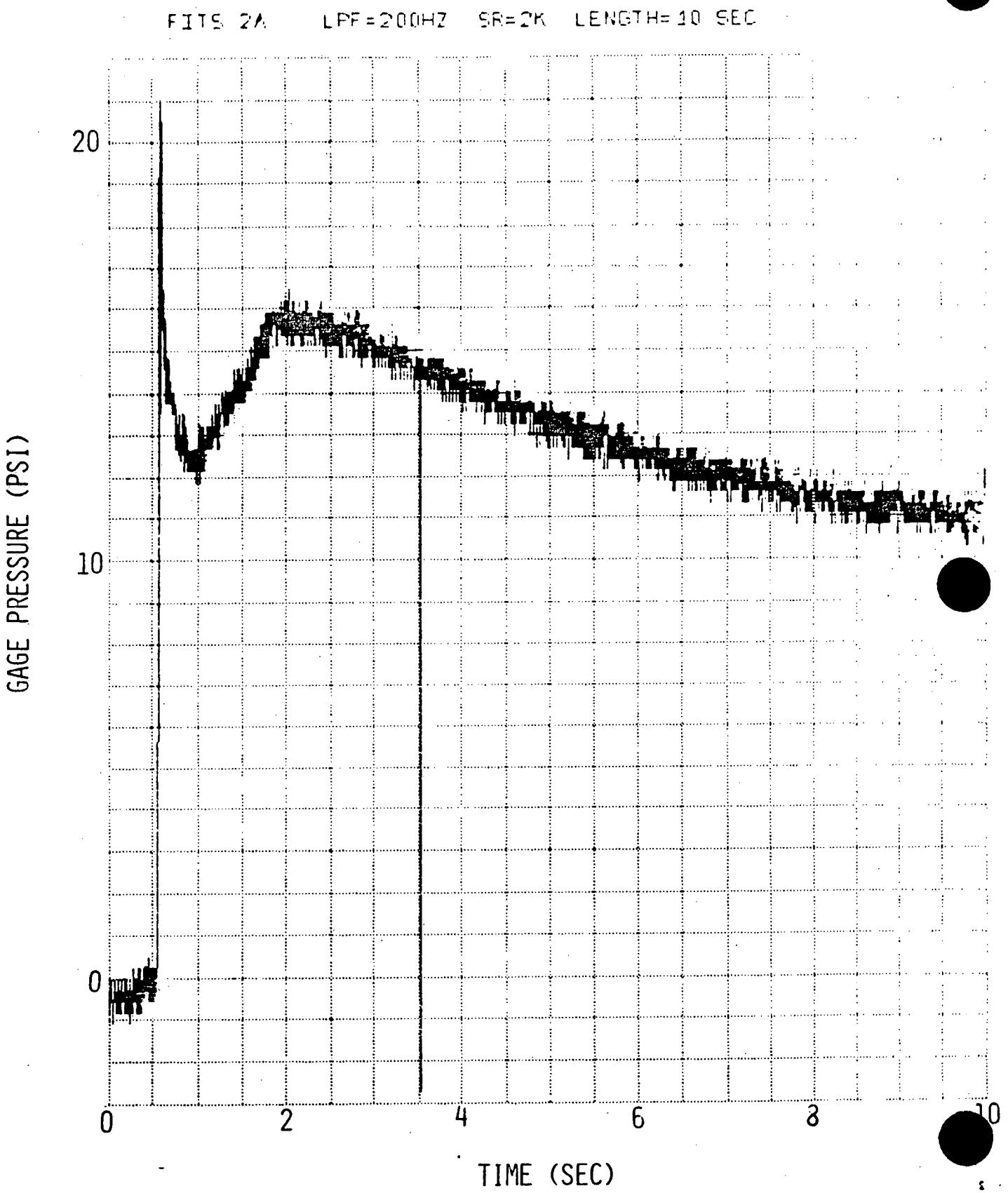


FIGURE 1." FITS " FACILITY DESIGN

PRESSURE TRANSIENT FOR FITS-2A TEST 18



POSTULATED VENT STRATEGIES FOR EXISTING REACTORS

VENT STRATEGY	EFFECTIVENESS FOR SEVERE ACCIDENTS	INTERFERENCE WITH LESS SEVERE ACCIDENT
• LOW VOLUME CONTAINMENT PRESSURE RELIEF	LOW	LOW
• LOW VOLUME CONTAINMENT DEPRESSURIZATION	↓	↓
• HIGH VOLUME CONTAINMENT PRESSURE RELIEF		
• HIGH VOLUME CONTAINMENT PRESSURE RELIEF PLUS LOW VOLUME CONTAINMENT DEPRESSURIZATION		
• PASSIVE CONTAINMENT FLOODING PLUS LOW VOLUME CONTAINMENT RELIEF OR DEPRESSURIZATION		
• DIVERSION OF SUMP AND ACCUMULATORS PLUS LOW VOLUME CONTAINMENT RELIEF OR DEPRESSURIZATION		
• ANTICIPATORY PRIMARY SYSTEM DEPRESSURIZATION PLUS LOW VOLUME CONTAINMENT RELIEF OR DEPRESSURIZATION		
• ANTICIPATORY CONTAINMENT DEPRESSURIZATION	HIGH	HIGH

SYSTEM INTERACTIONS

- CAVITATION OF RECIRCULATION PUMPS DUE TO SUMP FLASHING
- SEVERE VACUUM CAUSED BY DELAYED SPRAYS OR COOLERS
- DEGRADATION OF REFLOOD CAUSED BY PREMATURE VENTING
- OTHER INTERFACES

SOLUTIONS

- DESIGN CHANGES
- ADMINISTRATIVE PROCEDURES

Table B.1 Possible FVCS Systems Interactions

System	Interactions: No Effect	Control	Performance	Function	Comments
Electric Power	X				
Spray Injection				X	FVCS action could negate function or cause vacuum.
Coolant Injection		X	X	X	FVCS action could negate trigger or degrade performance.
Spray Recirculation			X	X	FVCS action could negate function; or create vacuum; action could cavitate pumps.
Containment Cooling		X	X	X	FVCS action could trigger change from emergency to normal operation or cause vacuum.
Coolant Recirc.			X		FVCS action could cavitate pumps.
NaOH Addition	X				
Reactor Protection	X				
Power Conversion	X				
Auxiliary Feedwater	X				
Pressurizer S/R Valves			X		FVCS action could degrade seals.
Chemical Volume			X		FVCS action could degrade seals.
Residual Heat Removal			X		FVCS action could degrade seals.

VENT RELIEF MODE

PURPOSE: TO PREVENT CONTAINMENT RUPTURE DUE TO OVERPRESSURE.

PASSIVE ACTUATION: RELIEF SETPOINT BASED ON CONTAINMENT PRESSURE OF 75-85 PSIA.

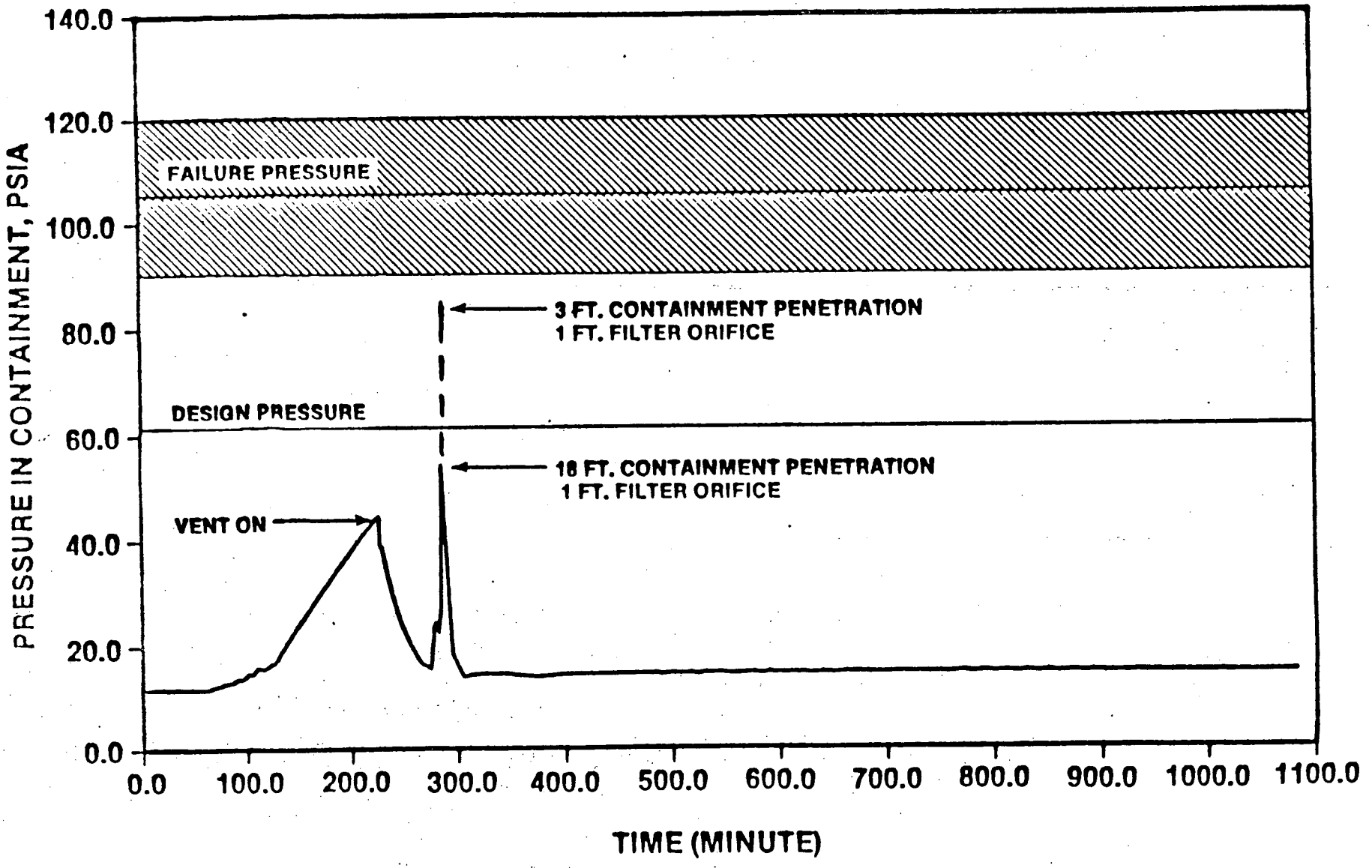
PASSIVE OPERATION: CONDENSING AND FILTERING COMPONENTS DO NOT OVERHEAT FOR AT LEAST 16 HOURS.

ACTIVE OPERATION: UTILIZES HEAT EXCHANGERS AND/OR BLOWERS FOR LONG-TERM HEAT REMOVAL.

MANUAL OVERRIDE: INHERENT LOGIC TO DISCOURAGE OVERRIDE UNLESS NECESSARY.

FLOW VOLUME: 160,000 CFM TOTAL FLOW AT DESIGN CONDITIONS; 40,000 CFM NONCONDENSIBLE FLOW.

CONTAINMENT PRESSURE HISTORY FOR TMLB'
WITH FILTERED ATMOSPHERIC VENTING



RECIRCULATION MODE

PURPOSE: ALTERNATE CONTAINMENT HEAT REMOVAL/DEPRESSURIZATION/ ATMOSPHERE CLEANUP SYSTEM.

OPERATOR ACTUATION: CAN BE ACTUATED AT ANY TIME. DOES NOT OVERRIDE VENT RELIEF ACTUATION AT CONTAINMENT PRESSURE SETPOINT.

ACTIVE OPERATION: VARIABLE SPEED RECIRCULATION BLOWER, HEAT EXCHANGER.

FLOW VOLUME: MAXIMUM 160,000 CFM TOTAL FLOW; 40,000 CFM NONCONDENSIBLE FLOW.

POSSIBLE PROBLEMS: HYDROGEN FLAMMABILITY.

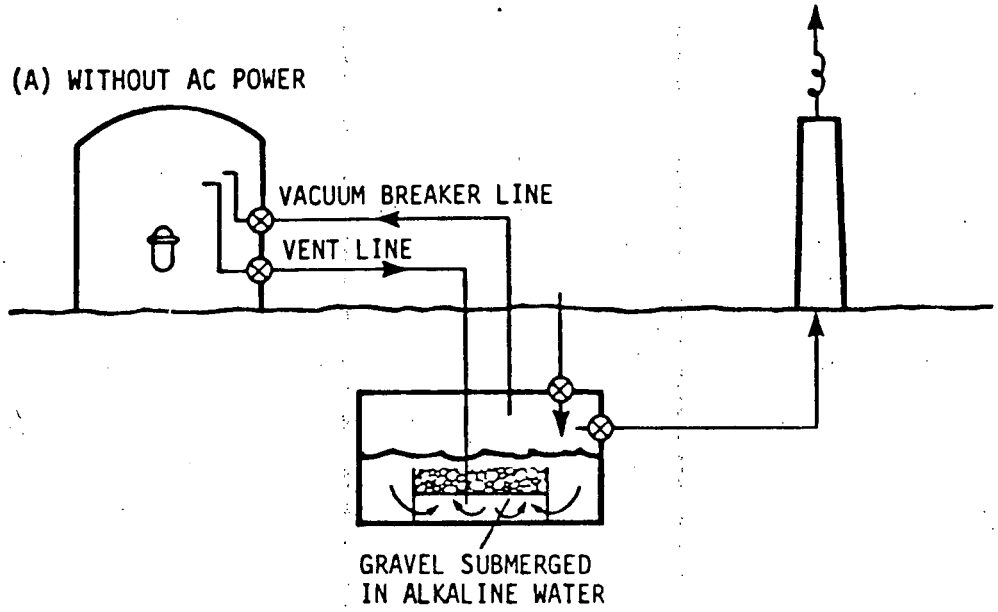
SPECIAL CONSIDERATIONS

PREVENTION OF VACUUM: SPRAYS AND RECIRCULATION BLOWERS SHOULD BE SET TO SHUT OFF IF CONTAINMENT PRESSURE FALLS BELOW A FEW PSIG.

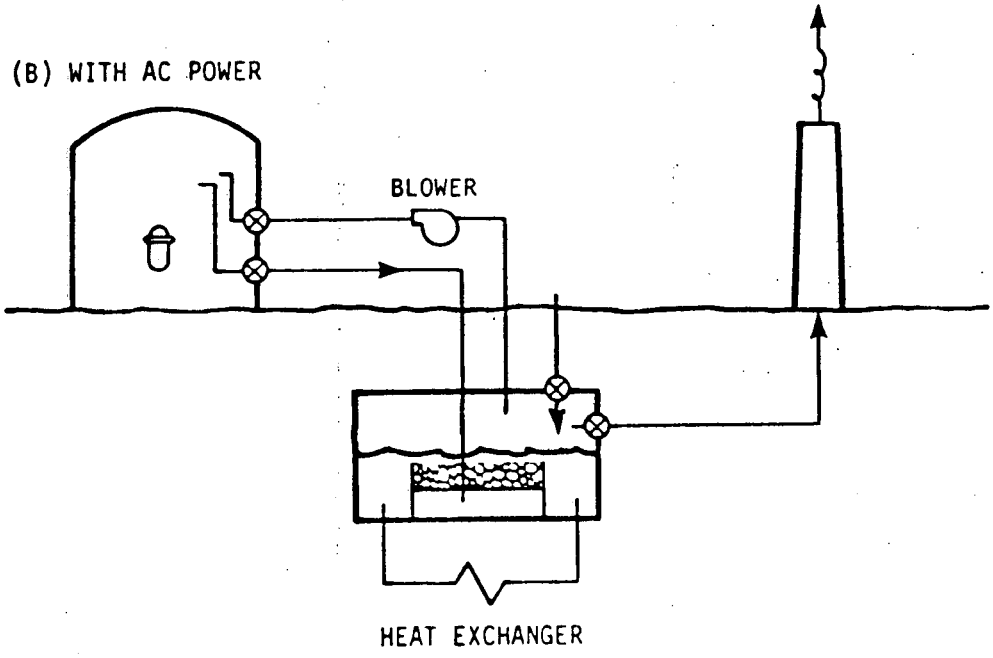
VALVE REDUNDANCY: FAILURE-TO-OPEN AND FAILURE-TO-CLOSE PROBABILITIES SHOULD BE MADE SUFFICIENTLY LOW BY USE OF MULTIPLE VALVE ARRANGEMENTS.

HYDROGEN CONTROL INTERFACE: HYDROGEN CONTROL METHODS (E.G., CONTINUOUS IGNITION OR WATER FOG) SHOULD AT SOME POINT BE FACTORED INTO THE FVCS DESIGN CRITERIA.

(A) WITHOUT AC POWER



(B) WITH AC POWER



ALKALINE WATER POOL

PURPOSE: TO CONDENSE STEAM, CAPTURE PARTICULATE, AND CAPTURE INORGANIC IODINE.

SIZE: WATER VOLUME - 150,000 CU. FT. (1.2×10^6 GALLONS). FREE VOLUME - 150,000 CU. FT., HEAT EXCHANGER - 10^8 BTU/HR.

VENT SUBMERGENCE DEPTH: 4 FT. OVERFLOW FEATURE TO PREVENT SUBMERGENCE DEPTH BECOMING GREATER THAN 4.5 FT.

PRESSURE DROP: NOMINAL 48 IN. WG. MAXIMUM 54 IN. WG.

DECONTAMINATION FACTORS: (WITH SUBMERGED GRAVEL) - 50 FOR PARTICULATE, 50 FOR INORGANIC IODINE, 2 FOR ORGANIC IODINE.

DESIGN PARAMETERS: 30 PSIG @ 300°F.

CONSTRUCTION FEATURES: STEEL TOROIDAL STRUCTURE ENCASED IN A CONCRETE-LINED VAULT BELOW GRADE. CORROSION RESISTANT MATERIALS INTERNALLY. NORMALLY SEALED ACCESS POINTS FOR ROUTINE INSPECTION AND MAINTENANCE.

INSTRUMENTATION: TEMPERATURE, PRESSURE, PRESSURE DROP, WATER LEVEL, ALKALINITY, RADIATION LEVELS.

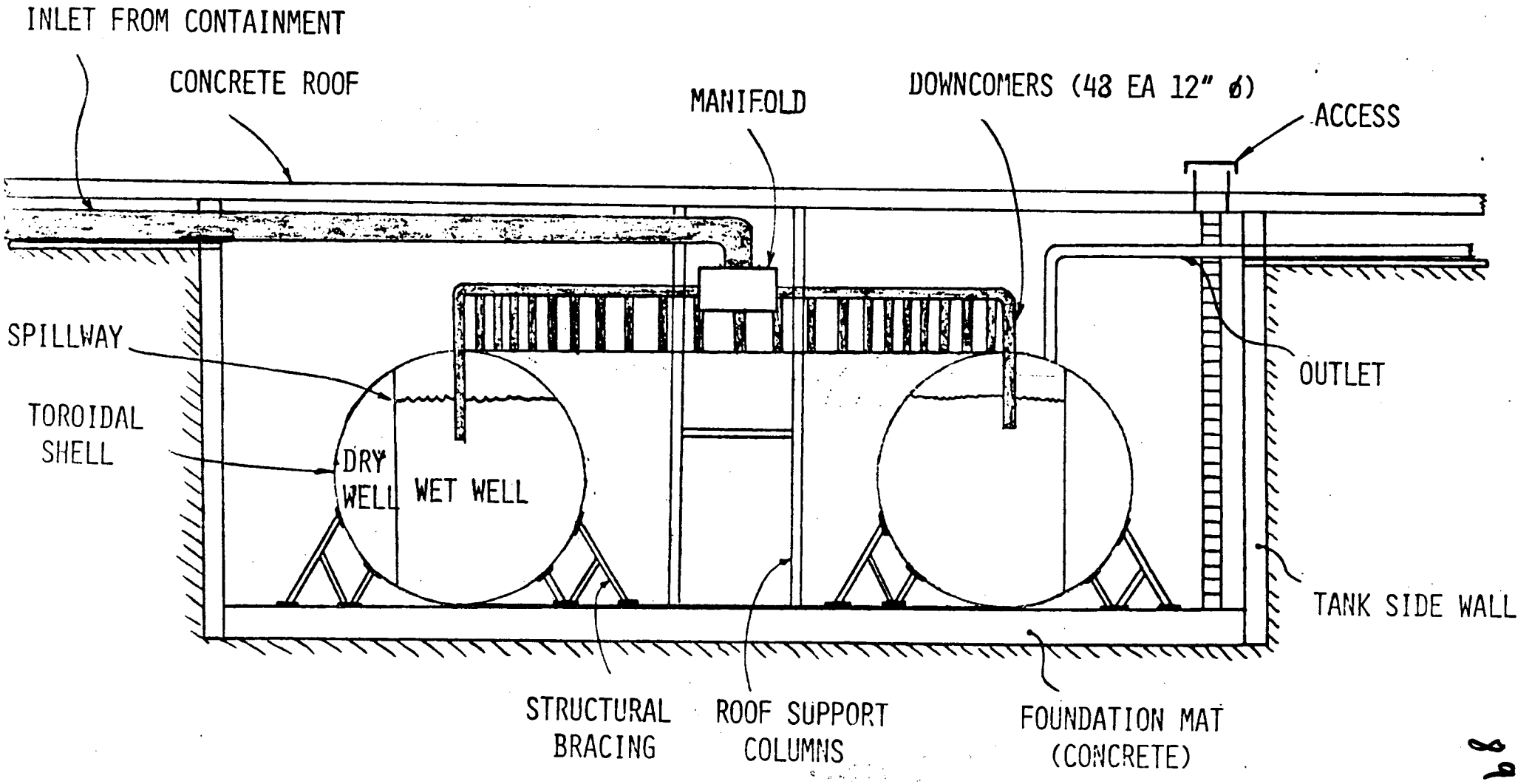
ALKALINE WATER POOL

COST: $9.0 MILLION IF SEISMIC I. $7.0 MILLION IF SEISMIC II.

MAJOR UNCERTAINTIES: LOADING LIMITS FOR PARTICULATE AND IODINE. DECONTAMINATION FACTORS.

POSSIBLE PROBLEMS: HYDROGEN IGNITION IN WETWELL. POSSIBILITY OF WATER LOSS.

SUPPRESSION POOL SECTION



CRUSHED GRAVEL

PURPOSE: TO CONDENSE STEAM, CAPTURE PARTICULATE, AND CAPTURE INORGANIC IODINE.

SIZE: GRAVEL PIT - 1.5×10^6 CU. FT. (1.5×10^8 LB OF GRAVEL)
CONDENSATE SUMP - 60,000 CU. FT. (475,000 GALLONS OF WATER).

PRESSURE DROP: SMALL.

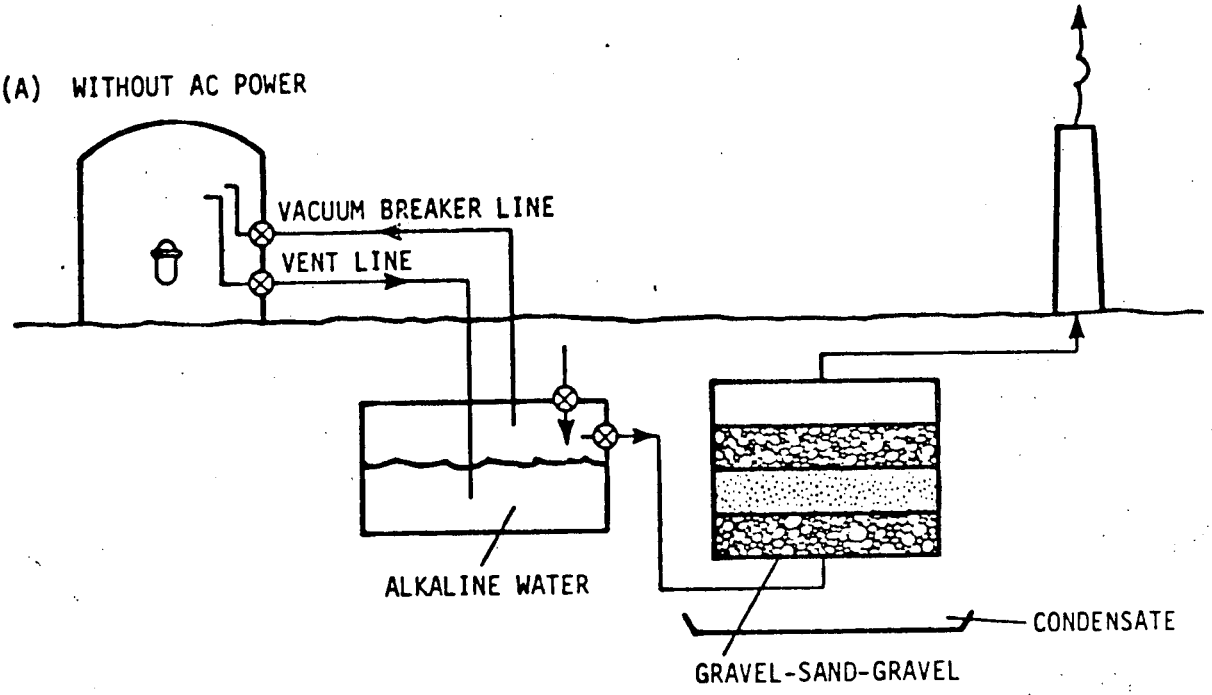
DECONTAMINATION FACTORS: MAY BE LOW.

COST: $6 MILLION ACCORDING TO CEC STUDY.

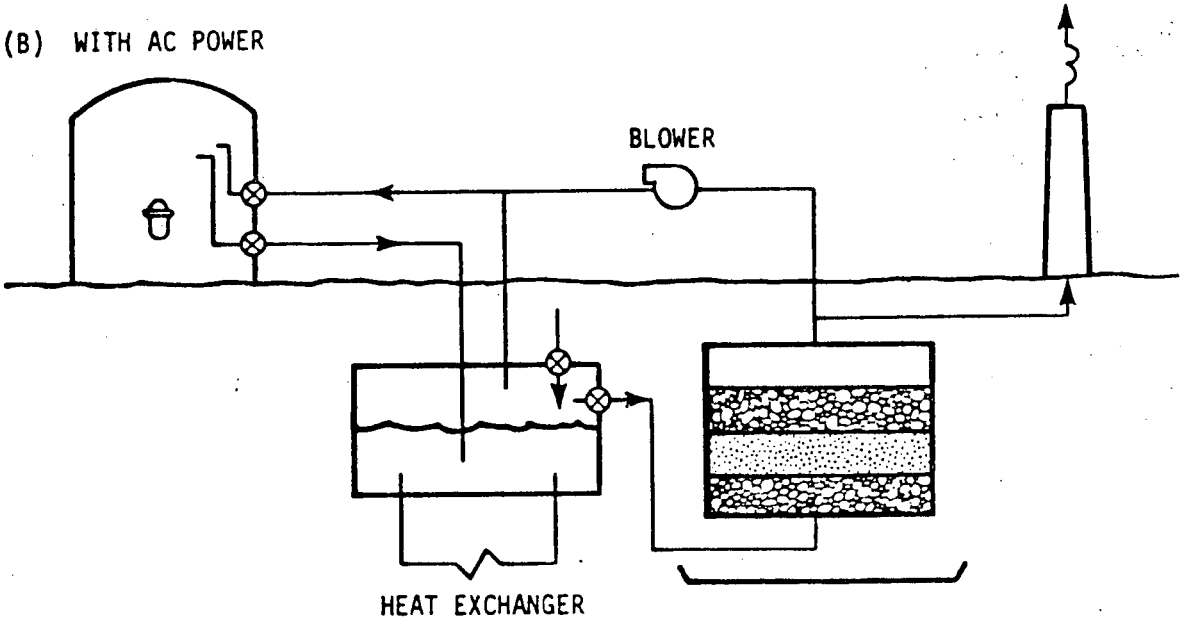
MAJOR UNCERTAINTIES: DECONTAMINATION FACTORS.

POSSIBLE PROBLEMS: LONG TERM HEAT REMOVAL/IODINE DESORPTION.
HYDROGEN IGNITION POSSIBILITY.

(A) WITHOUT AC POWER



(B) WITH AC POWER



SAND FILTER

PURPOSE: TO CAPTURE PARTICULATE AND TO PROVIDE A MEANS FOR CONTROLLED HYDROGEN BURNING.

SIZE: 240,000 CU. FT. INCLUDING HYDROGEN BURNING CHAMBER. 32,000 CU. FT. OF GRAVEL, 48,000 CU. FT. OF FINE MESH SAND.

PRESSURE DROP: 10 IN. WG.

DECONTAMINATION FACTORS: 500 FOR PARTICULATE.

DESIGN PARAMETER: 5 FPM FACE VELOCITY.

CONSTRUCTION FEATURES: CONTAINED IN LEAK TIGHT CONCRETE VAULT BELOW GRADE, WITH NORMALLY SEALED ACCESS POINTS FOR INSPECTION AND MAINTENANCE. IGNITION SOURCES FOR HYDROGEN. SUMP FOR CONDENSATE.

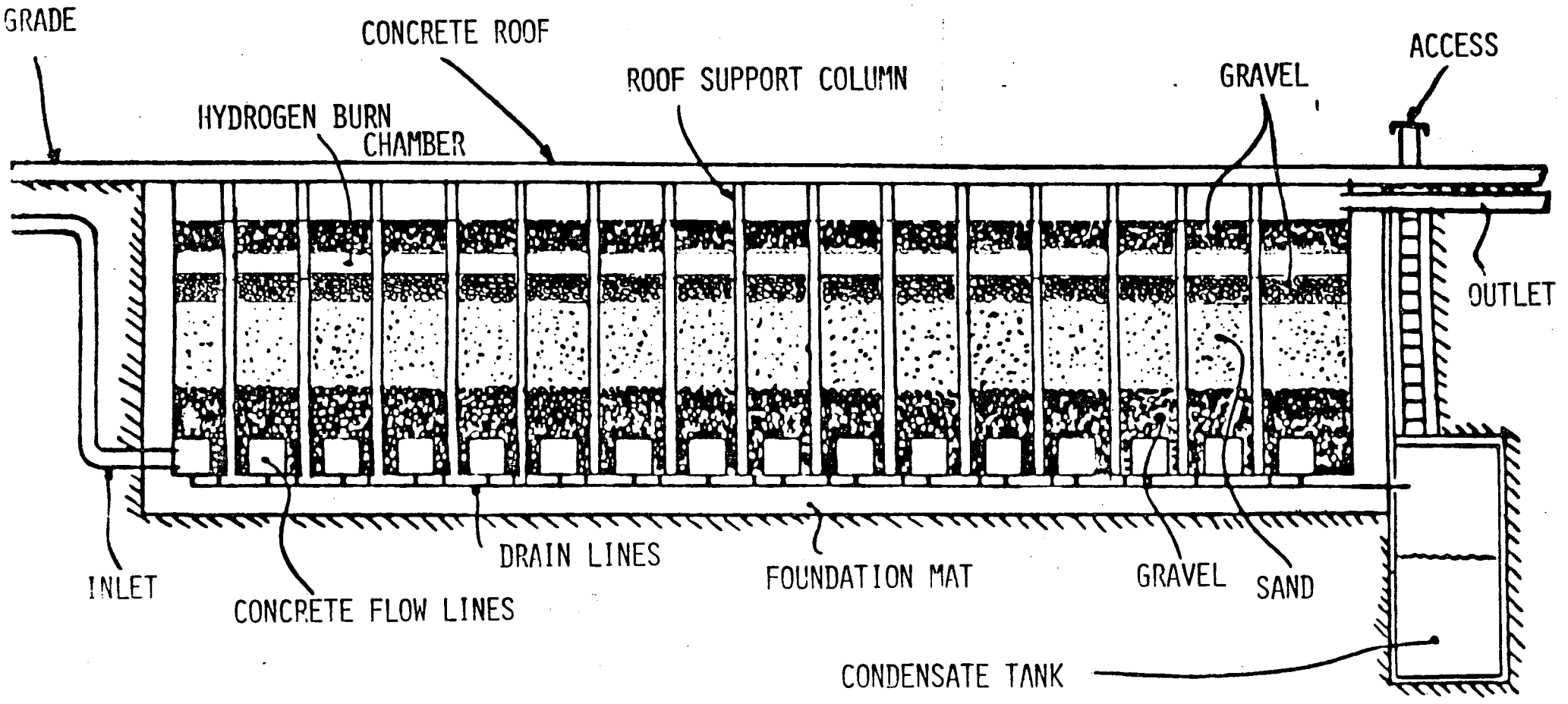
INSTRUMENTATION: TEMPERATURE, PRESSURE DROP, RADIATION LEVELS.

COST: $5.0 MILLION IF SEISMIC I, $3.2 MILLION IF SEISMIC II.

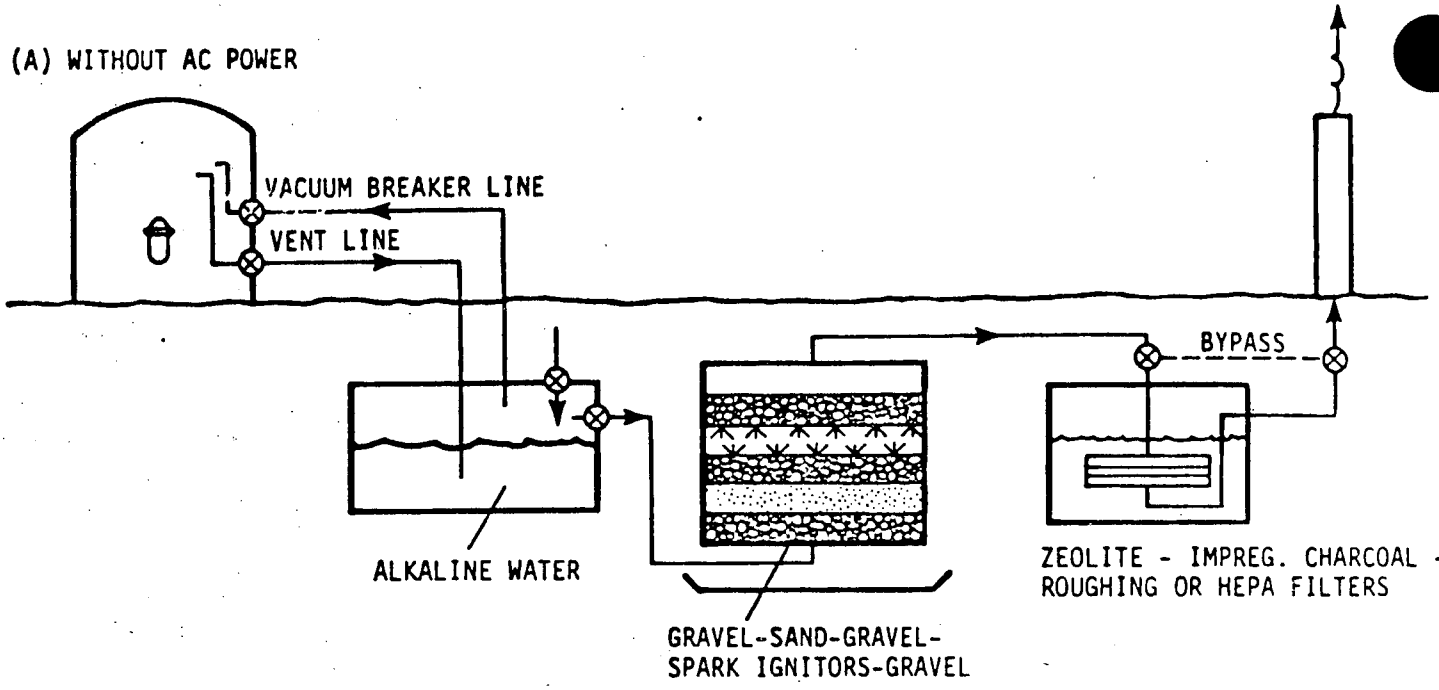
MAJOR UNCERTAINTIES: LOADING LIMITS FOR PARTICULATE.

POSSIBLE PROBLEMS: POSSIBILITY OF PLUGGING DUE TO WATER OR CONTAMINATION. HYDROGEN DETONATION IN COMBUSTION CHAMBER. ADEQUACY OF GRAVEL FOR FLAME ARRESTING.

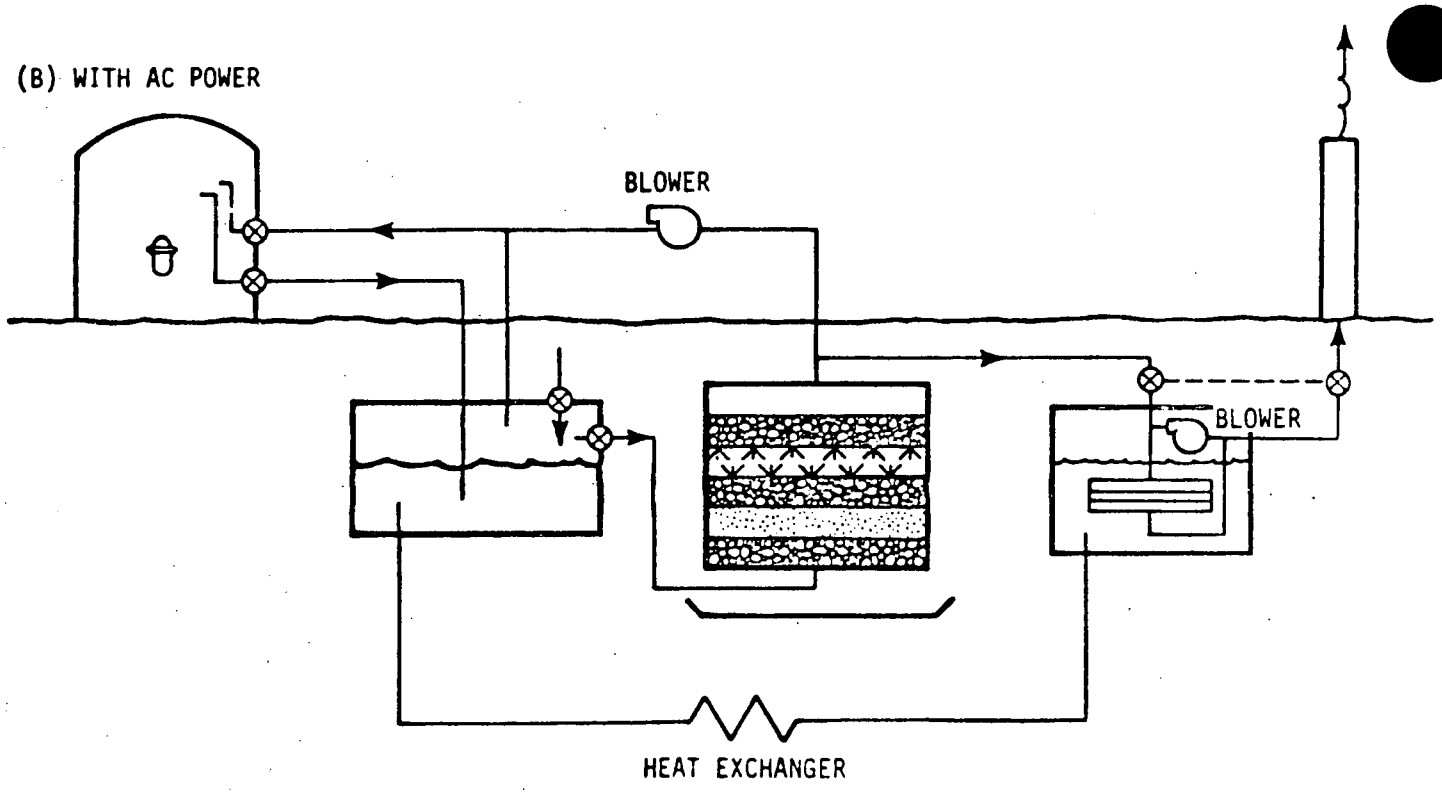
SAND/GRAVEL FILTER SECTION



(A) WITHOUT AC POWER



(B) WITH AC POWER



ADSORBERS

PURPOSE: TO CAPTURE INORGANIC AND ORGANIC IODINE.

COMPONENTS:

(1) 4" - DEEP 8 x 16 MESH INORGANIC ZEOLITE GUARD BED
(2) 2" - DEEP 8 x 16 MESH TEDA-IMPREGNATED CHARCOAL BED
(3) WATER BATH TO REMOVE DECAY HEAT FOR UP TO 16 HOURS
(4) AIR BLOWER TO REMOVE LONG TERM DECAY HEAT
(5) ROUGHING OR HEPA FILTERS

SIZES/WEIGHTS: 150,000 LBS OF ZEOLITE, 250 CHARCOAL FILTER TRAYS (5000 LBS OF CHARCOAL), 250 HEPA FILTER TRAYS, 20,000 GALLONS OF WATER, 5000 CFM AIR BLOWER.

PRESSURE DROP: 1.5 IN. WG THROUGH ZEOLITE, 0.3 IN. WG THROUGH CHARCOAL, 1.3 IN. WG THROUGH HEPAS.

DECONTAMINATION FACTORS: 200 FOR INORGANIC IODINE, 100 FOR ORGANIC IODINE.

DESIGN PARAMETERS: 40 FPM NOMINAL FACE VELOCITY, 170°F MAXIMUM CHARCOAL TEMPERATURE.

CONSTRUCTION FEATURES: LEAKTIGHT, CORROSION RESISTANT HOUSING (304 STAINLESS STEEL), SLIGHTLY PRESSURIZED INSIDE.

ADSORBERS

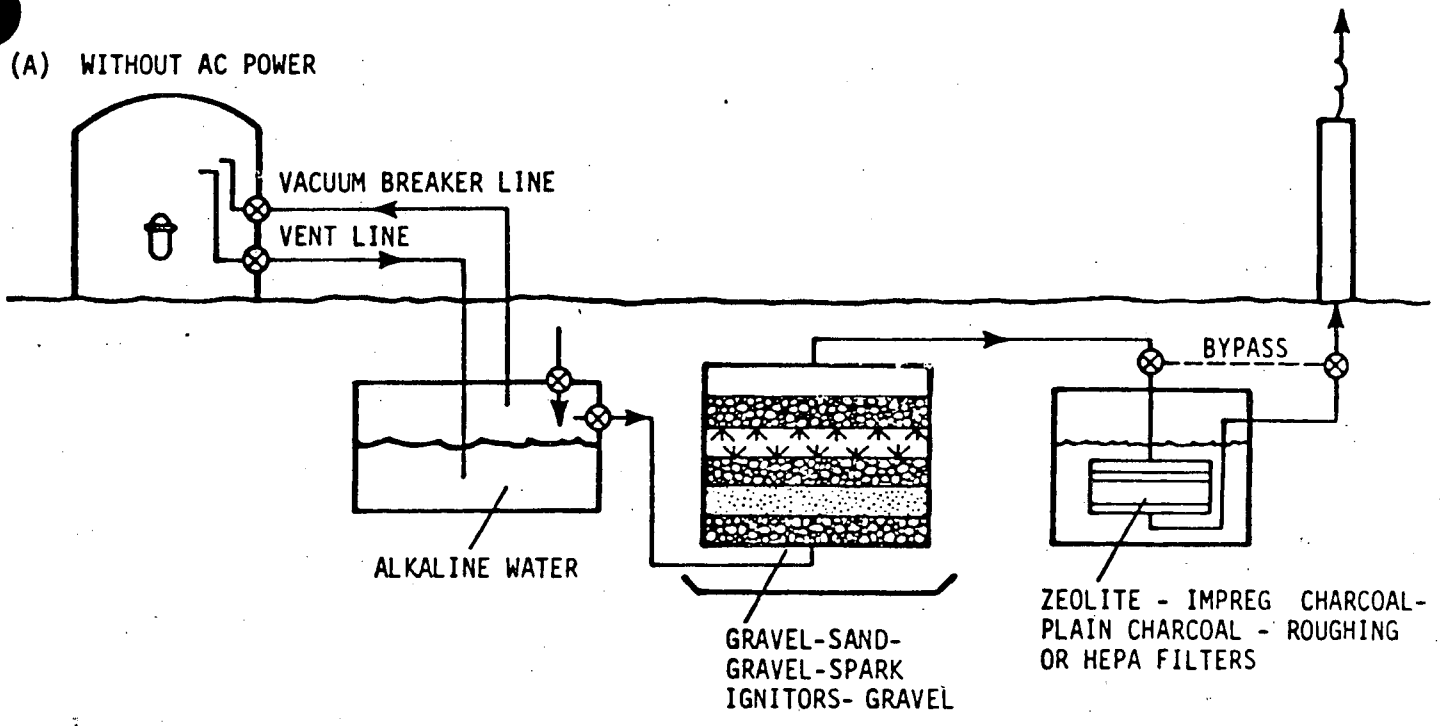
INSTRUMENTATION: TEMPERATURE, PRESSURE, RADIATION LEVELS, RELATIVE HUMIDITY.

COST: $2.3 MILLION IF SEISMIC I, $1.5 MILLION IF SEISMIC II.

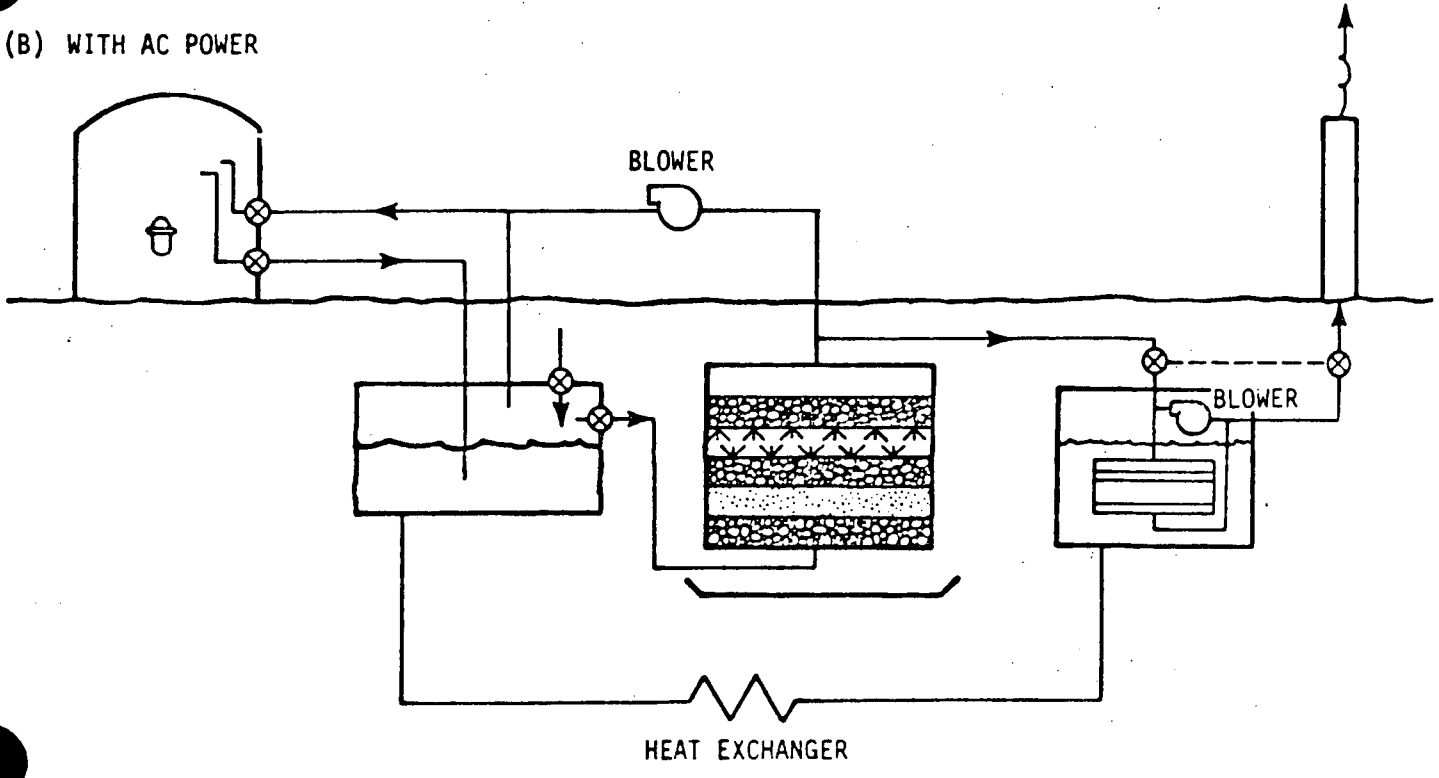
MAJOR UNCERTAINTIES: EFFECT OF TEMPERATURE AND HUMIDITY ON IODINE HOLDUP IN INORGANIC ZEOLITE.

POSSIBLE PROBLEMS: WATER INLEAKAGE. CHARCOAL IGNITIION DUE TO HYDROGEN BURN IN VICINITY. CHARCOAL IMPREGNANT STABILITY.

(A) WITHOUT AC POWER



(B) WITH AC POWER



XENON HOLDUP CHARCOAL BED

PURPOSE: TO HOLD UP AND ISOLATE XENON.

SIZE/WEIGHT: 5500 CU. FT. OF 4 x 8 MESH UNIMPREGNATED, ACTIVATED CHARCOAL (200,000 LBS) SUBMERGED IN A 100,000 GALLON WATER BATH. 20,000 CFM AIR BLOWER.

PRESSURE DROP: 11 IN. WG.

HOLDUP TIME: INDEFINITE.

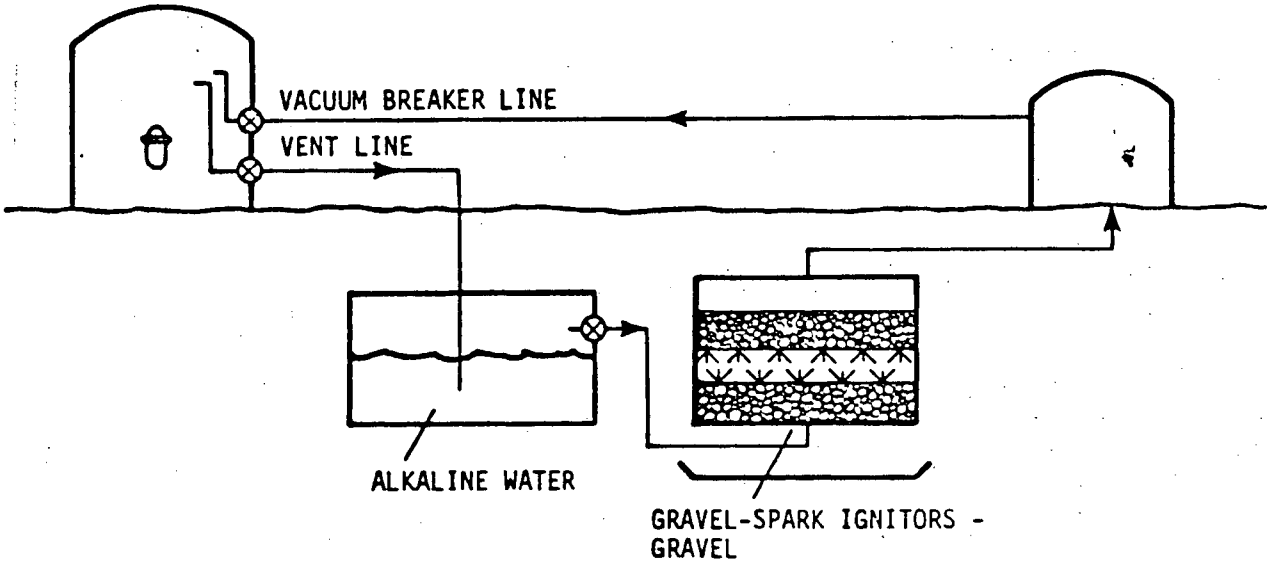
DESIGN PARAMETERS: 40 FPM NOMINAL FACE VELOCITY, 200°F MAXIMUM CHARCOAL TEMPERATURE.

COST: (WITH ADSORBER SYSTEM) $4.5 MILLION FOR SEISMIC I, $2.9 MILLION FOR SEISMIC II.

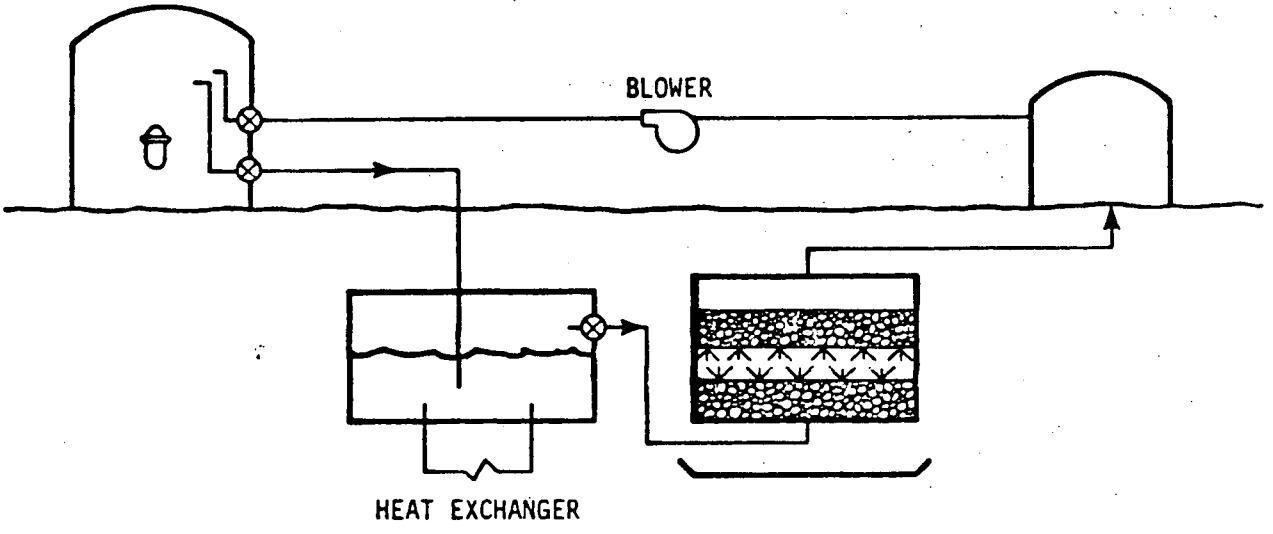
MAJOR UNCERTAINTIES: FLOW CHARACTERISTICS THROUGH CHARCOAL. EFFECT OF HUMIDITY ON ADSORPTION COEFFICIENT.

POSSIBLE PROBLEMS: CHANNELING POSSIBILITIES. WATER INLEAKAGE. CHARCOAL IGNITION DUE TO HYDROGEN BURNING.

(A) WITHOUT AC POWER



(B) WITH AC POWER



VENT BUILDING

PURPOSE: PRESSURE RELIEF AND 100% FISSION PRODUCT CONTAINMENT

SIZE/PRESSURE CAPACITY: PV = 4×10^9 FT-LB, GAGE.

FREE VOLUME (FT^3)	INTERNAL DESIGN PRESSURE (PSIG)	ABSOLUTE DESIGN PRESSURE (PSIA)
0.6×10^6	50	65
1.0×10^6	28	43
1.3×10^6	16	31

POSSIBLE PROBLEMS: HYDROGEN IGNITION IN VENT BUILDING, COST.

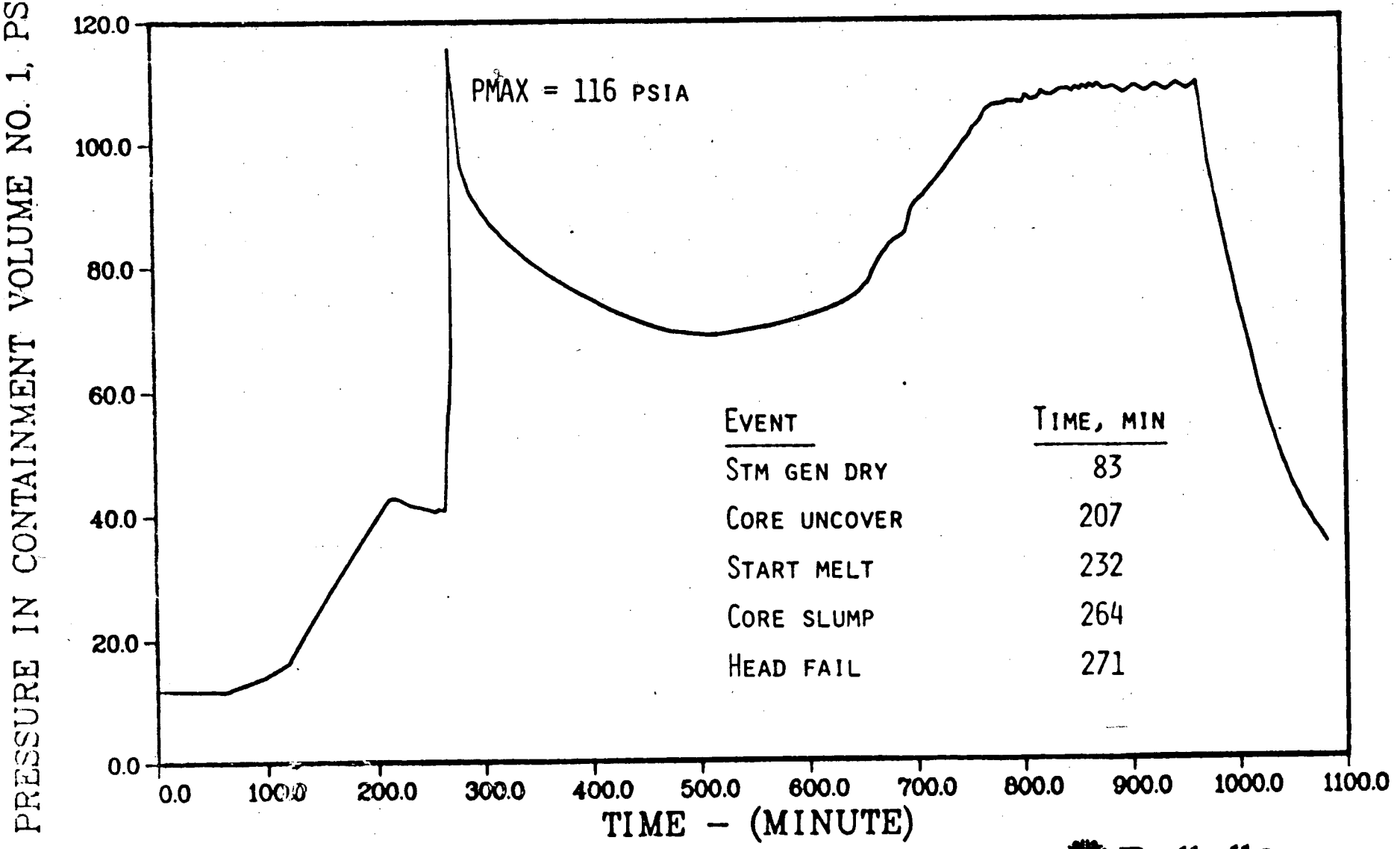
VIEWGRAPHS ACCOMPANYING PRESENTATION

BY P. CYBULSKIS

BCL

June 3, 1980

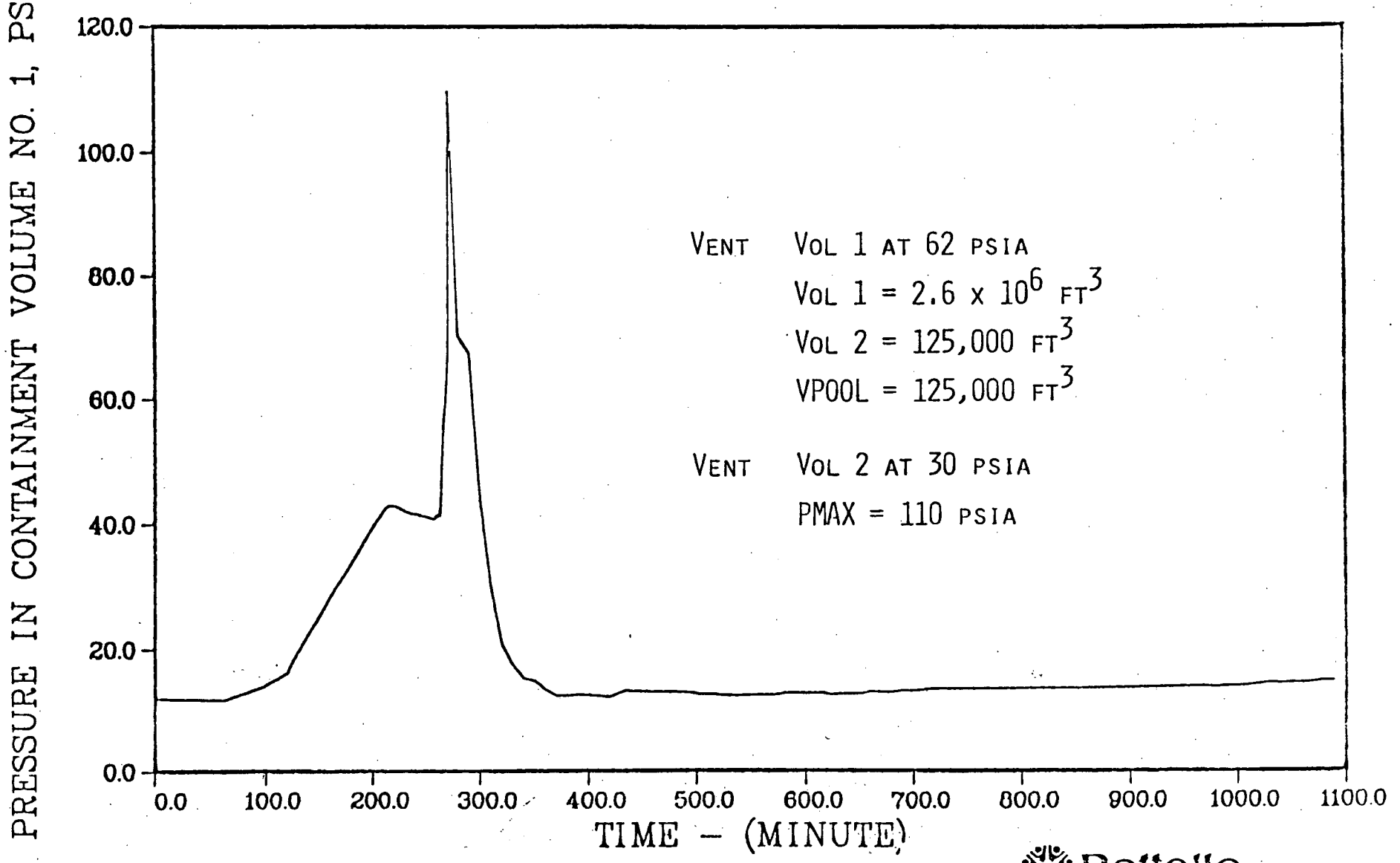
INDIAN PT 3, TMLB – BASE CASE



Battelle
Columbus Laboratories

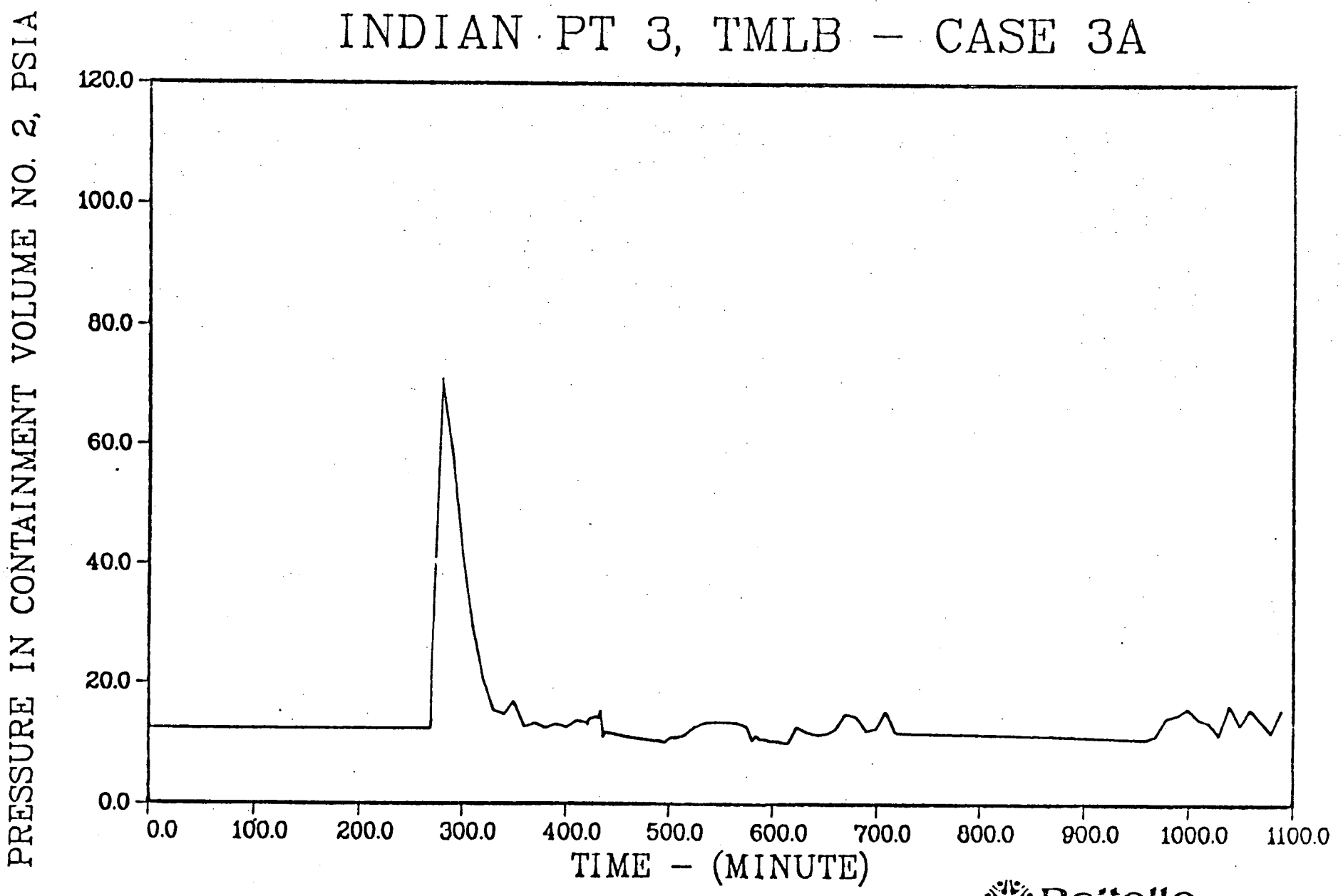
201

INDIAN PT 3, TMLB – CASE 3A



Battelle
Columbus Laboratories

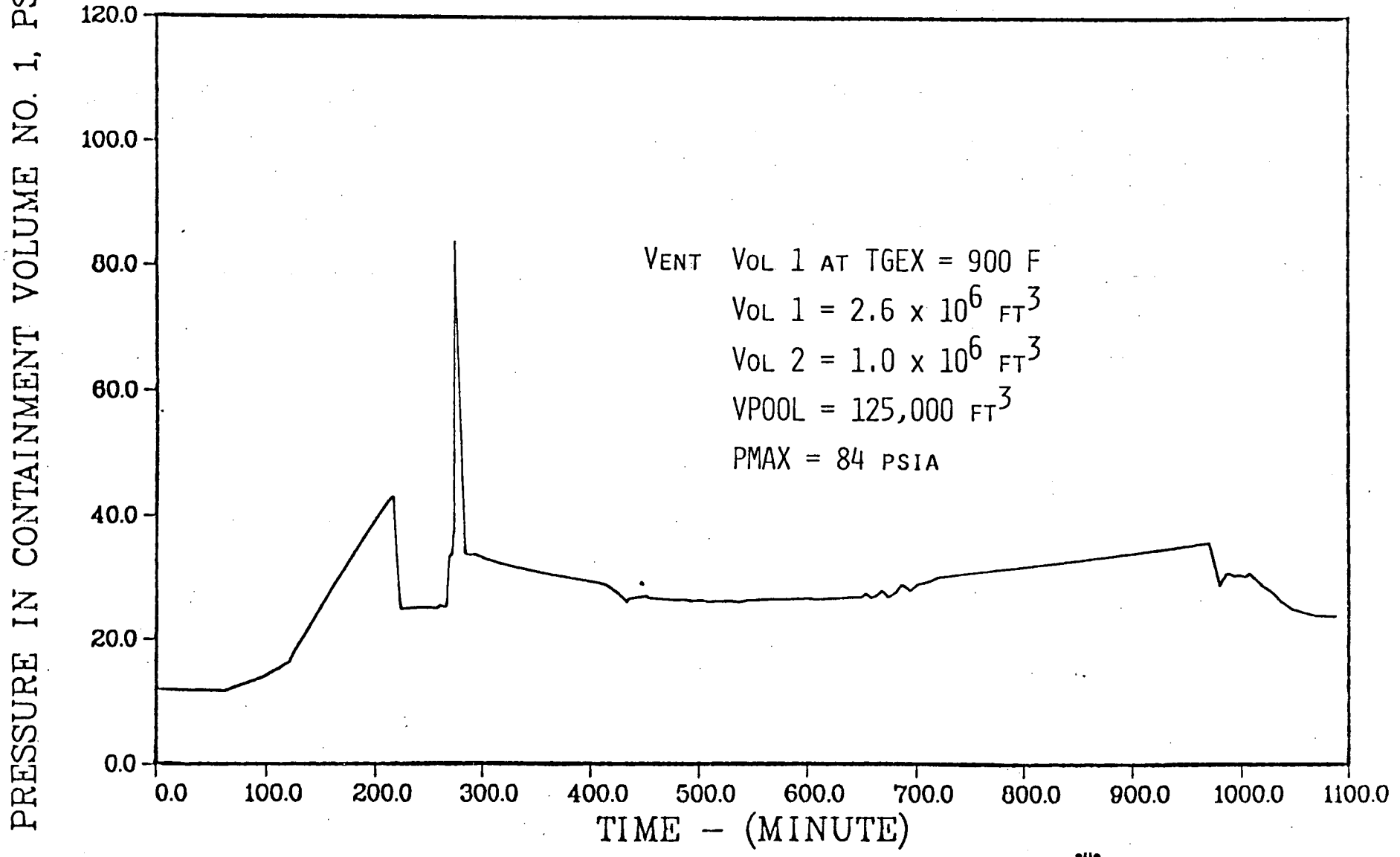
C91



Battelle
Columbus Laboratories

104

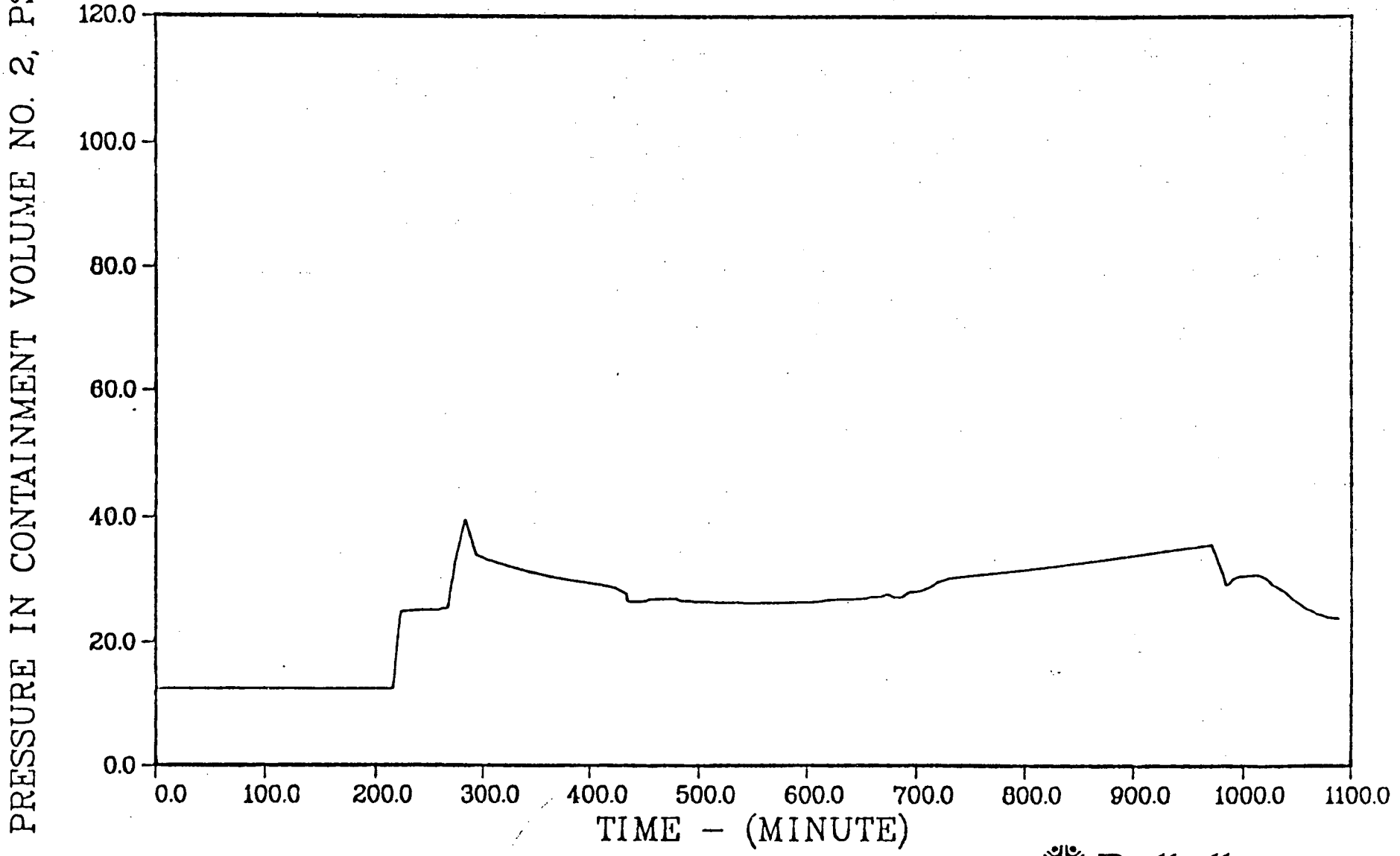
INDIAN PT 3, TMLB – CASE 2



Battelle
Columbus Laboratories

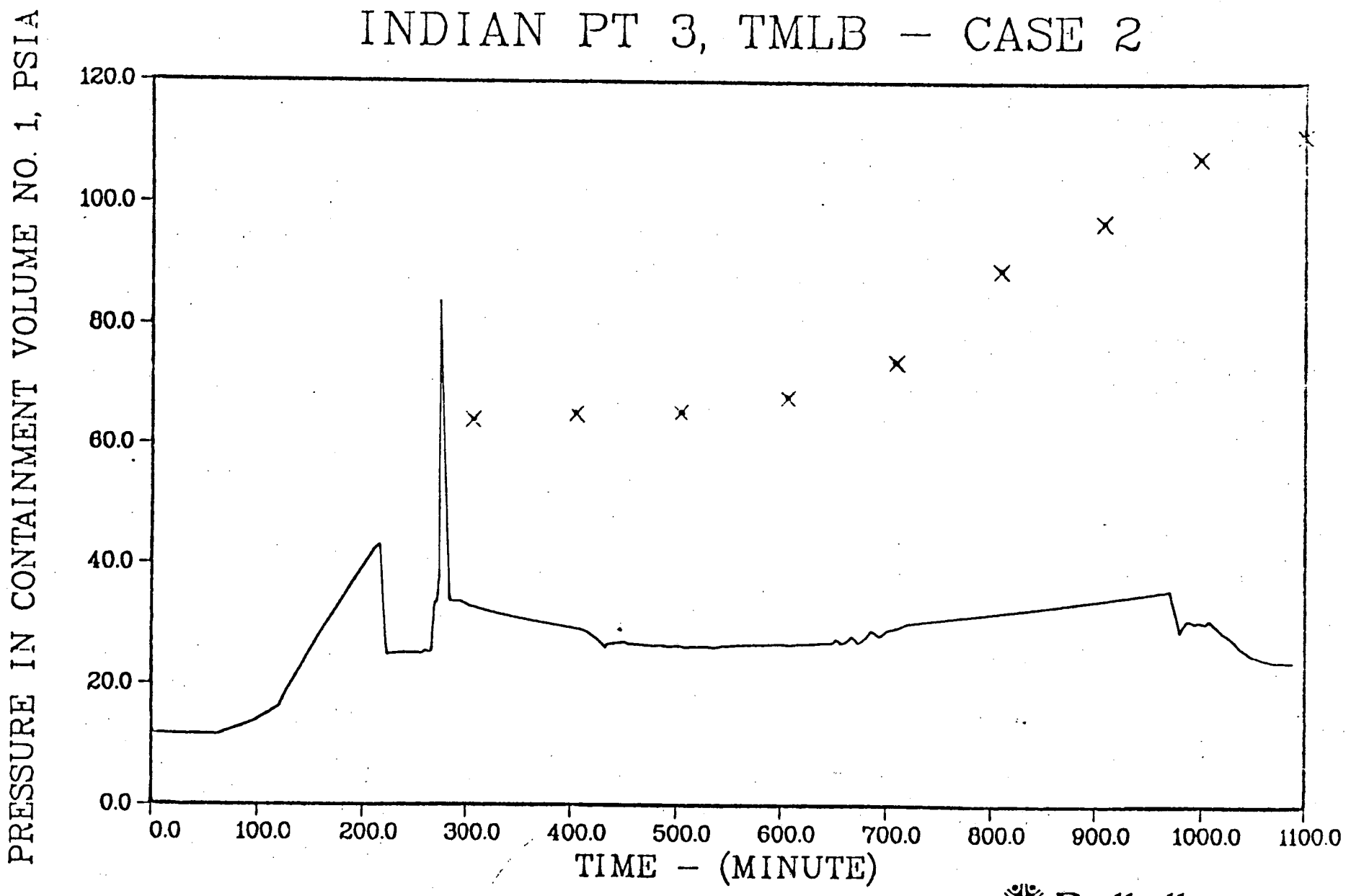
105

INDIAN PT 3, TMLB – CASE 2

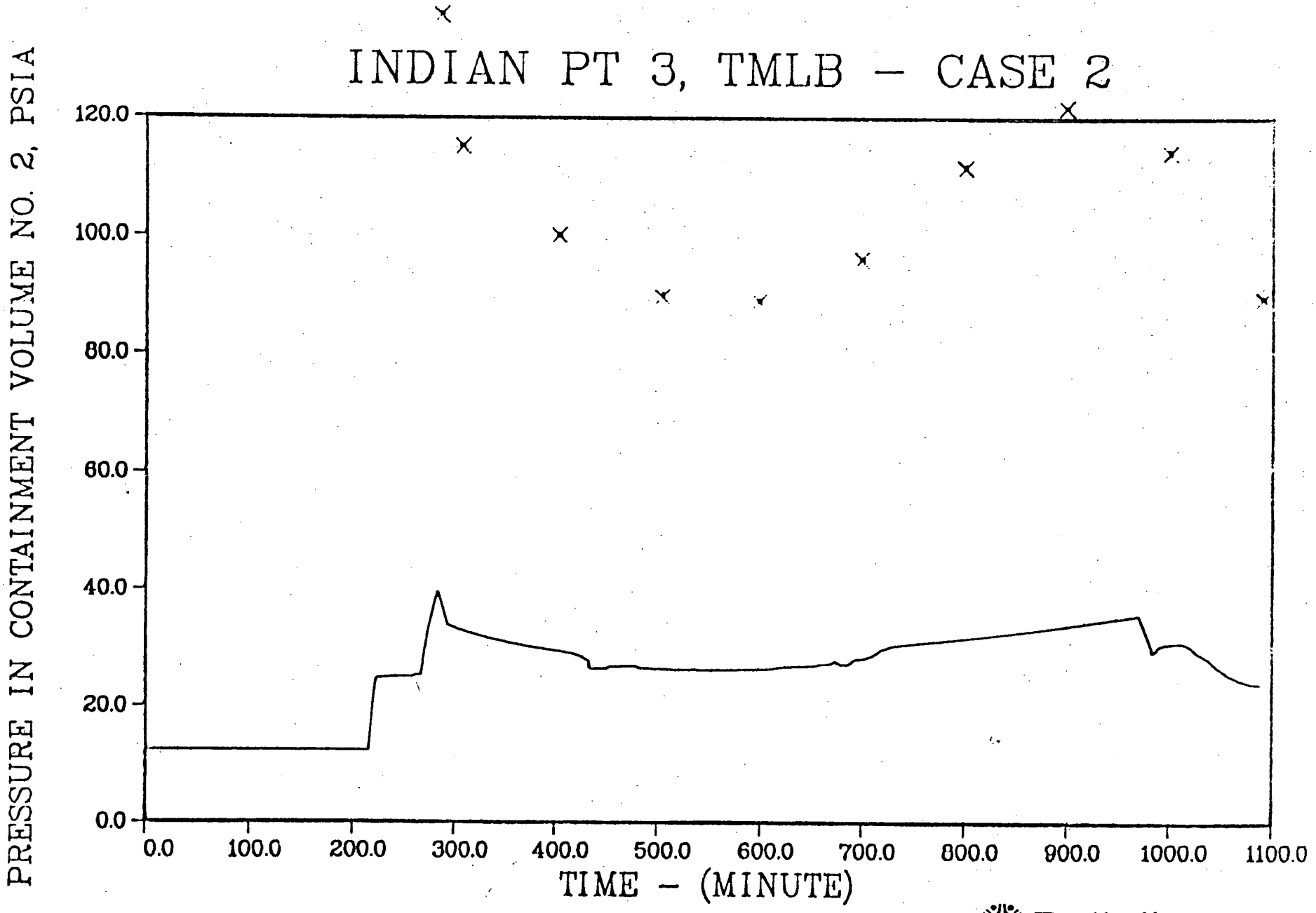


Battelle
Columbus Laboratories

106



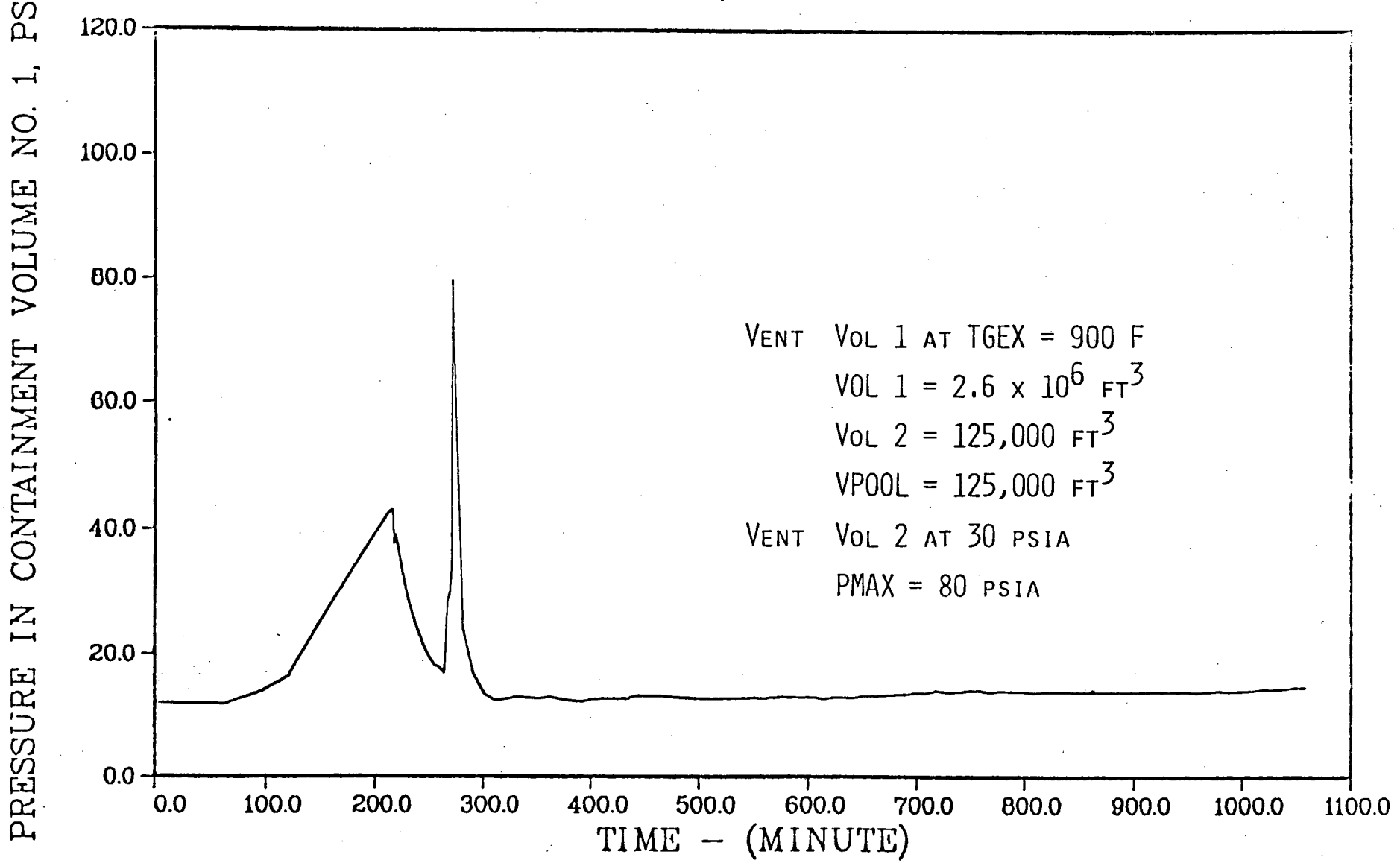
Battelle
Columbus Laboratories



Battelle
Columbus Laboratories

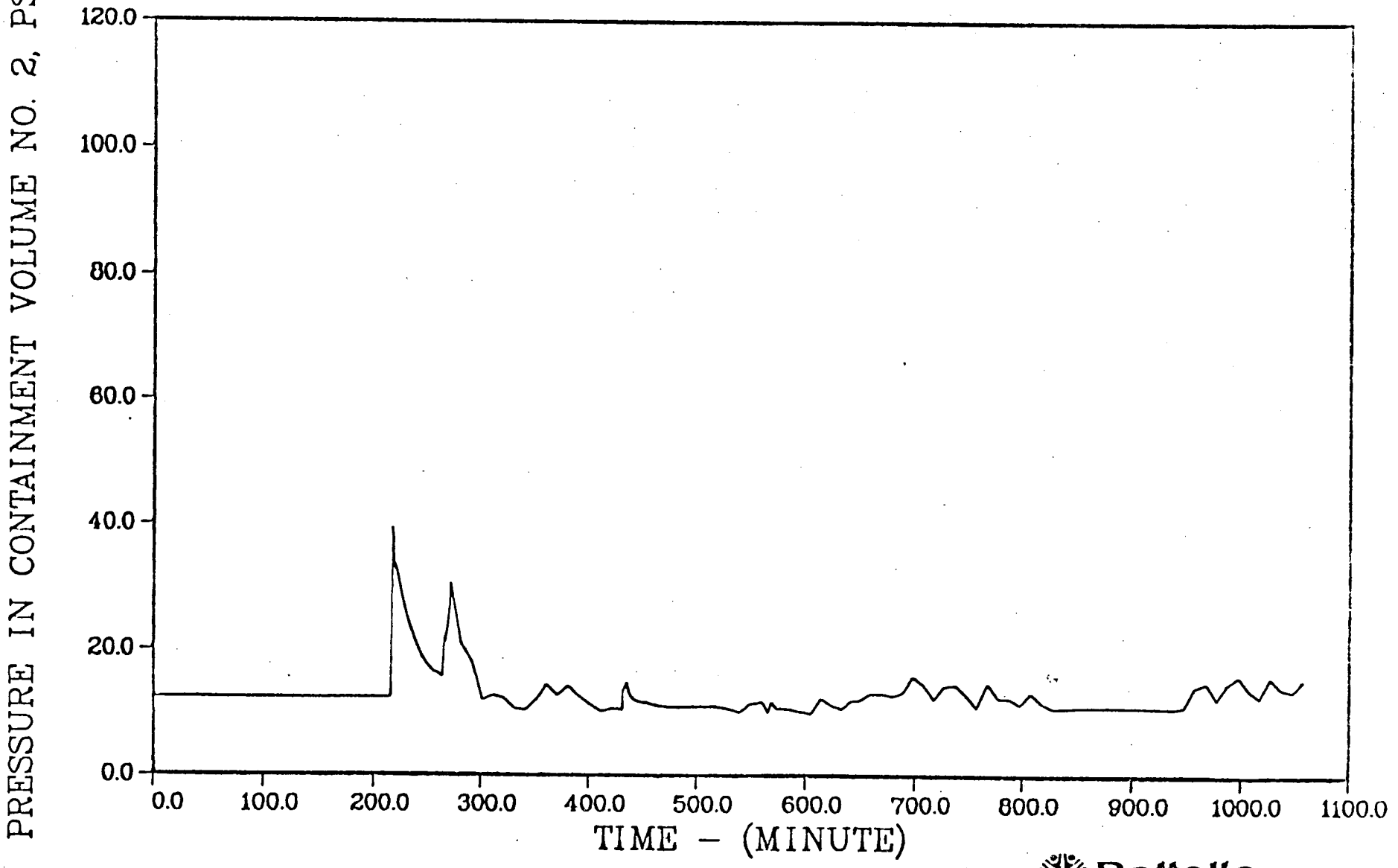
108

INDIAN PT 3, TMLB – CASE 3



Battelle
Columbus Laboratories

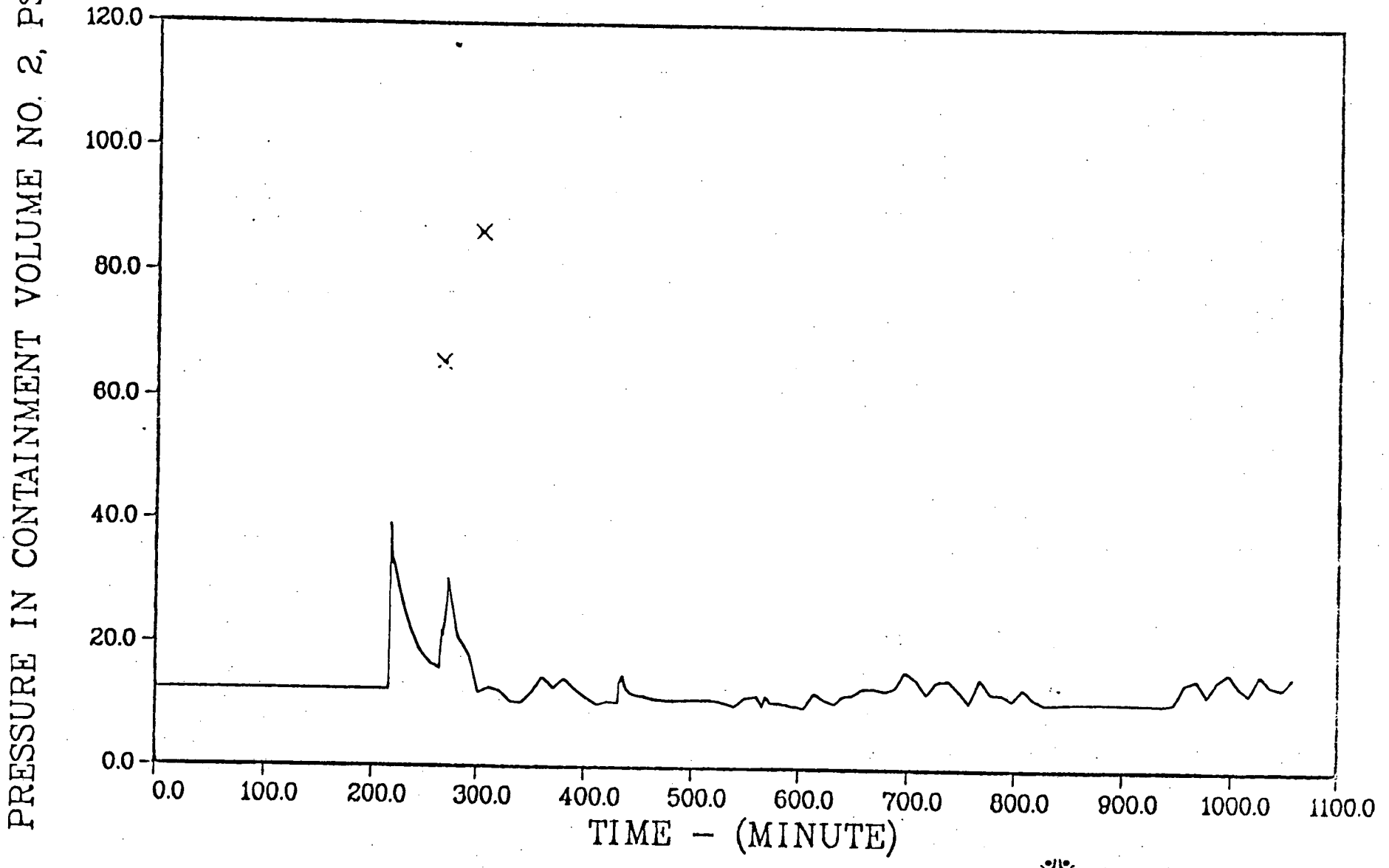
INDIAN PT 3, TMLB – CASE 3



Battelle
Columbus Laboratories

10

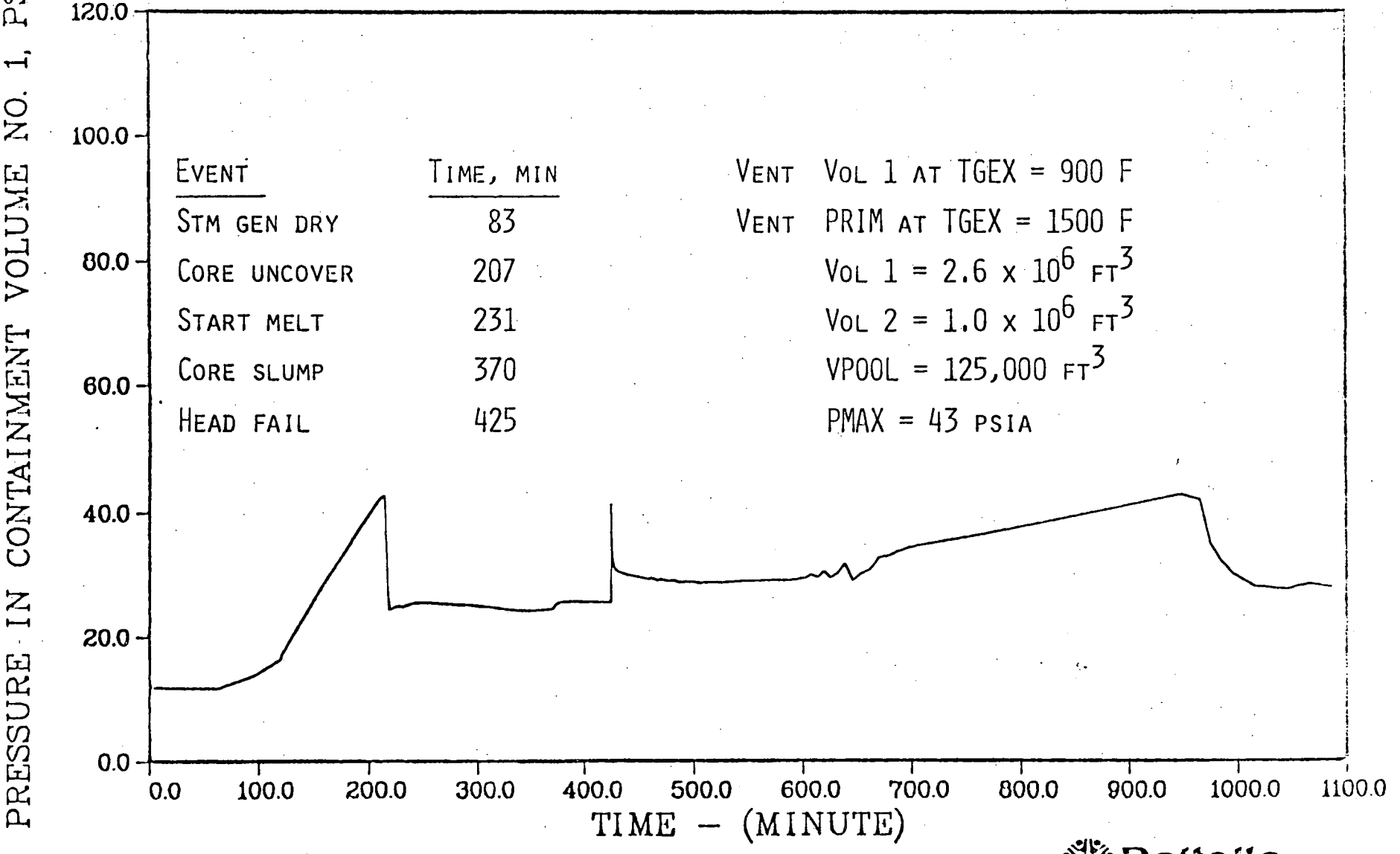
INDIAN PT 3, TMLB – CASE 3



Battelle
Columbus Laboratories

III

INDIAN PT 3, TMLB – CASE 4



EVENT	TIME, MIN
STM GEN DRY	83
CORE UNCOVER	207
START MELT	231
CORE SLUMP	370
HEAD FAIL	425

VENT VOL 1 AT TGEX = 900 F

VENT PRIM AT TGEX = 1500 F

VOL 1 = 2.6×10^6 FT^3

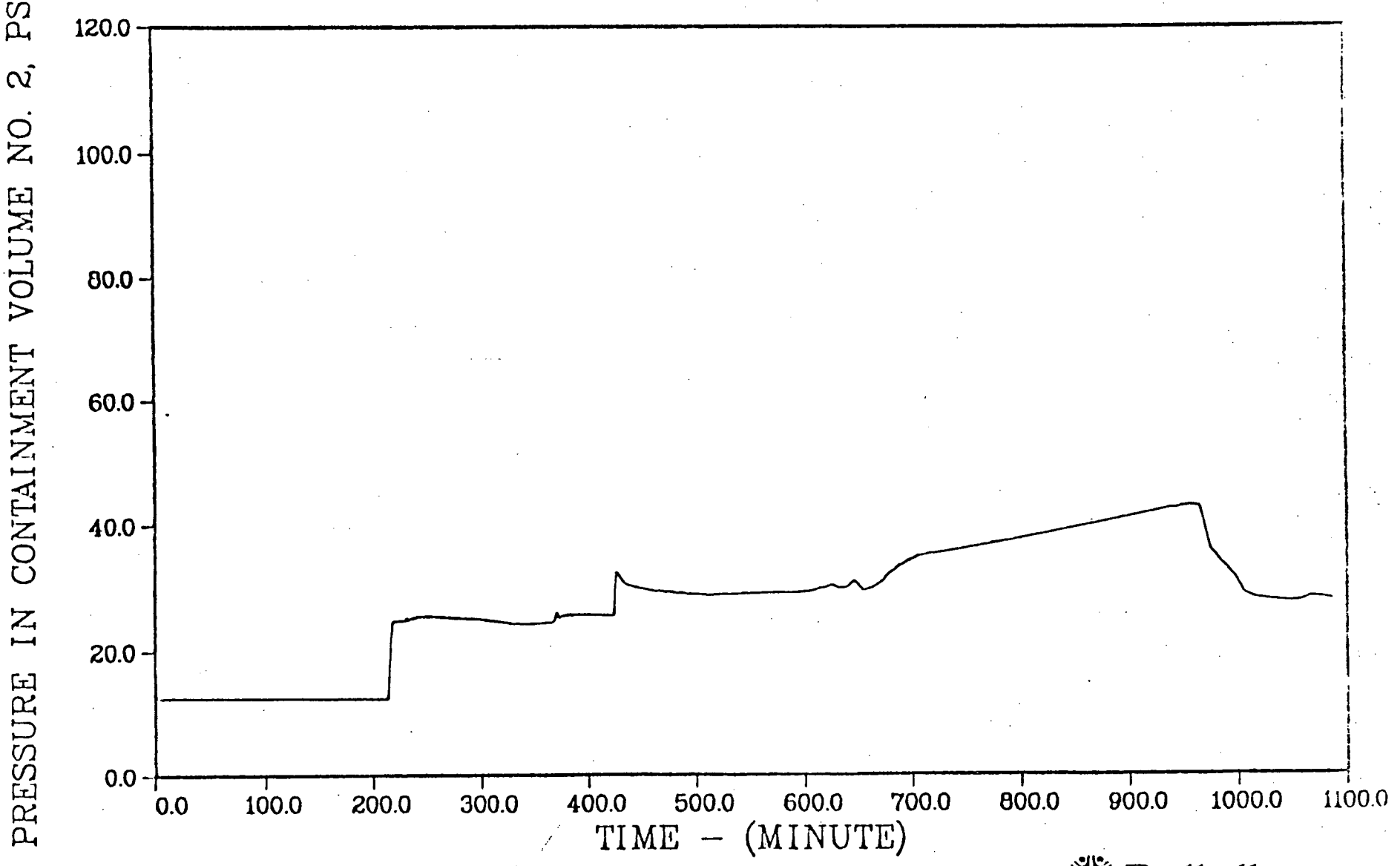
VOL 2 = 1.0×10^6 FT^3

VPOOL = 125,000 FT^3

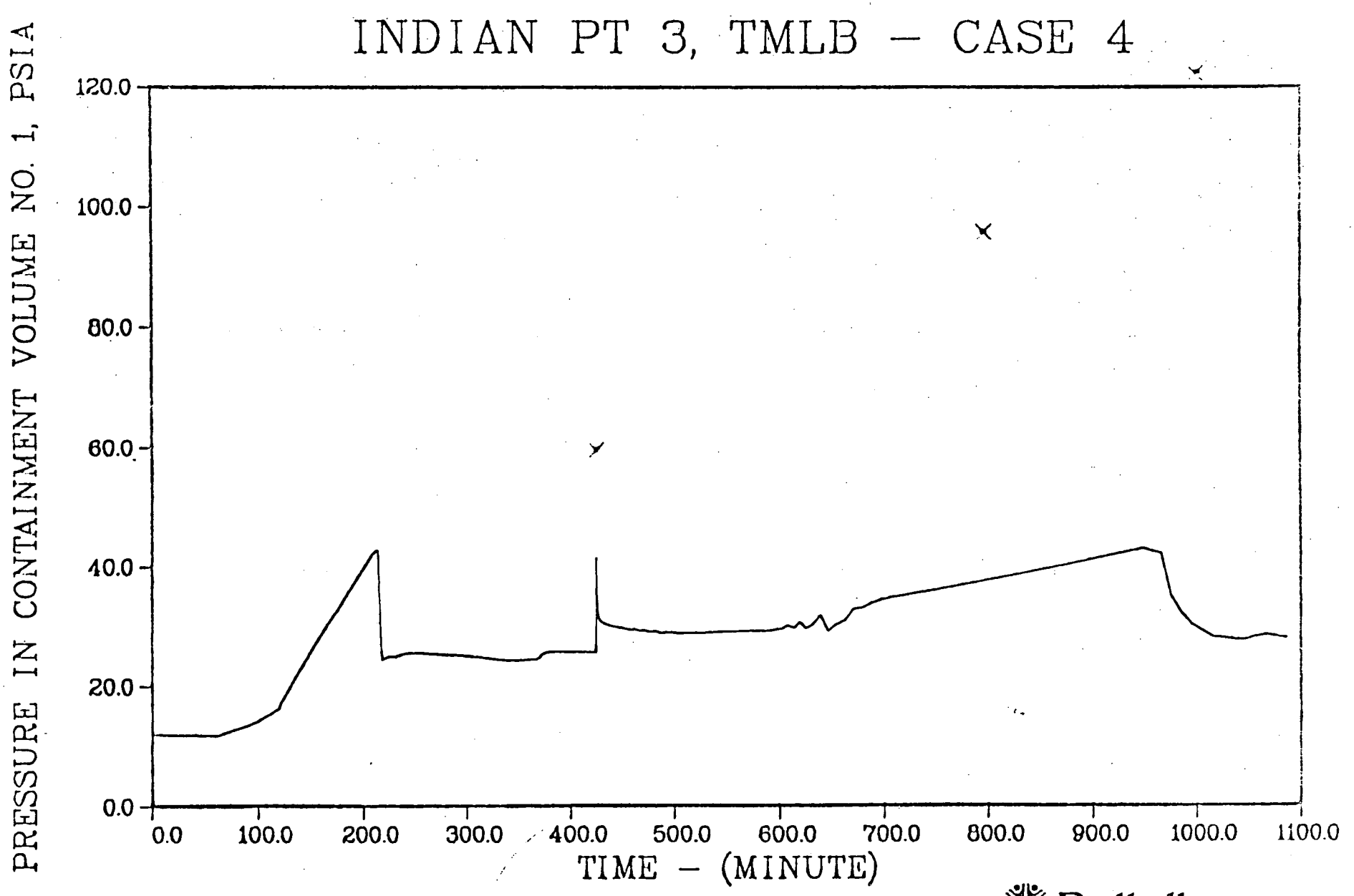
PMAX = 43 PSIA

Battelle
Columbus Laboratories

INDIAN PT 3, TMLB – CASE 4

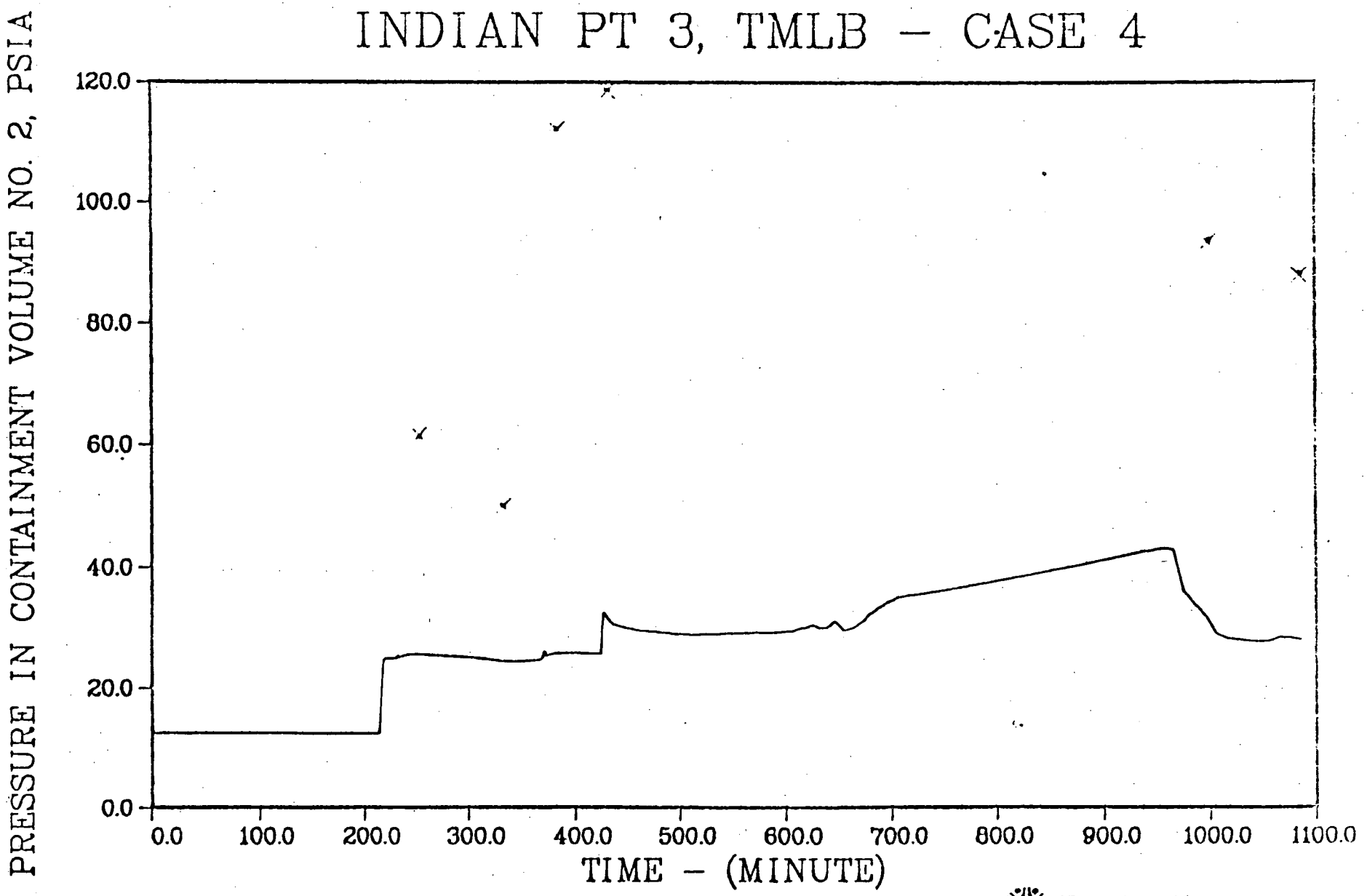


Battelle
Columbus Laboratories



Battelle
Columbus Laboratories

114



Battelle
Columbus Laboratories

115

116

UTILITY PRESENTATION:

CORE RETENTION CONCEPTS

JUNE 3, 1980

EFFECT OF CORE DEBRIS MITIGATION ON ACCIDENT CONSEQUENCES

	CAUSE OF CONTAINMENT FAILURE	CONTRIBUTION TO RISK		DEBRIS BED COOLING		CORE LADLE		CORE RETENTION DEVICE	
		MAN-REM	EARLY FATALITIES	PROB.	CONSEQ.	PROB.	CONSEQ.	PROB.	CONSEQ.
EARLY FAILURES	STEAM EXPLOSION	N	N	-	-	-	-	-	-
	OVERPRESSURE TRANSIENTS	H	H	-	-	-	-	-	-
	CHECK VALVE FAILURE (V)	M	M	-	-	-	-	-	-
DELAYED FAILURES	OVERPRESSURE TRANSIENTS	L	L	↓	↓	↓	↓	↓	↓
	BASE MAT MELT-THRU	L	L	↓	-	↓	-	ELIMINATES	

LEGEND, EFFECT ON CONSEQUENCES

N = NEGLIGIBLE

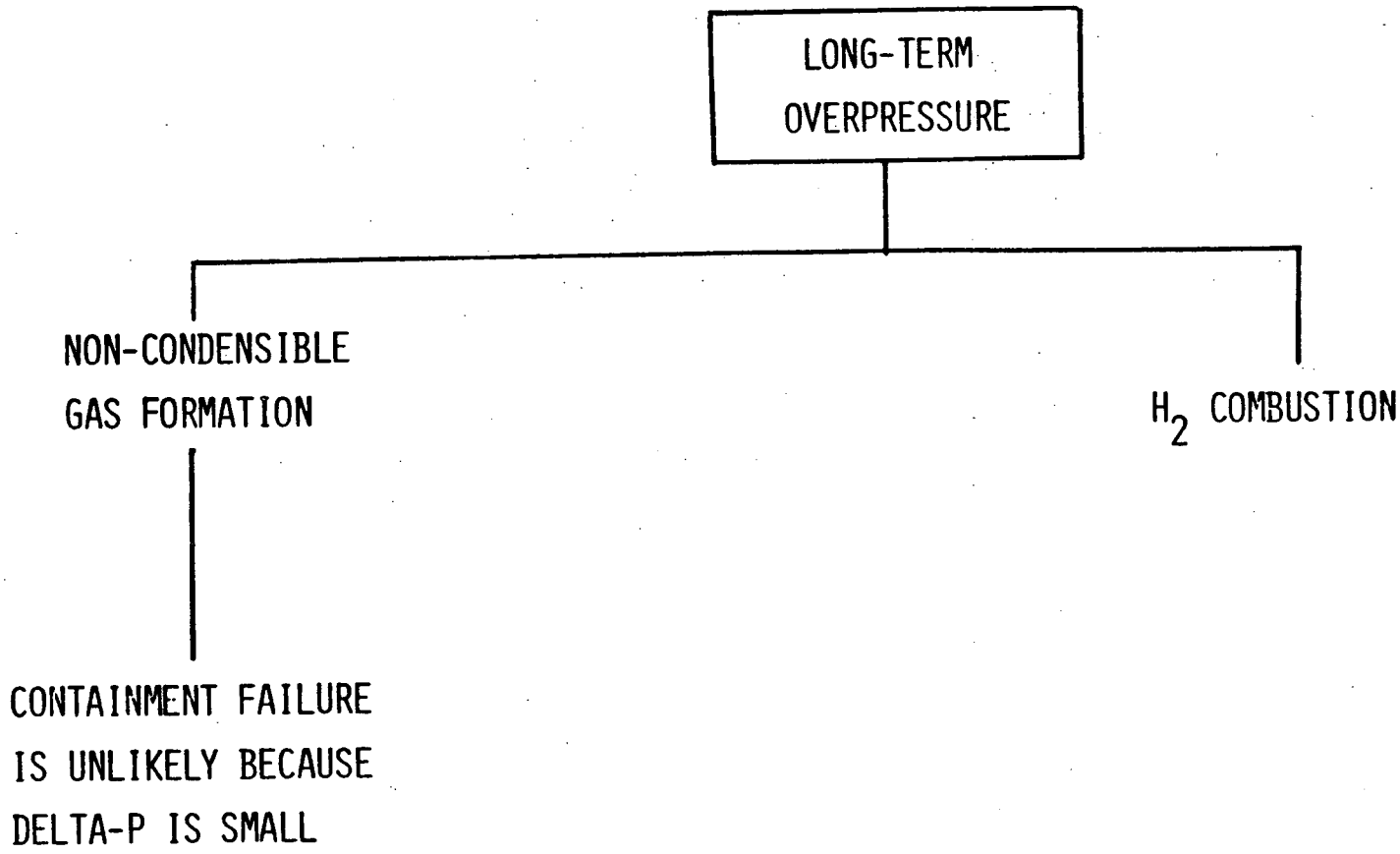
L = LOW

M = MODERATE

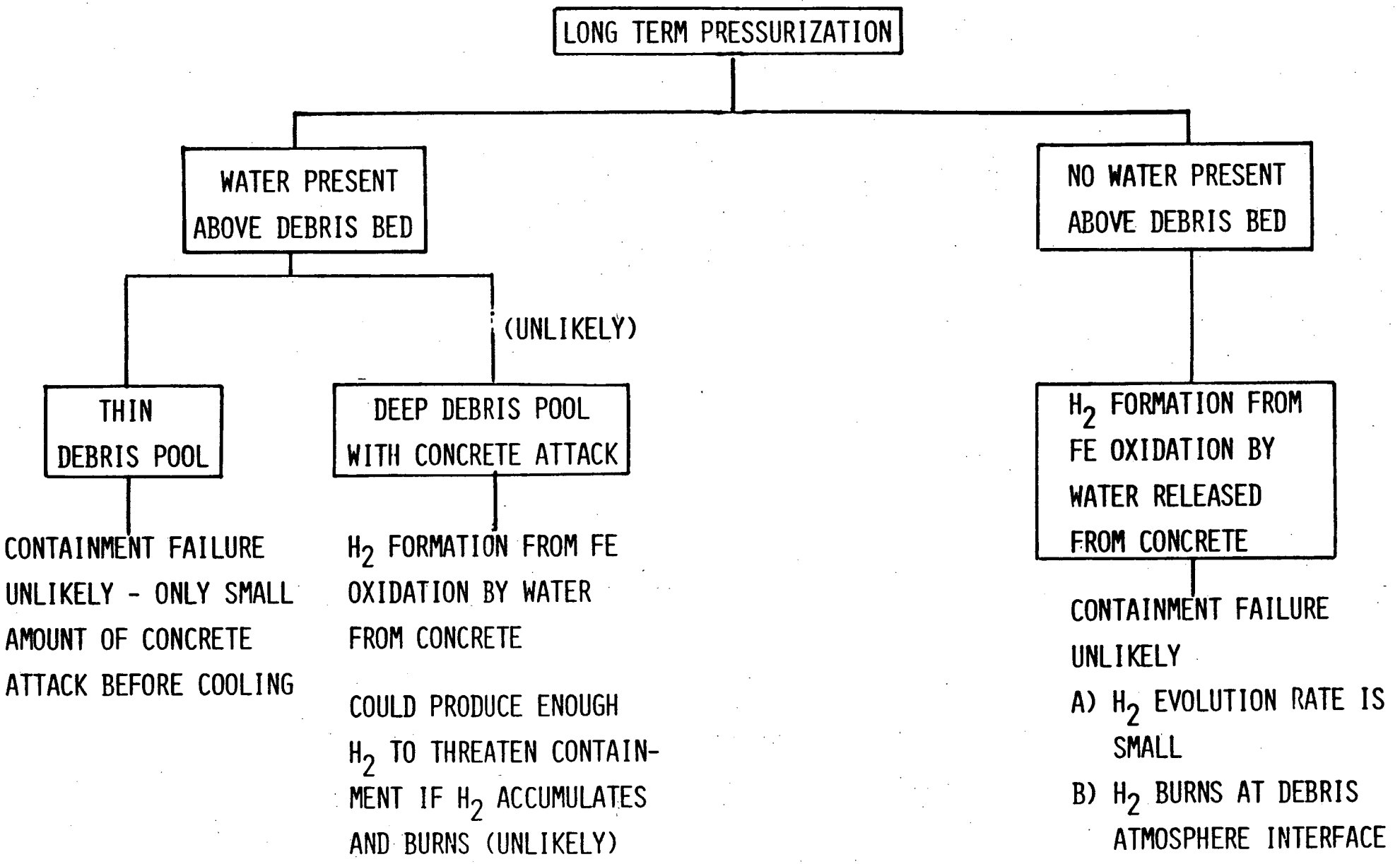
H = HIGH

- = NO EFFECT

↓ = REDUCES


LONG-TERM OVERPRESSURE
NON-CONDENSIBLE GAS FORMATION
H_2 COMBUSTION
CONTAINMENT FAILURE IS UNLIKELY BECAUSE DELTA-P IS SMALL

EVENT TREE - CONTAINMENT PRESSURIZATION FOLLOWING VESSLE MELT-THRU



FNP CORE LADLE

FUNCTIONAL REQUIREMENT

- DELAY MELT-THRU OF CORE TO BASIN SURROUNDING PLATFORM FOR AT LEAST 2 DAYS
- REDUCE QUANTITY OF GAS GENERATED BY CORE DEBRIS - BASE MAT INTERACTION

PERCEIVED LIQUID PATHWAYS BENEFITS

1) PROVIDE TIME TO ISOLATE BASIN AND HENCE LIQUID PATHWAYS SOURCE
2) PROVIDE TIME TO IMITATE OTHER PROTECTIVE ACTIONS OUTSIDE BREAKWATER

CONTAINMENT INTEGRITY BENEFIT

- REDUCE OVERPRESSURE THREAT TO ICE CONDENSER CONTAINMENT (ACCUMULATED UNBURNED H_2 FROM IRON OXIDATION)

LIQUID PATHWAYS DIFFERENCES, FNP VERSUS LAND BASED PLANT

FNP	LAND BASED PLANT	EFFECT
4' BASE MAT FOR SHIELDING	THICKER STRUCTURAL BASE MAT	DELAYS MELT-THRU
CORE DEBRIS AND SUMP LIQUIDS IMMEDIATELY CONTACT BASIN WATER	CONTACT WITH GROUND WATER DELAYED FOR A FEW MONTHS (SANDIA REPORT)	DELAYS TRANSPORT TO DOSE PATHWAYS
WATER FLOW RATES OF ORDER OF A FEW CM/SEC	GROUND WATER FLOW RATES MUCH SLOWER	MARKED DELAY IN TRANSPORT TO DOSE PATHWAYS
LIMITED CONTACT BETWEEN RADIOACTIVITY IN WATER COLUMN AND SOIL	SIGNIFICANT CONTACT BETWEEN SOIL AND RADIOACTIVE SPECIES	MARKED DELAY IN TRANSPORT TO DOSE PATHWAYS
TIME IS NEEDED TO ASSURE SOURCE ISOLATION	SUFFICIENT TIME FOR SOURCE ISOLATION AT MOST SITES	ISOLATION OF LIQUID PATHWAYS SOURCE FEASIBLE FOR MOST LAND BASED PLANTS

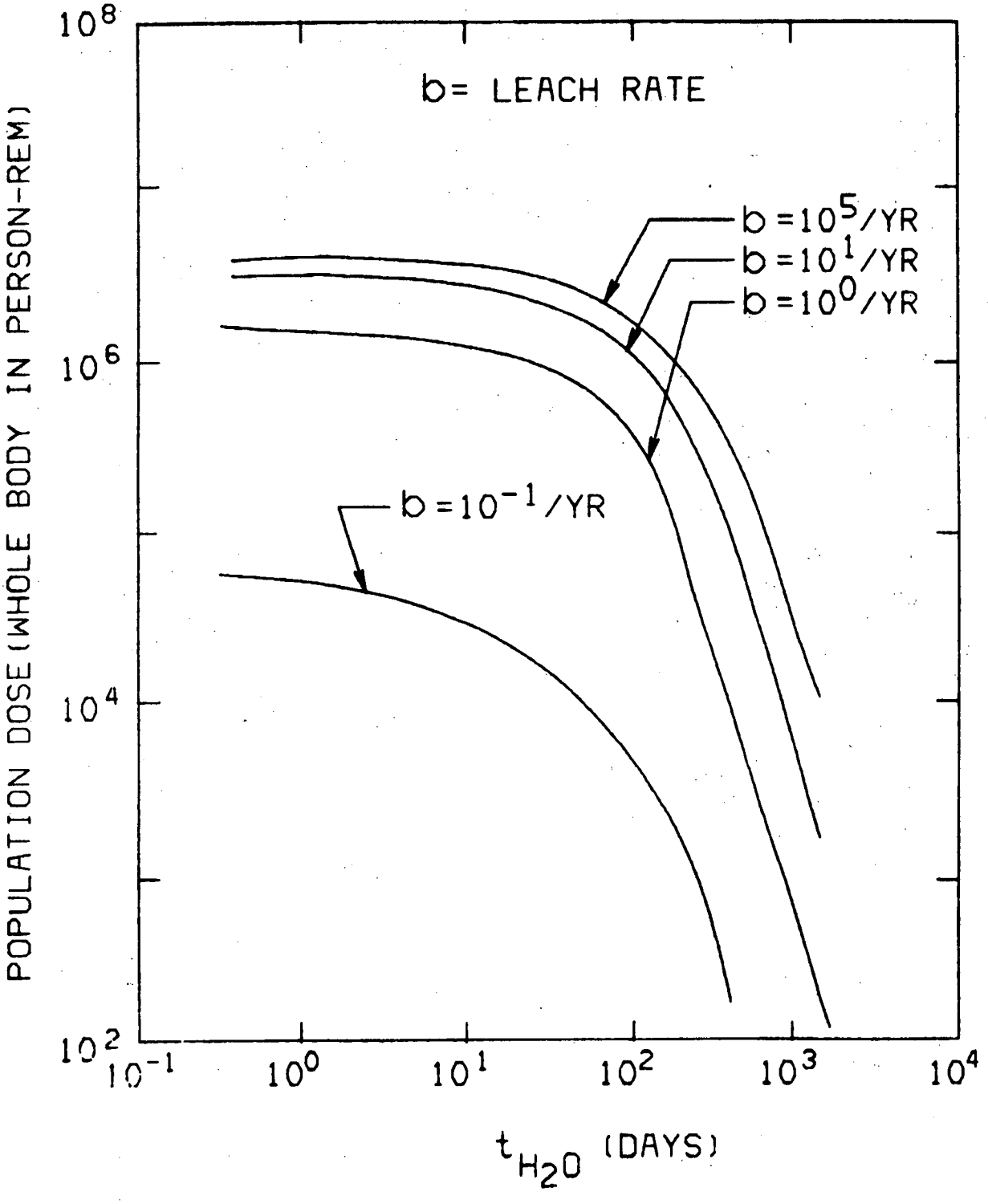
TYPICAL TIMES FOR MELT-DOWN PROCESSES - LAND BASED PLANTS

PROCESS	APPROXIMATE TIME FRAME
VESSEL MELT-THRU	A FEW HOURS TO A DAY
BASE MAT MELT-THRU	10 HOURS TO A FEW WEEKS (OR PERHAPS MORE)
COOLING OF CORE DEBRIS SUFFICIENT FOR GROUND WATER CONTACT (SANDIA REPORT)	A FEW MONTHS TO A FEW YEARS
COOLING OF CORE DEBRIS SUFFICIENT FOR SUMP LIQUIDS TO ESCAPE TO SOIL	WEEKS TO A FEW MONTHS

CONCLUSION - LAND BASED PLANTS

DELAY OF CORE MELT-THRU FOR A FEW DAYS BY A CORE LADLE DOES NOT SIGNIFICANTLY LENGTHEN TIME FOR SOURCE RELEASE TO GROUND WATER.

POPULATION DOSE AS A FUNCTION
OF AQUIFER TRANSPORT TIME
(FOR A LARGE LAKE)



DEBRIS BED COOLING ON BASE MAT

	EFFECT OF COOLING
H_2 PRODUCTION	RATE OF H_2 PRODUCTION VIA OXIDATION OF IRON BY STEAM FROM CONCRETE IS REDUCED; SOME OF IRON IN DEBRIS COULD BE OXIDIZED BY COOLING WATER PRODUCING H_2
NON-CONDENSIBLE GAS GENERATION	QUANTITY OF NON-CONDENSIBLE GASES GENERATED WILL BE REDUCED AND TIME OF GENERATION DELAYED.
CONTAINMENT SOURCE TERM	PROBABLY REDUCED BUT NOT BY LARGE FACTOR.
AIR PATHWAYS RELEASE	CONTAINMENT FAILURE MAY BE ELIMINATED; OR FAILURE TIME PROLONGED PERMITTING DECAY AND REDUCED SOURCE TERM.
LIQUID PATHWAYS RELEASE	LIQUID PATHWAYS RELEASE MAY BE ELIMINATED; IF MELT THROUGH OCCURS LITTLE EFFECT ON QUANTITY OF RADIOACTIVITY RELEASED TO AQUIFER.

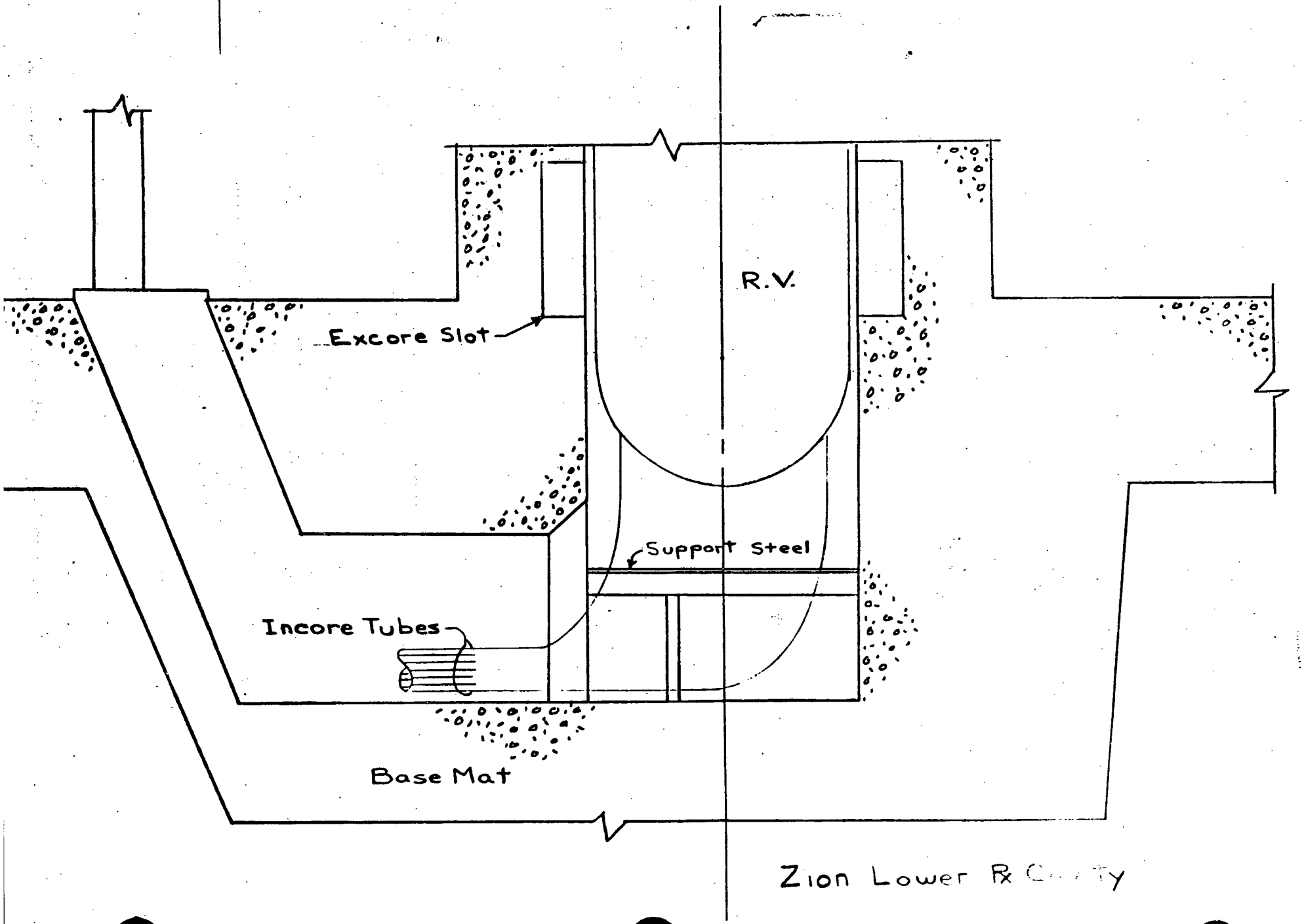
CONCLUSION

- DEBRIS BED COOLING ON BASE MAT APPEARS TO BE AT LEAST AS EFFECTIVE IN RISK REDUCTION AS A CORE LADLE

- DEBRIS BED COOLING IS
  - A SIMPLE CONCEPT
  - UTILIZES EXISTING PLANT DESIGN FEATURES WITH A FEW DESIGN MODIFICATIONS

- DEBRIS BED COOLING IS PREFERRED UTILITY APPROACH FOR CORE MELT DEBRIS CONTROL

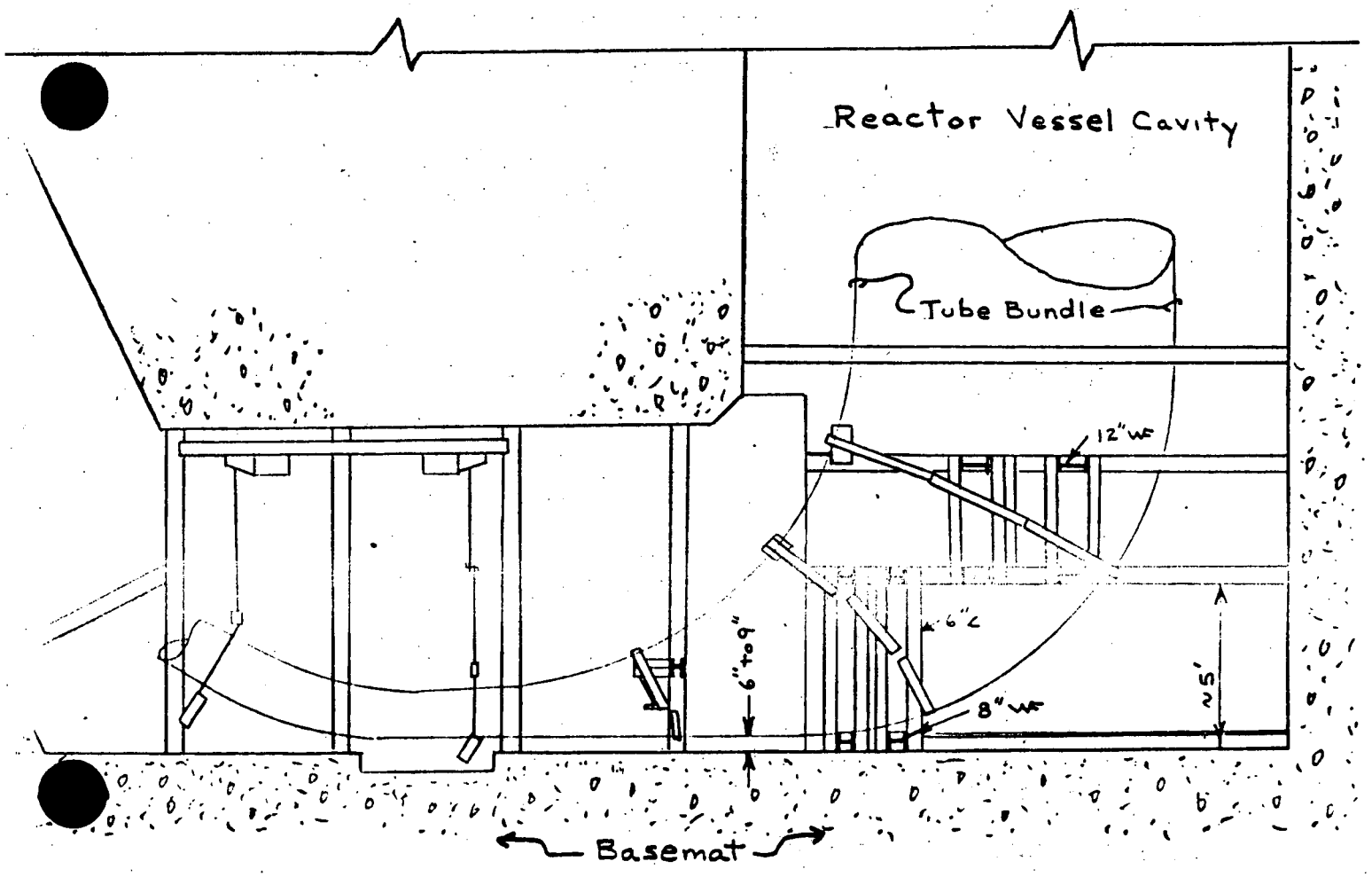
ATTACHMENT 3

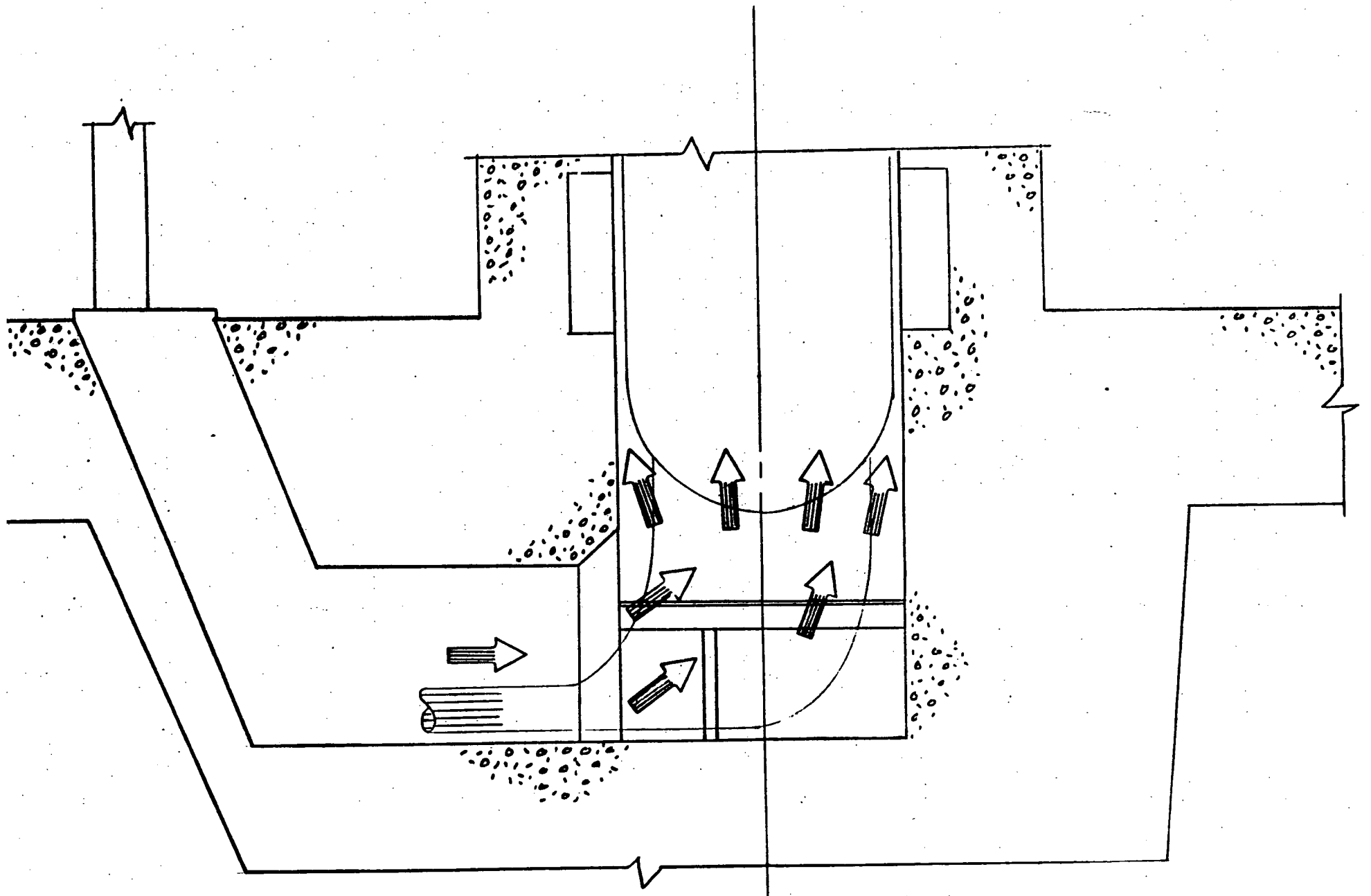


Zion Lower Rx Cavity

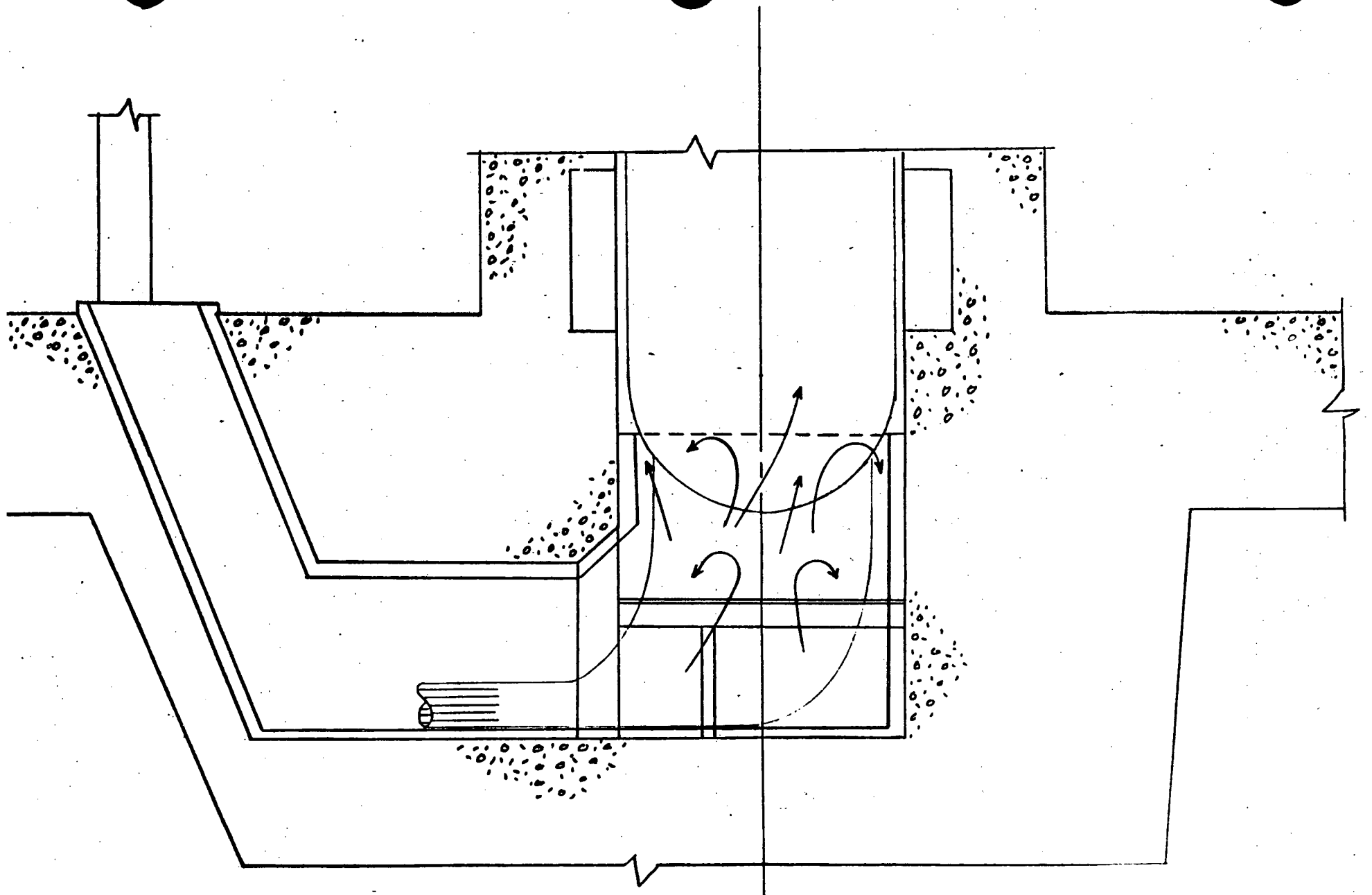
126

Zion Vessel Cavity Showing Incore Tubes
& Tube Bundle Seismic Support Steel





Zion Lower Cavity
Showing Critical Air
Flow



Effect o[illegible] Liner
on Critic[illegible] Flow

ATTACHMENT 5

130

COMMENTS ON

DEBRIS BED COOLABILITY

R. E. HENRY

CORE COOLABILITY

1. CHF CRITERION - VAPOR REMOVAL RATE UPWARD MUST NOT PRECLUDE LIQUID RETURNING TO THE SURFACE

$$- \quad Q/A = 0.14\, H_{fg}\sqrt{\rho_g}\left[g\sigma\left(\rho_f - \rho_g\right)\right]^{1/4}$$

II. DEBRIS BED LIMITATION - PRESSURE GRADIENT INDUCED BY VAPOR FLOW THROUGH THE BED MUST NOT EXCEED THE STATIC HEAD OF THE LIQUID. THIS LIMITATION APPLIES AT THE TOP OF THE BED SINCE THIS IS THE LOCALE OF MAXIMUM VAPOR VELOCITY.

$$- \frac{dP}{dZ} = 2\, C_f \frac{\rho_g J_g^2}{D} \quad \frac{1-\epsilon}{\epsilon^3} < \rho_f g$$

$$C = \frac{75}{R_E} + 0.875$$

$$R_E = \frac{\rho_g J_g D}{(1-\epsilon)\mu_g} \qquad J_g = \frac{Q}{\rho_g A\, H_{fg}}$$

PARTICLE BED DRYOUT MODELS

1. <u>60 DAY STUDY</u>

$$Q/A = H_{FG}\left[\frac{g\rho_{FG}\rho_G D\epsilon^3}{2C_F(1-\epsilon)}\right]^{1/2} \qquad C_F = \frac{75}{N_{Re}} + 0.875 \qquad N_{Re} = \frac{\rho_G J_G D}{\mu G}$$

SMALL PARTICLE APPROXIMATION

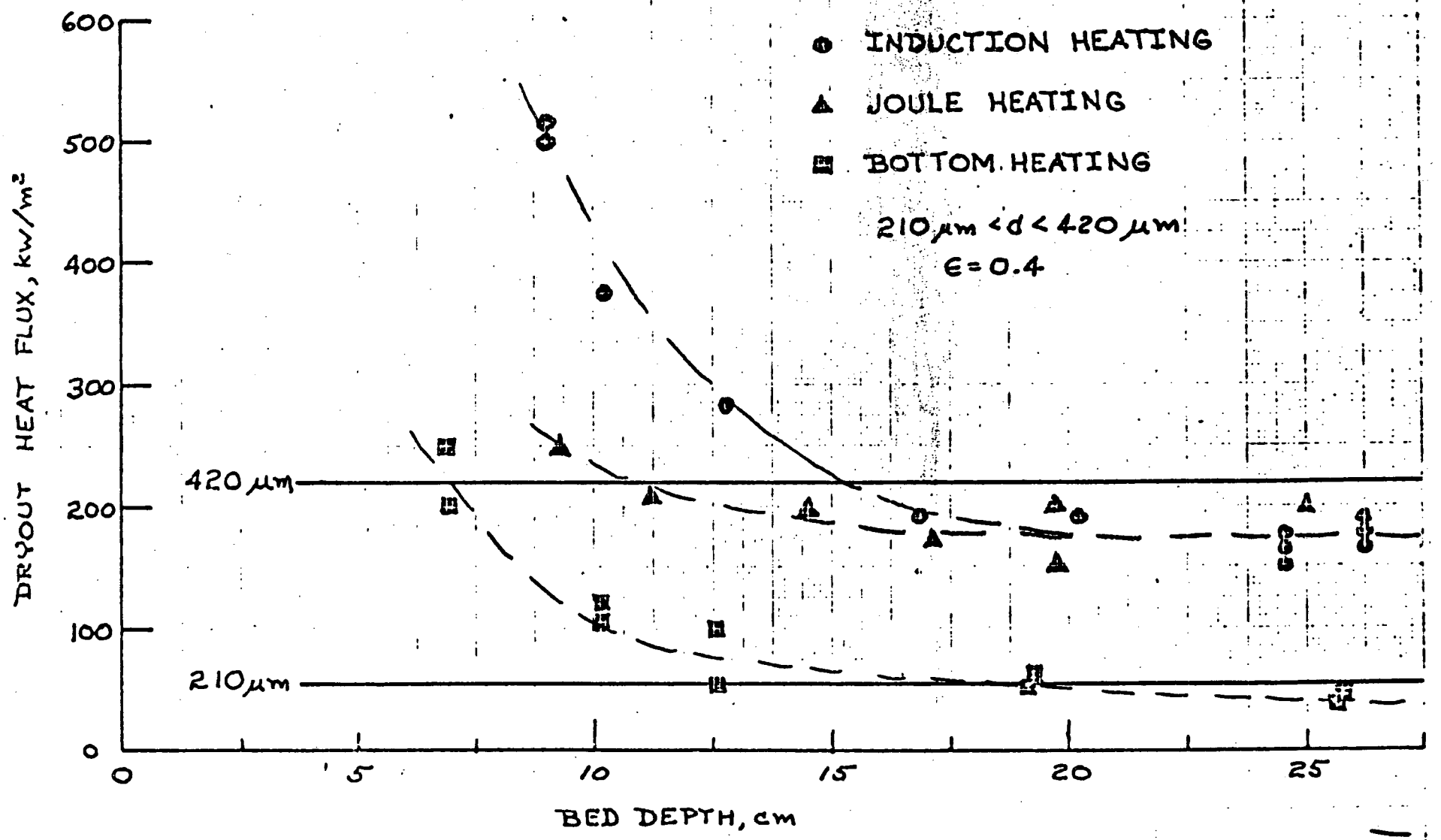
$$Q/A = \frac{g\rho_F}{\nu_G} H_{FG} \cdot \frac{D^2\epsilon^3}{150(1-\epsilon)^2}$$

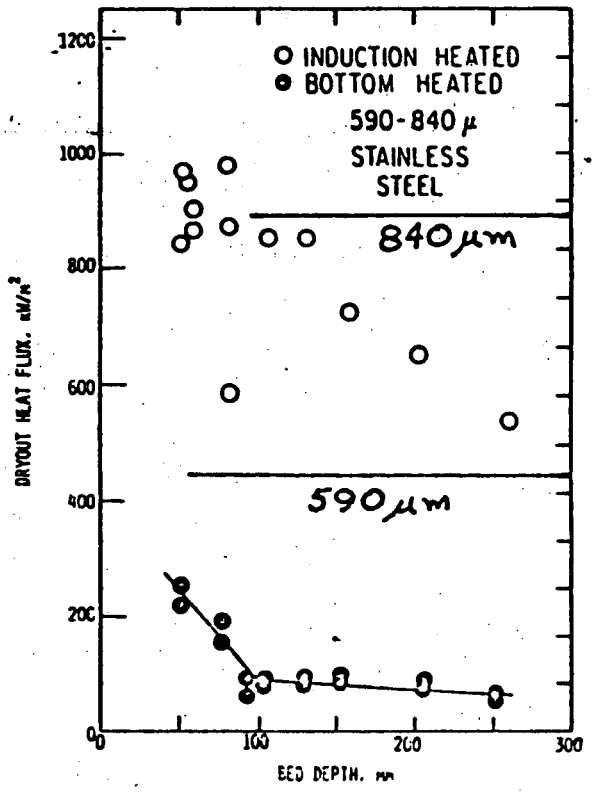
2. <u>HARDEE & NILSON</u>

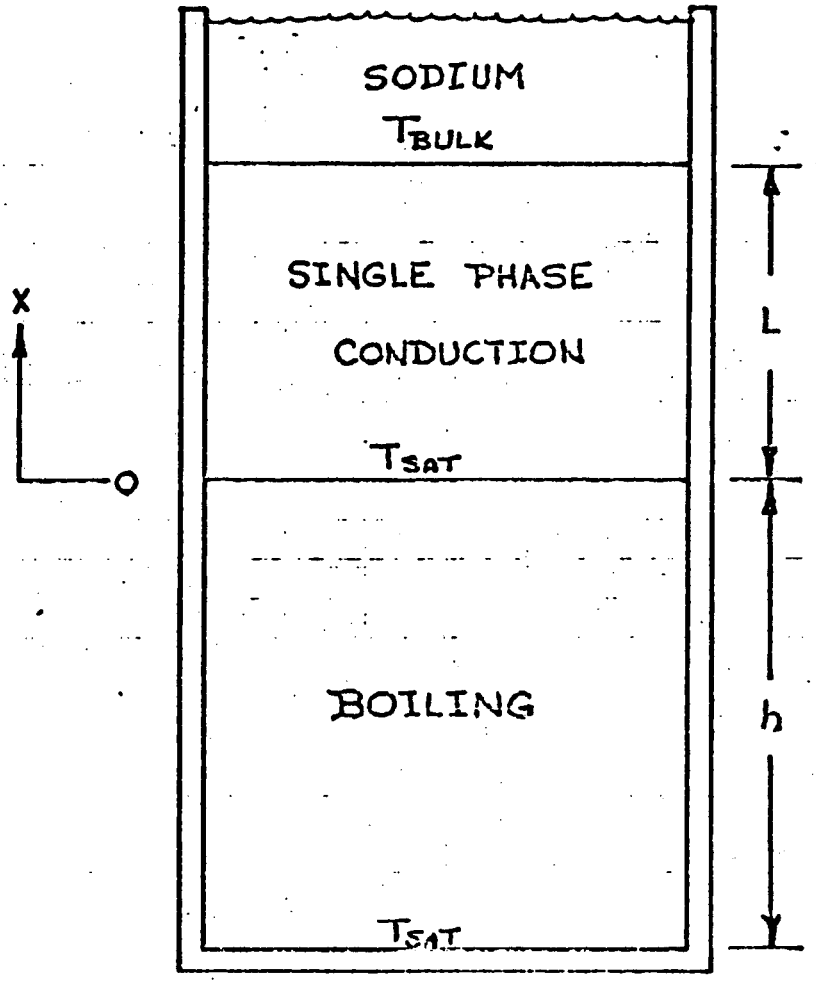
$$Q/A = \frac{g\rho_F H_{FG}}{\left[\sqrt{\nu_G} + \sqrt{\nu_F}\right]^2} \cdot \frac{D^2\epsilon^3}{180(1-\epsilon)^2}$$

3. <u>DHIR & CATTON</u>

$$Q/A = 0.0177\frac{g\rho_F H_{FG}}{\nu_F}(1 - \rho_G/\rho_F) \cdot \frac{D^2\epsilon^3}{180(1-\epsilon)^2}$$


INDUCTION HEATING
JOULE HEATING
BOTTOM HEATING
210 μm < d < 420 μm
ε = 0.4
420 μm
210 μm
DRYOUT HEAT FLUX, kW/m²
BED DEPTH, cm
0
100
200
300
400
500
600
0
5
10
15
20
25


INDUCTION HEATED
BOTTOM HEATED
590-840 μ
STAINLESS
STEEL
840μm
590μm
DRYOUT HEAT FLUX, kW/m²
BED DEPTH, mm
0
200
400
600
800
1000
1200
100
300



ASSUMED CONFIGURATION

CONDUCTION IN SINGLE PHASE REGION

$$-K \frac{D^2T}{DX^2} = \dot{Q}$$

BOUNDARY CONDITIONS

1) $x = 0,\ T = T_{SAT}$ 2) $x = 0,\ \frac{DT}{DX} = -\frac{Q_1}{KA}$

$Q_1 = \dot{M}_V H_{FG}$

$$\frac{DT}{DX} = C_1 - \frac{\dot{Q}X}{K} \qquad C_1 = -\frac{Q_1}{KA}$$

$$T = -\frac{\dot{Q}X^2}{2K} - \frac{Q_1 X}{KA} + C_2$$

$$T_{SAT} - T = \frac{\dot{Q}X^2}{2K} - \frac{Q_1 X}{KA}$$

EFFECTIVE $K = 31\ W/M^{O}K$

AT $x = L,\ T = T_{BULK}$

THIS MUST THEN BE COUPLED WITH THE TWO-PHASE ZONE

IN-PILE PARTICLE BED DRYOUT TESTS UO_2 AND SODIUM

Run	Bed Depth mm.	Sodium Bulk Temp. °K	Dryout Power Level Measured w/kg	Dryout Power Level Predicted w/kg
D-1	58	673		2730
D-2	106	673	760	748
D-3	158	673	430	432
D-3	158	773	410	400

CONDITIONS EVALUATED
TIME INTO THE ACCIDENT - 4 HRS.

	ZION	IP-2	IP-3
TOTAL DECAY POWER (MW)	28.6	24.3	26.7
DECAY POWER IN MELT (MW)	19.1	16.2	17.8
SURFACE AREA (M^2)	54.0	39.1	39.1
REQUIRED HEAT FLUX (KW/M^2)	354	414	455
COOLABLE PARTICLE SIZE, μ M (ϵ = 0.5)			
0.1 MPA	320	374	411
0.2 MPA	254	297	327
0.5 MPA	183	214	235

CONSERVATISMS IN SANDIA ANALYSES

1. USED TOTAL DECAY POWER AT ANY GIVEN TIME AS OPPOSED TO THE DECAY POWER IN THE MELT.

2. USED 100% OF THE CORE MATERIAL IN FINELY FRAGMENTED FORM AND RETAINED IN THE CAVITY AND KEYWAY.

3. IN NON-DISPERSED ANALYSIS, ASSUMED FINELY FRAGMENTED MATERIAL WAS RETAINED ONLY WITHIN THE CAVITY REGION.

4. ASSUMED A VERY TIGHTLY PACKED BED, $\epsilon = 0.4$.

FRAGMENTATION MECHANISMS

1. HYDRODYNAMIC - ONLY SIGNIFICANT IN THE CASE OF A STEAM EXPLOSION.

2. VIOLENT BOILING - REQUIRES DIRECT CONTACT.

3. RAPID GAS RELEASE - REQUIRES DIRECT CONTACT.

4. THERMAL STRESS - REQUIRES DIRECT CONTACT.

5. CAVITATION - REQUIRES PRESSURE DRIVEN SPHERICAL BUBBLE COLLAPSE, ONLY RELATES TO MATERIAL INVOLVED IN THE EXPLOSION.

6. BUBBLE COLLAPSE - REQUIRES EITHER LARGE SUBCOOLING OR PRESSURE DRIVEN COLLAPSE, ONLY RELATES TO MATERIAL INVOLVED IN THE EXPLOSION.

MAXIMUM COOLABLE SIZE

$$\frac{\dot{Q}R^2}{6K} = -\frac{D}{DR}\left(R^2 \frac{DT}{DR}\right)$$

$$\frac{\dot{Q}R^2}{6K} = T_M - T_S$$

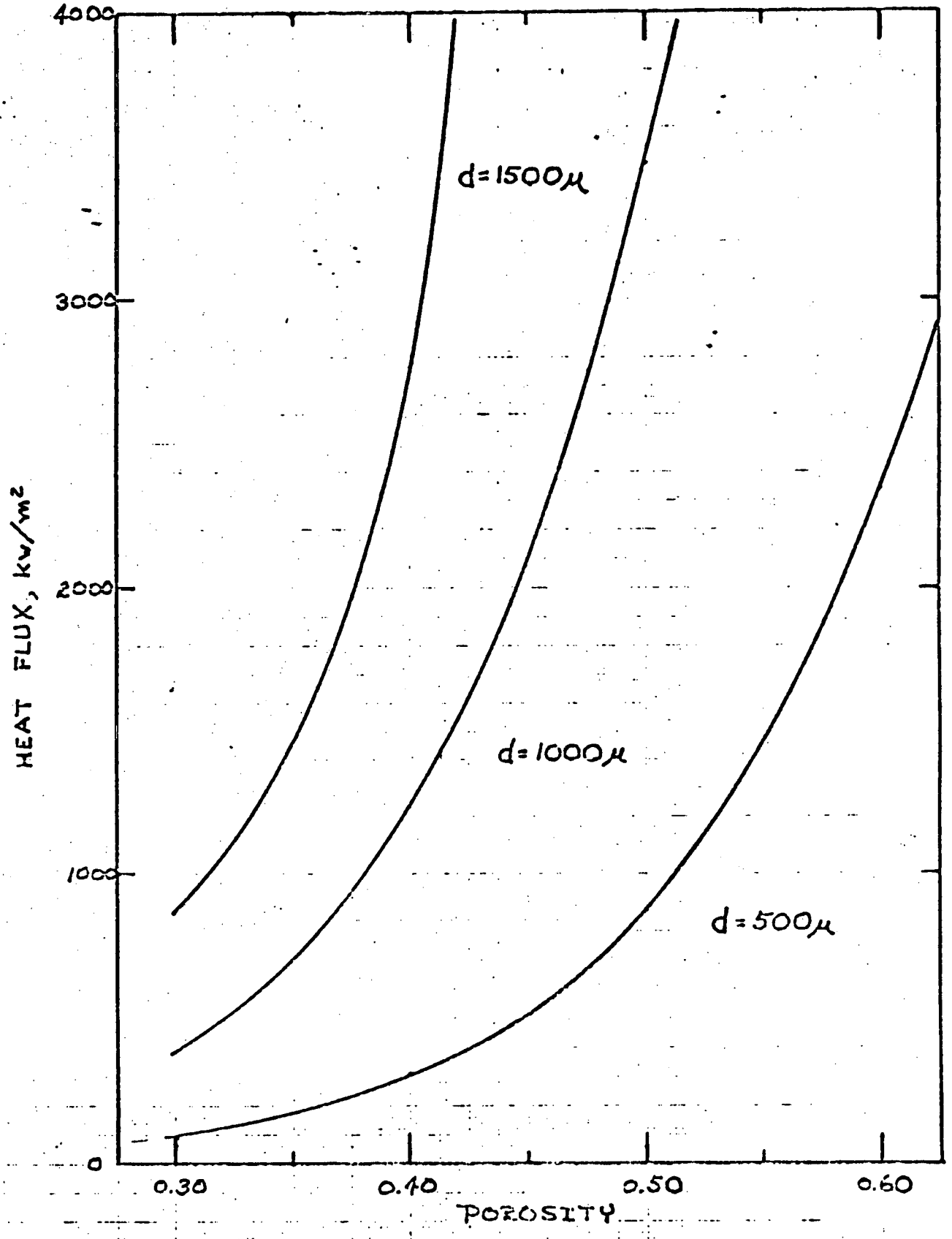
$$R = \left\{\frac{6K\,(T_M - T_S)}{\dot{Q}}\right\}^{1/2}$$

$T_M = 2800°C$ $\qquad$ $T_S = 100°C$

$K = 0.0025$ KW/M°C $\qquad$ $Q = 2550$ KW/M^3 (30 MW)

$R = 13$ CM $\qquad$ $D = 26$ CM $= 10$ IN.

- THIS SIZE IS PERMANENTLY COOLABLE -

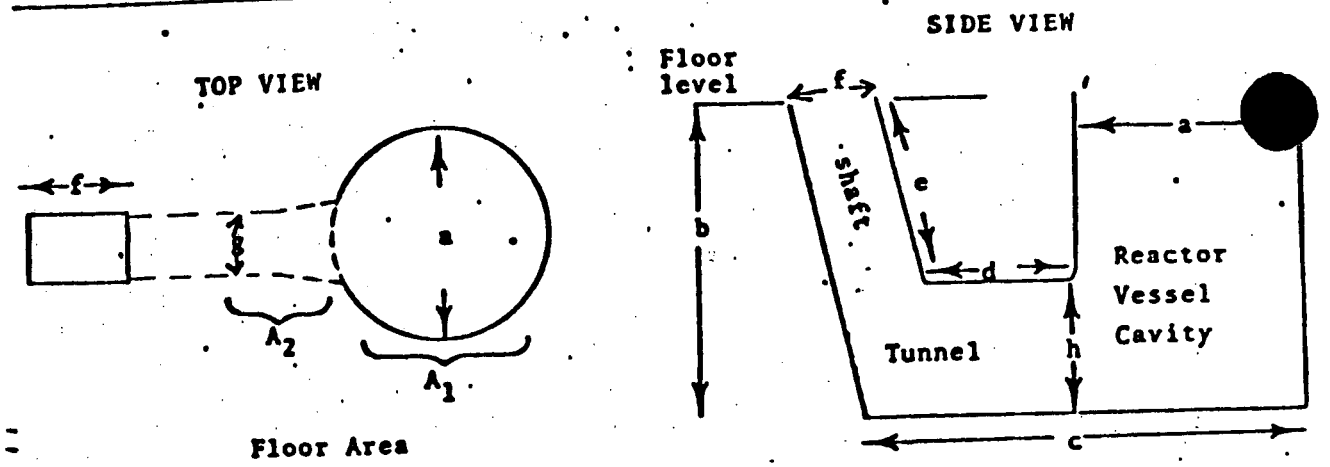

4000
3000
2000
1000
0
HEAT FLUX, kw/m²
d=1500μ
d=1000μ
d=500μ
0.30
0.40
0.50
0.60
POROSITY

EX-VESSEL CORE COOLABILITY

	Zion	Indian Point
Decay Power	30 Mw	30 Mw
Floor Area - Reactor cavity & instrument tunnel	53.6 m^2	39.1 m^2
Required Heat Flux	560 kw/m^2	767 kw/m^2
Critical Heat Flux		
0.1 MPa	1131 kw/m^2	
0.2 MPa	1515 kw/m^2	
0.3 MPa	1794 kw/m^2	

- No Heat Flux Limitation -

Table 1. Dimensions of Reactor Vessel Cavity and Instrumentation Shaft



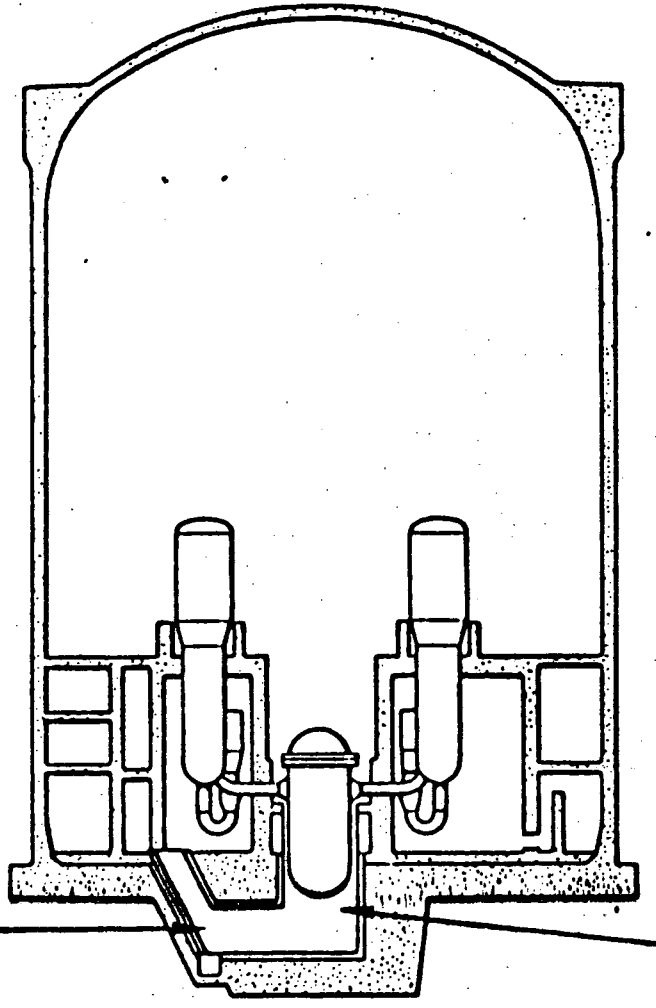
(Dimension in ft or ft^2)

Parameters	Zion I	Indian Point 2 & 3
a	21.0	20.0
b	26.0	27.0
c	48.0	40.0
d	23.0	17.0
e	22.0	18.0
f	11.0	10.0
g	7.0	7.0
h	13.0	10.0
A_1	350	300
A_2	230	120
$A_1 + A_2$	580	420

Table 2. Summary of Bed Debris Characteristic and Coolability

	Zion I	Indian Pt. 2	Indian Pt. 3
Core Full Power (MW)	3250	2760	3030
Fuel UO_2 (lbm)	217,000	217,000	216,000
Zircaloy (lbm)	44,500	44,500	42,000
Total Core Debris (lbm)	260,000	260,000	260,000
Bed Depth (ft)			
Porosity 0%	1.0[a]--1.7[b]	1.3--1.8	1.3--1.8
50%	2.0--3.3	2.7--3.6	2.7--3.6
75%	4.0--6.7	5.4--7.3	5.4--7.3
Req. Heat Flux @			
1% full power	191,000[a]	224,000	246,000
(Btu/hr-ft^2)	318,000[b]	313,000	344,000
Peak Heat Flux (Btu/hr-ft^2)			
Pressure 1 atm	352,000	352,000	352,000
2 atm	468,000	468,000	468,000
3 atm	535,000	535,000	535,000

Note: [a]Based on cavity area A_1 plus tunnel area A_2
[b]Based on cavity area A_1 only



ZION REACTOR BUILDING

STEAM SPIKE

$$R_1 = \sqrt{\alpha T} \qquad T = R^2/\alpha$$

$$Q = M_F C_P \Delta T \qquad U_G = \frac{Q}{T H_{FG} \rho_G A}$$

LEVITATION OF FUEL PARTICLE

$$(\rho_F - \rho_G)\ 4/3\pi R^3 G = C_D(\pi R^2)\frac{\rho_G U_G^2}{2} \qquad C_D = 0.5$$

$$R_2 = \frac{3}{16}\frac{\rho_G U_G^2}{FG}$$

ASSUME P = 0.3 MPA $\qquad \rho_G = 1.65\ \text{KG/M}^3$

A. AREA = 54 M^2

R_1 M	T SEC	U_G M/SEC	R_2 M
3×10^{-4}	0.2	3600	506
10^{-3}	2.0	320	4
→ 5×10^{-3}	51	12.8	6.4×10^{-3}
10^{-2}	204	3.2	4×10^{-4}

B. AREA = 8.5 M^2

R_1 M	T SEC	U_G M/SEC	R_2 M
5×10^{-3}	51	80	0.25
→ 10^{-2}	204	20	1.6×10^{-2}
1.5×10^{-2}	459	8.9	3.1×10^{-3}

NRC PRESENTATION:

CORE RETENTION DEVICES

JUNE 3, 1980

STAFF VIEWS

ON

CORE RETENTION SYSTEMS

PRESENTED BY
ANDREW R. MARCHESE
U.S. NUCLEAR REGULATORY COMMISSION

PRESENTED JUNE 3, 1980
THE Z/IP TECHNOLOGY EXCHANGE MEETING,
BETHESDA, MARYLAND

STAFF VIEWS ON CORE RETENTION SYSTEMS

- GENERAL CONCERNS OF LICENSING STAFF
- GENERAL GUIDANCE ON PROTECTION AGAINST CORE MELT
- WHY CORE RETENTION SYSTEMS MUST BE CONSIDERED
- KEY UNCERTAINTIES IN PHENOMENA AND CORE MELT SEQUENCES
- PROBLEMS ASSOCIATED WITH CORE/CONCRETE INTERACTIONS
- PRELIMINARY GENERAL DESIGN CRITERIA FOR CORE RETENTION SYSTEM
- INFORMATION NEEDS FROM Z/IP PROJECT
- NRC'S FUTURE DIRECTION OF CORE RETENTION SYSTEM WORK

GENERAL CONCERNS OF LICENSING STAFF

- Emphasis Should be Given to:
  - Preventing Core Melt and to
  - Dealing with Core Melt
- Too Much Dependence on Concrete; Causes Additional Problems
- Proposed Conclusions on Core Melt Consequences now Based Largely on Unverified Models

GENERAL CONCERNS OF LICENSING STAFF (CONT.)

- Materials that are Compatible with Core Debris need Emphasis
- Burden of Proof is on Developers/Designers, yet NRC Research is now Leading Contributor to Technology in the U.S.
- Developers/Designers Need to Consider:
  - Increased Interest in Core Melt Accidents
  - Potential Significant Delay and Increased Costs Due to Lack of Information and Resolution
  - Dealing with Core Melt now can have Significant Future Payoff

GENERAL GUIDANCE

- Reduce Core Melt Accident Probability to Justify Exclusion from Design Basis Accident Spectrum
- Take Additional Measures to Limit Consequences and Reduce Risks from Core Melt Accident
- Basic Approach Should be to Preserve Containment System Integrity for a Core Meltdown Accident

GENERAL GUIDANCE (CONT.)

- Incorporate Engineering Conservatisms in Design and its Evaluation so there is Extremely Low Likelihood that Core Melt Could Result in Containment Failure

- Reduce Possibility and Extent of Hydrogen Producing Reactions, and Other Potential Overpressurization Reactions

- Protect Against Containment Failure by Hydrogen Burning or Explosions

WHY CORE RETENTION SYSTEMS MUST BE CONSIDERED

- DO NOT KNOW PRECISE SEQUENCE OF EVENTS DURING CORE MELTDOWN
- NEED TO CONSIDER A RANGE OF CORE MELT SCENARIOS
- NEED TO ENVELOPE UNCERTAINTIES IN PHENOMENA AND CORE MELT SEQUENCES
- CORE DEBRIS MAY NOT BE COOLABLE
  - -- EITHER FINE FRAGMENTATION OR UNDISPERSED CORE DEBRIS COULD PRECLUDE COOLABILITY
  - -- LOSS OF POWER OR LOSS OF HEAT SINK WOULD PRECLUDE MAINTAINING A COOLABLE DEBRIS BED
- NEED TO CONSIDER CORE DEBRIS IN A MOLTEN POOL FORM ATTACKING CONCRETE

KEY UNCERTAINTIES IN PHENOMENA & CORE MELT SEQUENCES

- MANNER AND MECHANISMS FOR SLUMPING OF CORE MATERIAL FROM CORE REGION TO LOWER VESSEL HEAD
- MODES OF RV LOWER HEAD FAILURE
  - -- SMALL LOCAL FAILURE RESULTING IN SLOW DEPRESSURIZATION
  - -- MASSIVE HEAD FAILURE RESULTING IN RAPID DEPRESSURIZATION
- DATA BASE ON DEBRIS FRAGMENTATION, DISPERSAL AND DEEP BED DRYOUT PHENOMENA IS INSUFFICIENT TO CONFIRM COOLABILITY
- CONSIDERABLE UNDERTAINTY IN INITIAL CONDITIONS OF CORE MELT MATERIAL IN REACTOR CAVITY

PROBLEMS ASSOCIATED WITH CORE/CONCRETE INTERACTIONS

- INCREASES PRESSURE IN CONTAINMENT VIA SIGNFICANT GAS AND VAPOR GENERATION
- INCREASES H_2 AND OTHER COMBUSTIBLE GAS (E.G., CO & CH_4) CONCENTRATIONS IN CONTAINMENT
- GAS SPARGING OF ACTIVITY OUT OF CORE MELT DEBRIS
  (TE RELEASE IS A SIGNIFICANT CONCERN BECAUSE OF INCREASED AIRBORNE RELEASE)
- INCREASES AEROSOLS IN CONTAINMENT
- INCREASES LOADING CONDITIONS ON A VENT-FILTER SYSTEM OR H_2 CONTROL SYSTEM
- PENETRATION OF CONTAINMENT BASEMENT MAY LEAD TO LIQUID PATHWAY PROBLEMS
  OR PUBLIC CONFUSION OR HYSTERIA

PRELIMINARY GENERAL DESIGN CRITERIA FOR CORE RETENTION SYSTEM

- DESIGN FOR FULL CORE MELTDOWN, ONE (1) HOUR AFTER REACTOR SHUTDOWN
- DESIGN FOR PERMANENT RETENTION OF CORE DEBRIS
- PROTECT CONCRETE WITH A REFRACTORY MATERIAL THAT DOES NOT GENERATE GASES WHEN IT INTERACTS WITH MOLTEN CORE DEBRIS
- PROVIDE A COOLING SYSTEM TO DISSIPATE HEAT TRANSFERRED TO REFRACTORY MATERIAL (NATURAL & FORCED CONVECTION WILL BE CONSIDERED)
- PREVENT CORE DEBRIS ATTACK OF CONCRETE
- VENT GAS AND VAPOR GENERATION FROM CONCRETE (I.E., ELIMINATE SPARGING)
- INCORPORATION OF CORE RETENTION SYSTEM SHALL NOT COMPROMISE DESIGN BASIS SAFETY REQUIREMENTS

INFORMATION NEEDS FROM Z/IP PROJECT

- MUCH MORE DETAILED INFORMATION ON LOWER REACTOR CAVITY SITUATION
- VISITS TO Z/IP PLANTS BY A TEAM OF CORE MELT SPECIALISTS
- DETAILED EVALUATION OF PROBLEMS ASSOCIATED WITH BACKFITTING A CORE RETENTION DEVICE INTO THE Z/IP PLANTS
- SPECIFIC CONCEPTUAL DESIGNS OF CORE RETENTION SYSTEMS FOR Z/IP PLANTS

NRC'S FUTURE DIRECTION OF CORE RETENTION SYSTEM WORK

- ACTIVELY PURSUING CORE RETENTION SYSTEMS FOR Z/IP, AS WELL AS FOR FNPs AND THE TMI TASK ACTION PLAN, WHICH INCLUDES RULEMAKING FOR ALL LWRs
- INVESTIGATING BOTH PASSIVE AND ACTIVE CORE RETENTION SYSTEMS
- WILL CONSIDER VARIOUS MATERIALS, GEOMETRICAL CONFIGURATIONS AND COOLING ARRANGEMENTS (I.E., NATURAL AND FORCED)
- WILL CONSIDER THE SPECIAL PROBLEMS ASSOOCIATED WITH BACKFITTING INTO EXISTING LWRs
- INTEGRATE THIS WORK WITH OTHER MITIGATION FEATURES TO DETERMINE SYSTEMS INTERACTIONS AND OVERALL REDUCTION IN CONSEQUENCES
- CONSIDERABLE CORE MELT RESEARCH PROGRAM

NRC CORE RETENTION RESEARCH

- NRR USER NEEDS REQUESTS
  - CRBR (1976)
  - FNP + GENERIC (APRIL 79, SEPTEMBER 79)
- IMPROVED SAFETY PROGRAM (NUREG 0438)
- ACRS RECOMMENDATIONS
  - DECEMBER 78; JULY 79; FEBRUARY 80
- TMI ACTION PLAN

NRC CORE RETENTION RESEARCH

- SCOPING EXPERIMENTS (200 KG MOLTEN STEEL; FEW HRS.)
  - REFRACTORY (MgO, UO_2, HIGH-ALUMINA-CEMENT)
  - SACRIFICIAL (BORAX, BASALT, METALS)
- LABORATORY SCALE AND SEPARATE EFFECTS
  - EROSION RATE (MgO)
  - ATTACK MECHANISMS (MgO)
- IN-PILE PILE SUPPORTING EXPTS.
- ENGINEERING TESTS (200 Kg MOLTEN UO_2 & CORIUM) - FUTURE

NRC CORE RETENTION RESEARCH

CONCEPTUAL DESIGN STUDIES

- OBJECTIVE
  - IDENTIFY REQ'TS FOR MOLTEN CORE RETENTION CONCEPTS
  - ASSESS FEASIBILITY, PRACTICALITY, RISK REDUCTION VALUE AND IMPACTS
- SCOPE
  - FUNCTIONAL/DESIGN REG'TS
  - CONCEPTUAL DESIGNS
  - RISK-COST COMPARISIONS
  - ENGINEERING ASSESSMENTS (SYSTEM INTERACTIONS)

NRC CORE RETENTION RESEARCH

CONCEPTUAL DESIGN STUDIES

- SCHEDULE
  - START FY 80 (4TH Q.)
  - PRELIMINARY RESULTS (DECEMBER 1980)
  - IDENTIFY RESEARCH TO CONFIRM FEASIBILITY, REQ'TS (FY 81)
  - COMPLETE STUDY FY 82

165

POST ACCIDENT HEAT REMOVAL
DEBRIS BED DRYOUT
CORE CATCHER DESIGN

IVAN CATTON

UNIVERSITY OF CALIFORNIA, LOS ANGELES

DEBRIS BED DRYOUT

GOVERNING PHYSICAL PROCESSES

BOUYANCY DRIVEN COUNTER CURRENT TWO PHASE FLOW IN A POROUS MEDIUM WITH PHASE CHANGE DRIES OUT WHEN THE LIQUID PHASE CANNOT REACH ALL PORTIONS OF THE BED.

MAJOR UNCERTAINTIES

THE EFFECT OF PARTICLE SIZE DISTRIBUTION ON THE BED PERMEABILITY IS NOT FULLY UNDERSTOOD.

THE EXPECTED DEBRIS BED PARTICLE SIZE DISTRIBUTION IS ONLY KNOWN TO WITHIN RATHER LARGE TOLERANCES.

IT IS NOT KNOWN HOW MUCH OF THE CORE WILL MELT AND BECOME PART OF THE DEBRIS BED NOR IS IT KNOWN HOW MUCH STEEL NEEDS TO BE INCLUDED AS A NON-HEAT GENERATING CONSTITUENT.

PARTICLE SIZE STRATIFICATION IS KNOWN TO OCCUR BUT ITS EFFECT IS NOT QUANTIFIED.

IT IS NOT KNOWN HOW MUCH DEBRIS BED SELF-LEVELING WILL OCCUR.

REFERENCES TO DEBRIS BED DRYOUT WORK

1. GABOR, J.D., E.S. SOWA, L. BAKER JR., AND J.C. CASSULO, "STUDIES AND EXPERIMENTS ON HEAT REMOVAL FROM DEBRIS IN SODIUM" PROC. OF ANS FAST REACTOR SAFETY CONFERENCE, BEVERLY HILLS, CONF-740401, P. 823, 1974.
2. DHIR, V.K. AND I. CATTON, "PREDICTION OF DRYOUT HEAT FLUXES IN BEDS OF VOLUMETRICALLY HEATED PARTICLES" PROC. OF FAST REACTOR SAFETY CONF., CHICAGO, CONF-761001, P. 2026, 1976.
3. SOWA, E.S., J.D. GABOR, L. BAKER JR., J.R. PAVLIK, J.C. CASSULO AND W. HOLLOWAY, "STUDIES OF THE FORMATION AND COOLING OF PARTICULATE FUEL DEBRIS BEDS IN SODIUM" PROC. OF FAST REACTOR SAFETY CONF., CHICAGO, CONF-761001, P. 2036, 1976.
4. DHIR, V.K., I. CATTON AND W.E. KASTENBERG, "STUDY OF DRYOUT HEAT FLUXES IN BEDS OF INDUCTIVELY HEATED PARTICLES" NUREG-0262, 1977.
5. DHIR, V.K. AND I. CATTON, "DRYOUT HEAT FLUXES FOR INDUCTIVELY HEATED PARTICLE BEDS" J. HEAT TRANSFER, VOL. 99, PP. 251-256, MAY 1977.
6. GABOR, J.D., E.S. SOWA, J.R. PAVLIK AND J.C. CASSULO, "PARTICULATE BED FORMATION AND PHENOMENA" ANL-7810, P. 74, 1978.
7. DHIR, V.K. AND I. CATTON, "THE EFFECT OF PARTICLE SIZE DISTRIBUTION AND NONHEATED CONSTITUENTS ON DEBRIS BED DRYOUT" ANL-78-10, 1978.
8. RIVARD, J.B., "PRELIMINARY RESULTS FROM INITIAL IN-PILE

DEBRIS BED EXPERIMENTS" ANL-78-10, 1978.

9. LE RIGOLEUR, C., "PARTICLE BED DRYOUT IN SODIUM", FOURTH PAHR INFORMATION EXCHANGE MEETING, ISPRA ITALY, OCTOBER 1978.

10. LIPINSKI, R.J. AND J.B. RIVARD, "DEBRIS BED HEAT REMOVAL MODELS: BOILING AND DRYOUT WITH TOP AND BOTTOM COOLING" PROC. OF THE INT. MEETING ON FAST REACTOR SAFETY TECHNOLOGY, SEATTLE, P. 757, AUG. 1979.

11. GLUEKLER, E.L., T.C. HUANG, J.D. TERESI, "IN-VESSEL RETENTION OF CORE DEBRIS IN LMFBRS" PROC. OF THE INT. MEETING ON FAST REACTOR SAFETY TECHNOLOGY, SEATTLE, P. 698, AUG. 1979.

12. RIVARD, J.B. AND R.L. COATES, "PAHR: AN OVERVIEW OF SOME IN-VESSEL SAFETY CONSIDERATIONS" PROC. OF THE INT. MEETING ON FAST REACTOR SAFETY TECHNOLOGY, SEATTLE, P. 709, AUG. 1979.

13. DHIR, V.K., "DRYOUT HEAT FLUXES IN DEBRIS BEDS CONTAINING PARTICLES OF DIFFERENT SIZE DISTRIBUTIONS" PROC. OF THE INT. MEETING ON FAST REACTOR SAFETY TECHNOLOGY, SEATTLE, P. 770, AUG. 1979.

14. LERIGOLEUR, C. AND G. KAYSER, "AN INTERNAL CORE CATCHER FOR A POOL LMFBR AND CONNECTED STUDIES" PROC. OF THE INT. MEETING ON FAST REACTOR SAFETY TECHNOLOGY, SEATTLE, P. 781, AUG. 1979.

15. SHIRES, G.L. AND G.F. STEVENS, "DRYOUT DURING BOILING IN HEATED PARTICULATE BEDS" UNITED KINGDOM ATOMIC ENERGY AUTHORITY REPORT AEEW-M1779, APRIL 1980.

DEBRIS BED DRYOUT CORRELATIONS

DHIR AND CATTON (REFS. 4 AND 5) AND DHIR (REF. 13)

$$\frac{Q_v h(1-\varepsilon)}{q_z} = \frac{24}{\pi} C \kappa^* \Gamma^{1/2} M$$

$$q_z = \frac{\pi}{24} h_{fg} \rho_g \left[\frac{\sigma g(\rho_f - \rho_g)}{\rho_g^2}\right]^{1/4}$$

ZUBER CHF FOR A FLAT PLATE

$$\Gamma = \frac{\rho_f}{\rho_g}$$

$$M = \left[\frac{\rho_f^2 \sigma^3}{\mu_f^4} (\rho_f - \rho_g) g\right]^{1/4}$$

$$\kappa^* = \kappa \left(\frac{g(\rho_f - \rho_g)}{\sigma}\right)$$

$$\kappa = \left[\frac{1}{180mf} \frac{(1-\varepsilon)^2}{\varepsilon^3} \left(\frac{f}{100} \sum_i \frac{P_i}{d_i}\right)^2\right]^{-1}$$

FROM LE RIGOLEUR (REF. 9)

$4 < m < 5$ PACKING FACTOR

$6 < f < 8$ SHAPE FACTOR

SPHERES ANGULAR PARTICLES

d_i = MEAN PARTICLE DIAMETER

P_i = MASS PERCENTAGE OF PARTICLES

C = 0.56 WITH mf = 31.5 TO CORRELATE EXPERIMENTS

LIPINSKI AND RIVARD (REF. 10)

$$\frac{Q_v h(1-\varepsilon)}{q_z} = \frac{24}{\pi} \kappa^* \frac{\rho_f}{\rho_f - \rho_g} M \frac{\mu_f/\mu_g}{(1 + \sqrt{\nu_f/\nu_g})^2}$$

LAMINAR

FOR TURBULENT LIMIT SEE NUREG/CR-1410 PAGE VI-110.

SHIRES AND STEVENS (REF. 15)

$$\frac{Q_v(1-\varepsilon)h}{q_z} = \left(D\frac{24}{\pi}\right)\kappa^* \frac{\rho_f}{\rho_f - \rho_g} M \frac{\mu_f}{\mu_g}\left[1 + \frac{6\sigma(1-\varepsilon)}{C\varepsilon d\rho_f\, gh}\right]$$ SURFACE TENSION CORRECTION

GABOR, SOWA, PAVLIK AND CASSULO (REF. 6)

$$\frac{Q_v(1-\varepsilon)h}{q_z} = (1-\varepsilon)\ \frac{\sqrt{2}\ 24}{\pi}\left(\frac{\mu_f}{\rho_g}\right) M \left(\frac{\rho_g}{\rho_f - \rho_g}\right)^{\frac{1}{2}}$$

$$\times\left[\frac{dD_{CH}Nh^3}{(h - h_{CH})f_1 D_{CH}\ N + 4fh_{CH}\ d}\right]^{\frac{1}{2}}$$

f_1 = 2ϕ FRICTION FACTOR

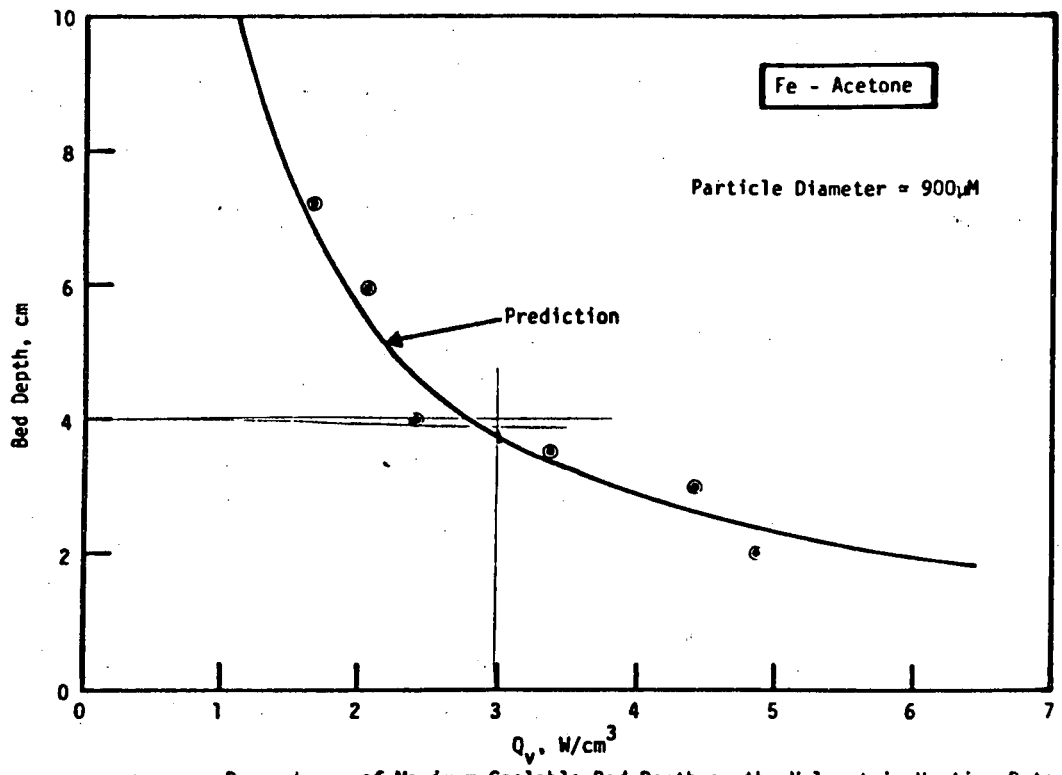
f = FRICTION FACTOR

N = CHANNELS PER UNIT AREA

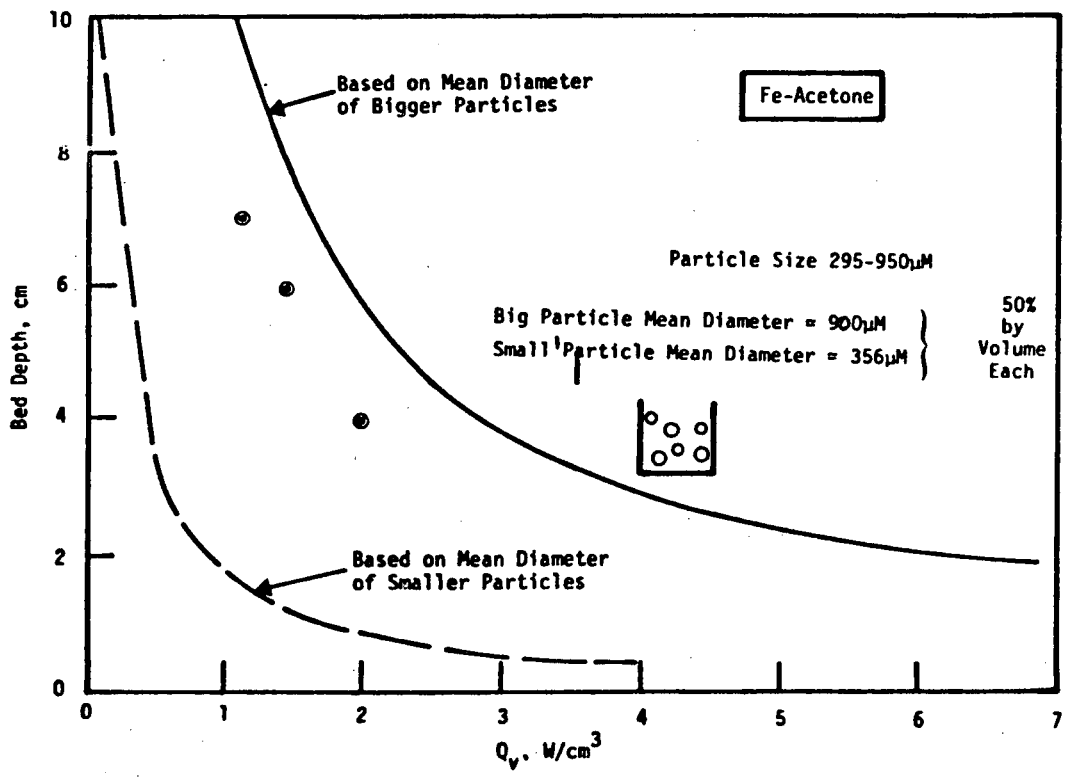
D_{CH} = CHANNEL DIAMETER

h_{CH} = CHANNEL DEPTH

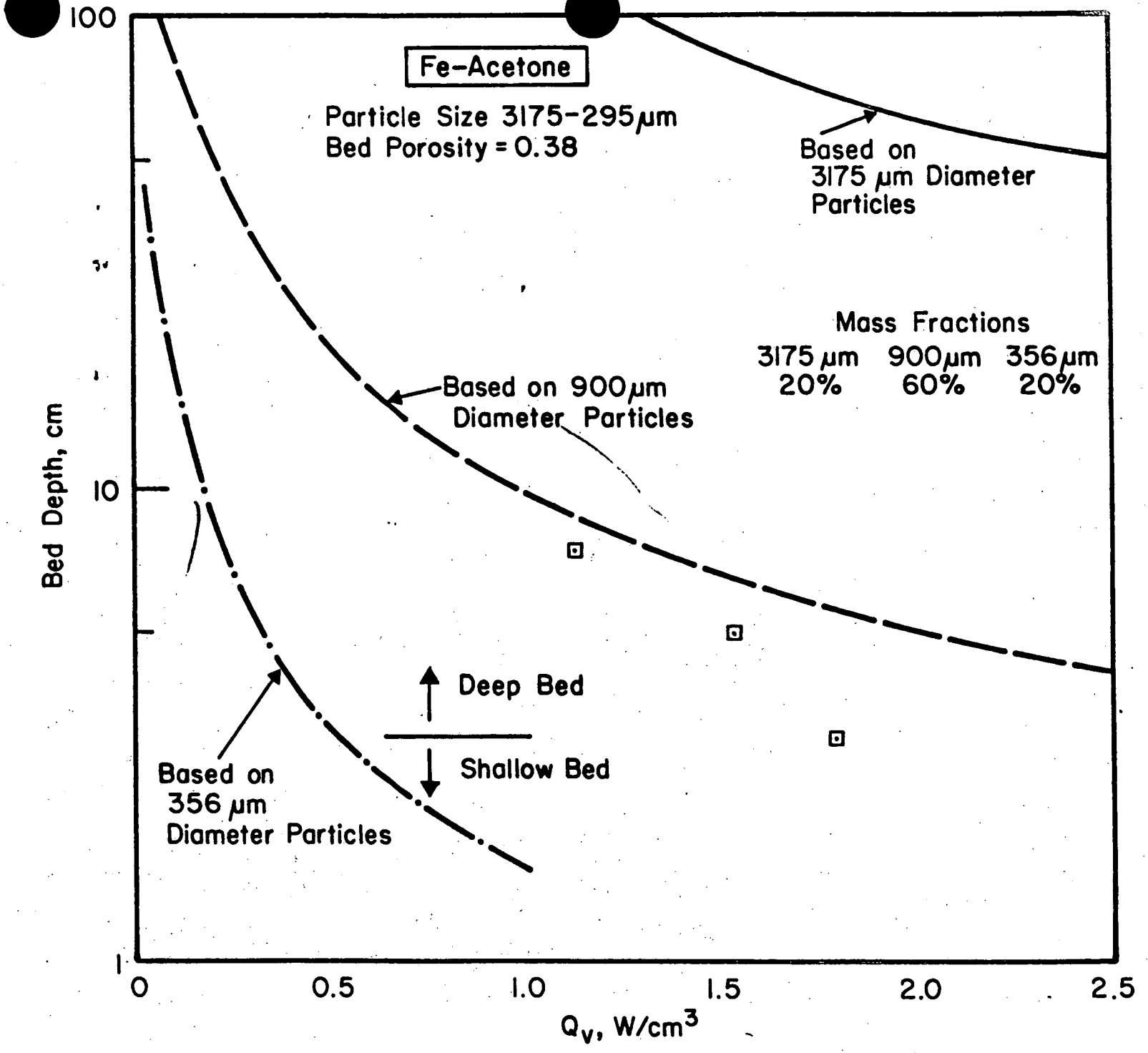
EFFECTS OF PARTICLE SIZE DISTRIBUTION

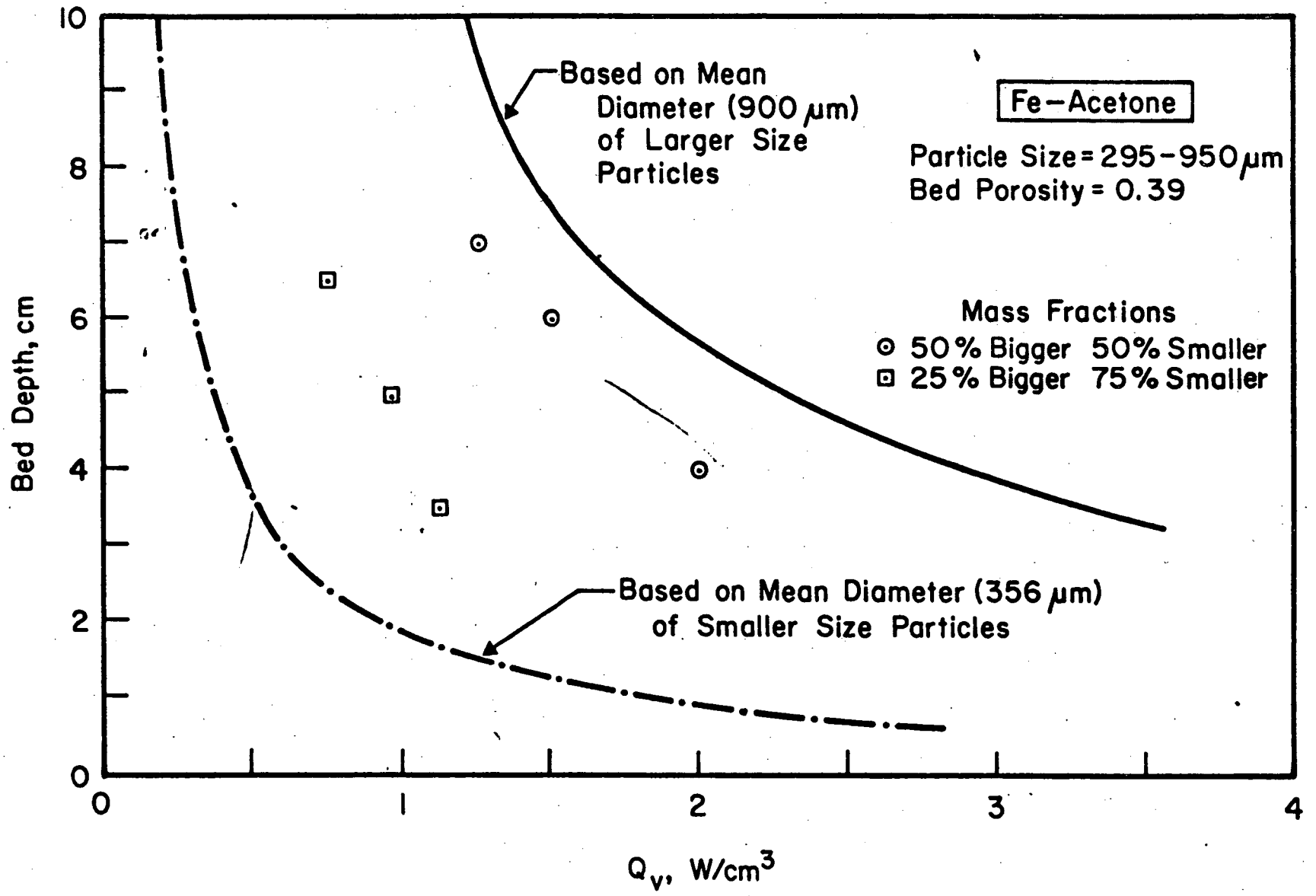


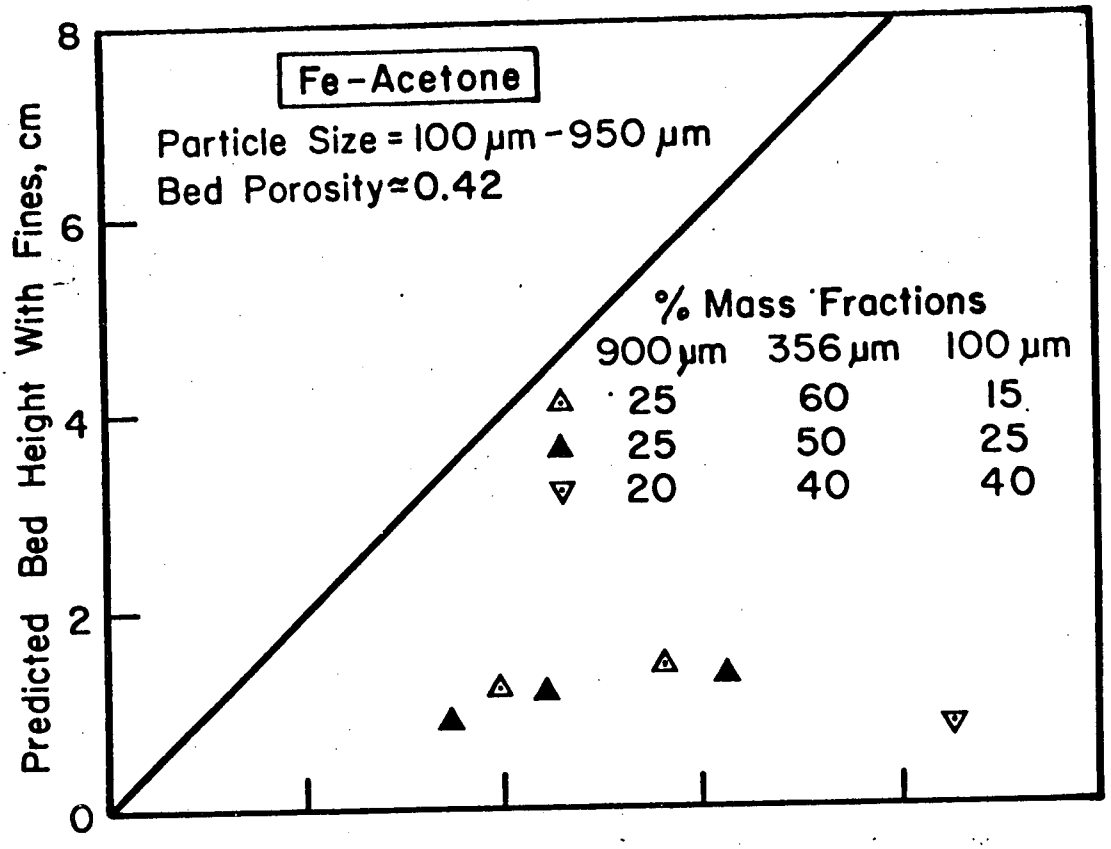
Dependence of Maximum Coolable Bed Depth on the Volumetric Heating Rate

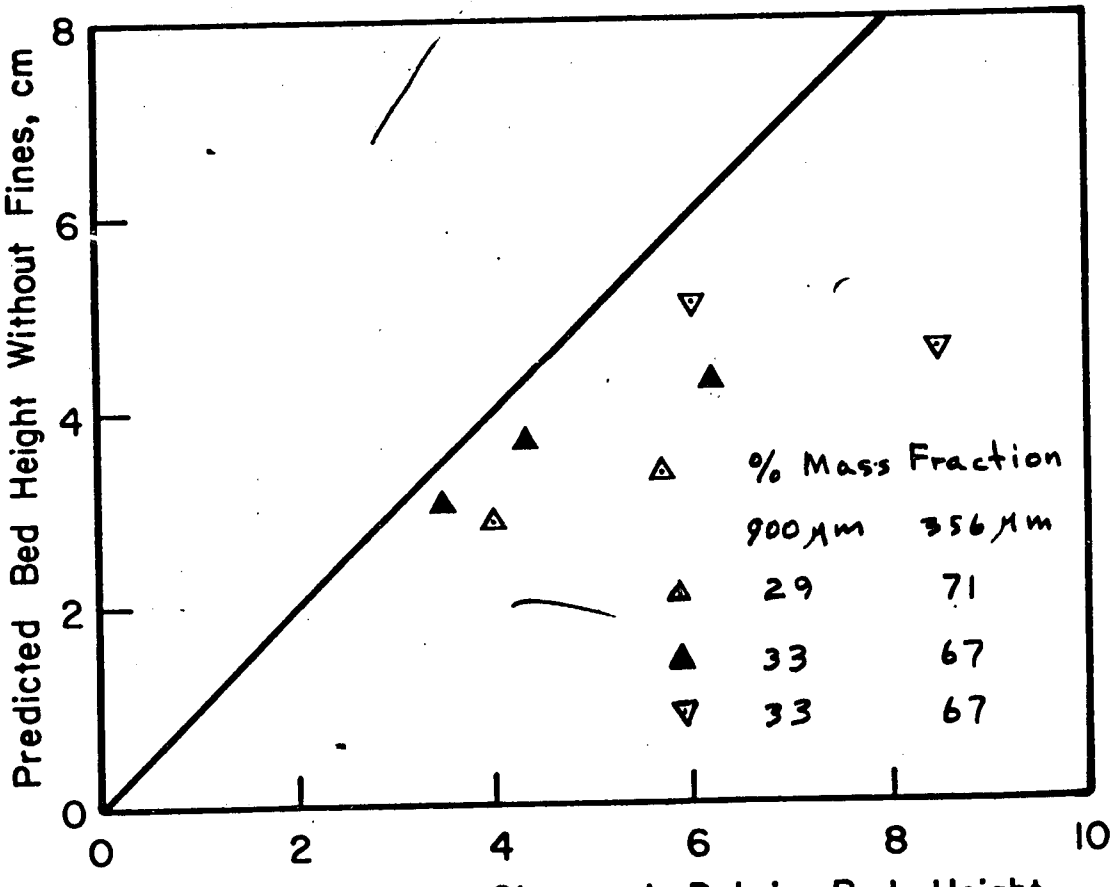


Effect of Presence of Particles of Various Sizes on the Maximum Coolable Debris Bed Depth


Fe-Acetone
Particle Size 3175-295μm
Bed Porosity = 0.38
Based on 3175 μm Diameter Particles
Mass Fractions
3175 μm 20%
900μm 60%
356μm 20%
Based on 900μm Diameter Particles
Deep Bed
Shallow Bed
Based on 356 μm Diameter Particles
Bed Depth, cm
100
10
1
0
0.5
1.0
1.5
2.0
2.5
Q_v, W/cm^3

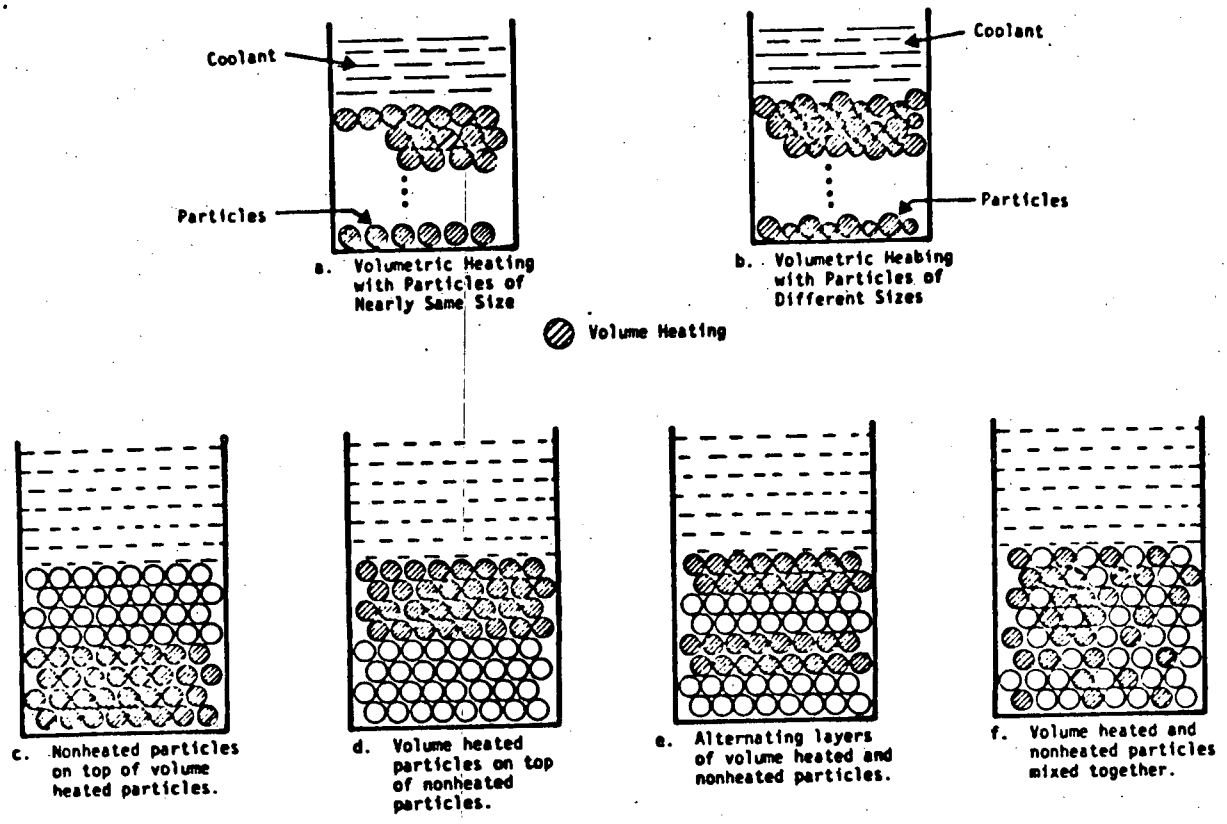

Based on Mean Diameter (900 μm) of Larger Size Particles
Fe–Acetone
Particle Size = 295–950 μm
Bed Porosity = 0.39
Mass Fractions
50% Bigger 50% Smaller
25% Bigger 75% Smaller
Based on Mean Diameter (356 μm) of Smaller Size Particles
Bed Depth, cm
Q_v, W/cm^3
0
2
4
6
8
10
0
1
2
3
4



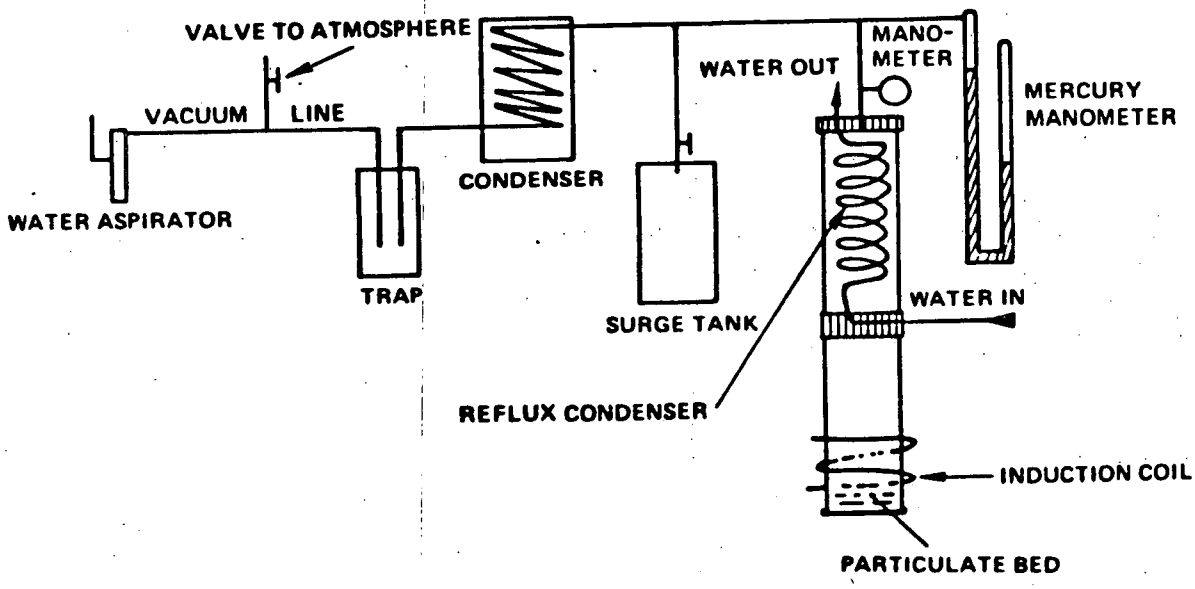


Predicted bed height based on $\bar{d}$

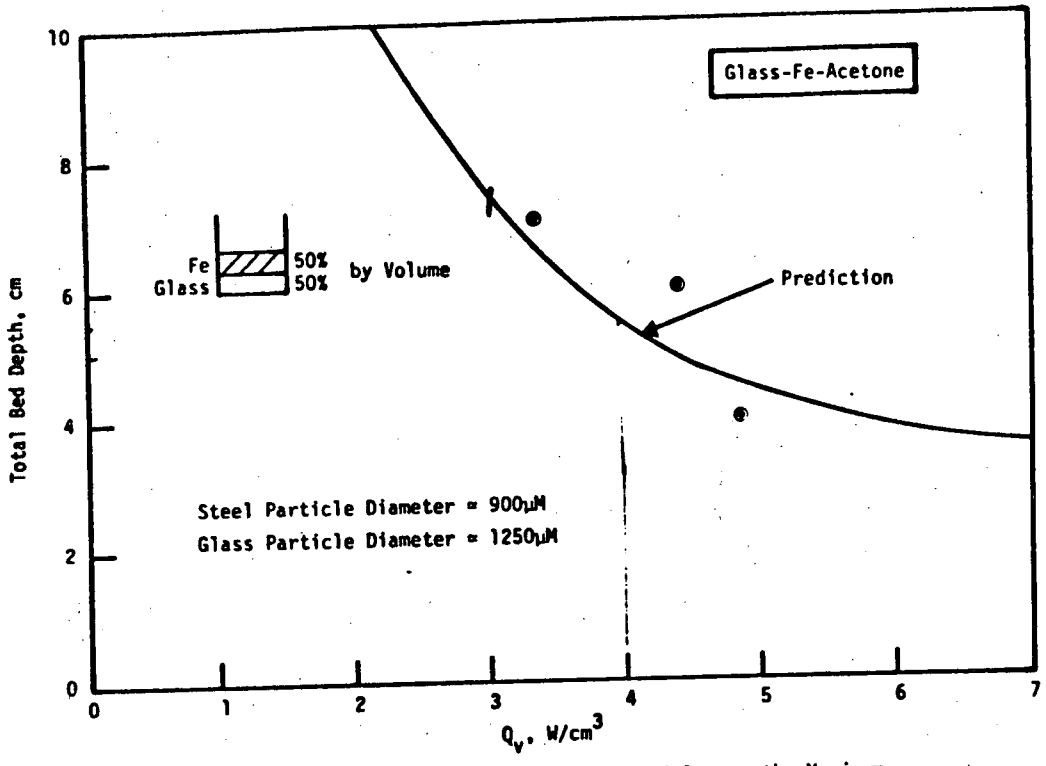
EFFECT OF NON-HEATED MATERIALS IN THE BED



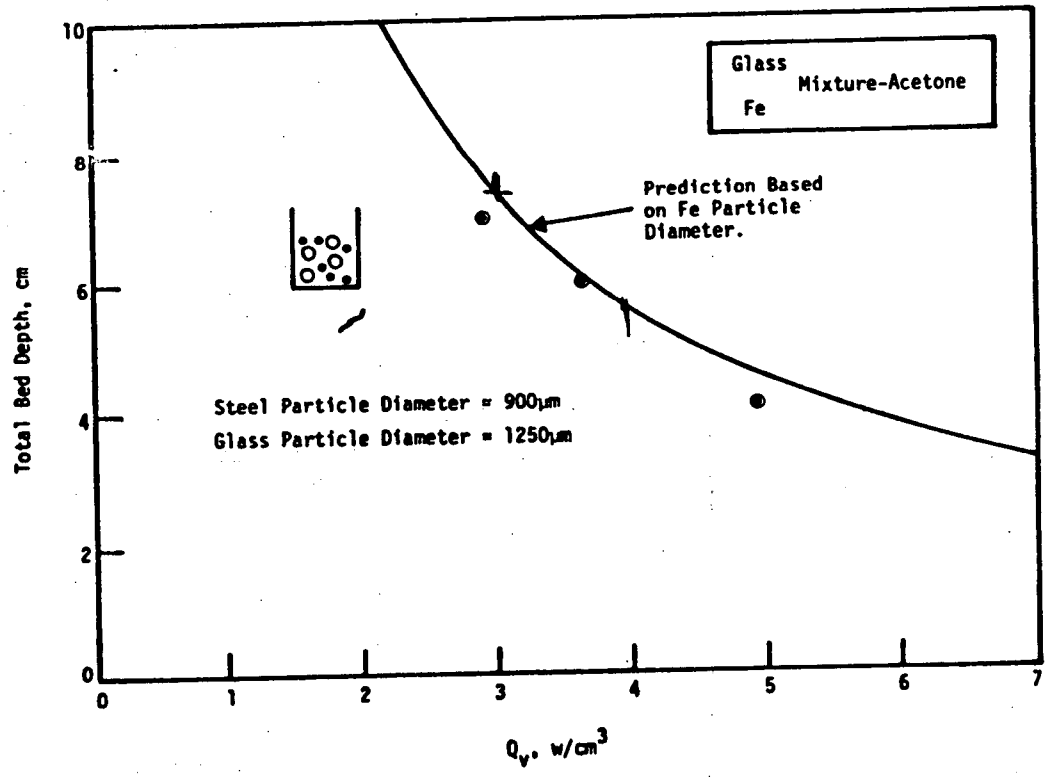
Various configurations of deep beds containing both volume heated and nonheated particles.



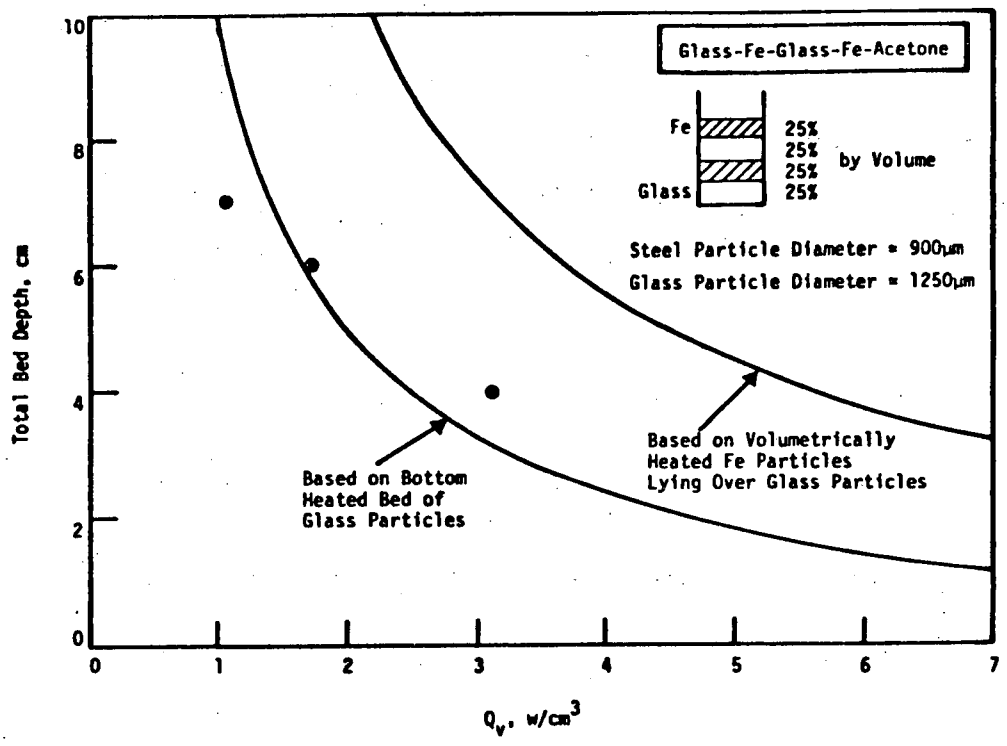
Schematic Diagram of Experimental Set Up.



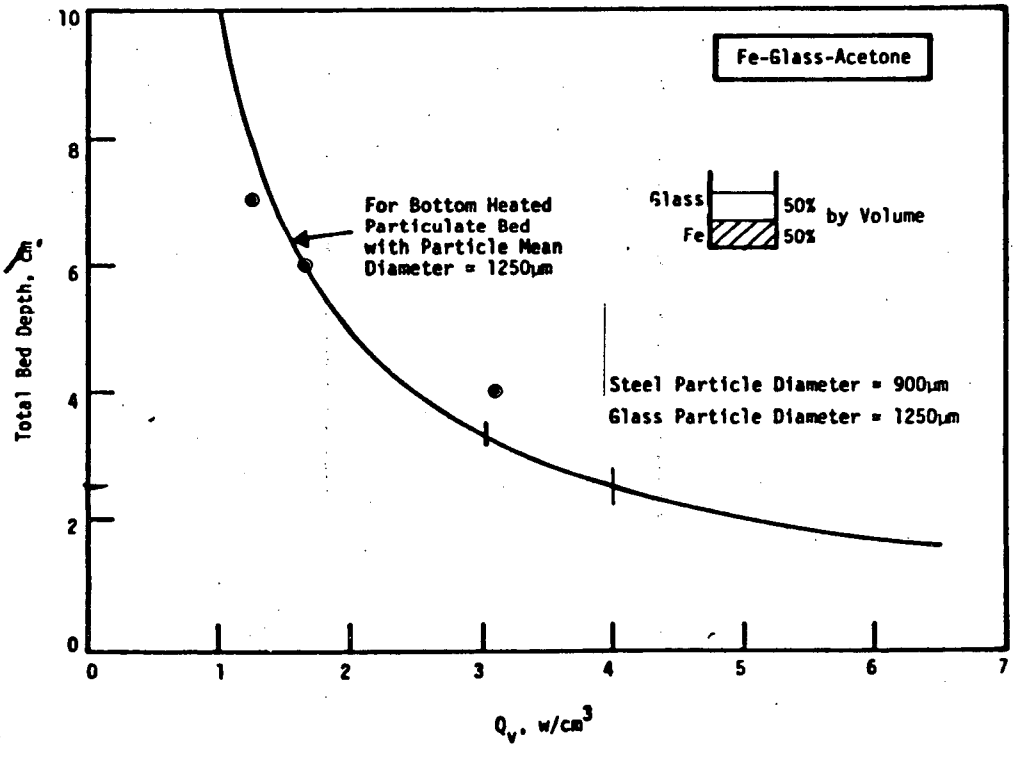
Effect of Presence of Non-Heated Particles on the Maximum Coolable Total Bed Depth



Effect of Presence of Mixture of Volumetrically Heated and Non-heated Particles on the Maximum Coolable Debris Bed Depths.



Effect of Presence of Several Alternating Layers of Volumetrically Heated and Non-Heated Particles on Maximum Coolable Degris Bed Total Depth.



Effect of Presence of Non-Heated Particles on the Maximum Coolable Bed Depth.

FRAGMENTATION

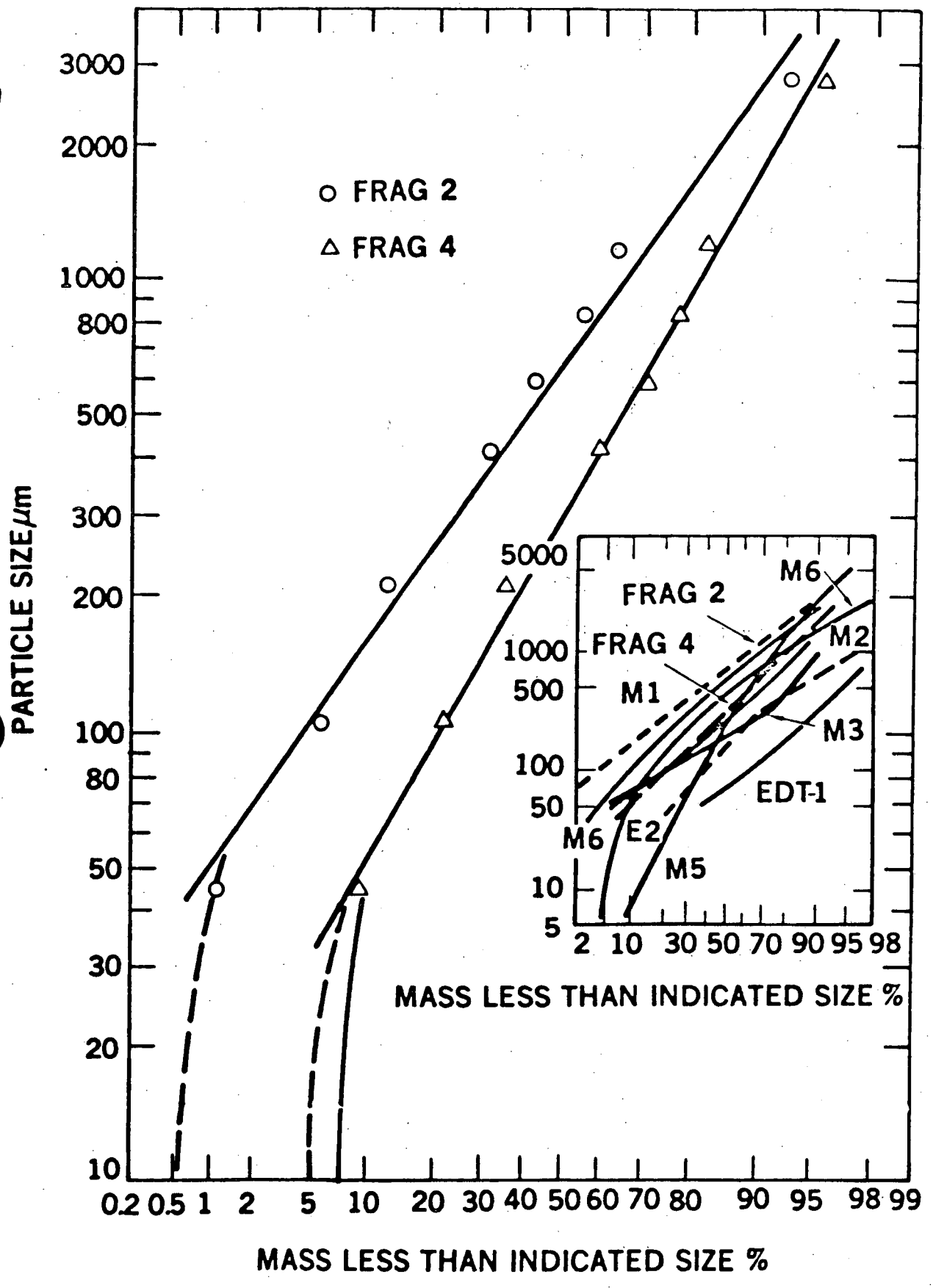
ALL DATA SEEMS TO FALL ON OR NEAR THE ANL M-SERIES TEST DATA.

REFS.: CHU ET AL., "MEDIUM SCALE MELT-SODIUM FRAGMENTATION EXPERIMENTS" PROC. OF INT. MEETING ON FAST REACTOR SAFETY, SEATTLE, P. 743, 1979.

SOWA ET AL., "MOLTEN CORE DEBRIS-SODIUM INTERACTIONS: M-SERIES EXPERIMENTS" IBID., P. 733.

BEDS WILL TEND TO STRATIFY WITH LARGER PARTICLES AT THE BOTTOM (CHU ET AL.).

IMPROVEMENT IN OUR UNDERSTANDING OF THE FRAGMENTATION PROCESS AND STRATIFICATION IS MORE THAN A YEAR AWAY.


FRAG 2
FRAG 4
PARTICLE SIZE μm
3000
2000
1000
800
500
300
200
100
80
50
30
20
10
0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99
MASS LESS THAN INDICATED SIZE %
5000
1000
500
100
50
10
5
2 10 30 50 70 90 95 98
FRAG 2
FRAG 4
M6
M2
M1
M3
EDT-1
M6
E2
M5
MASS LESS THAN INDICATED SIZE %

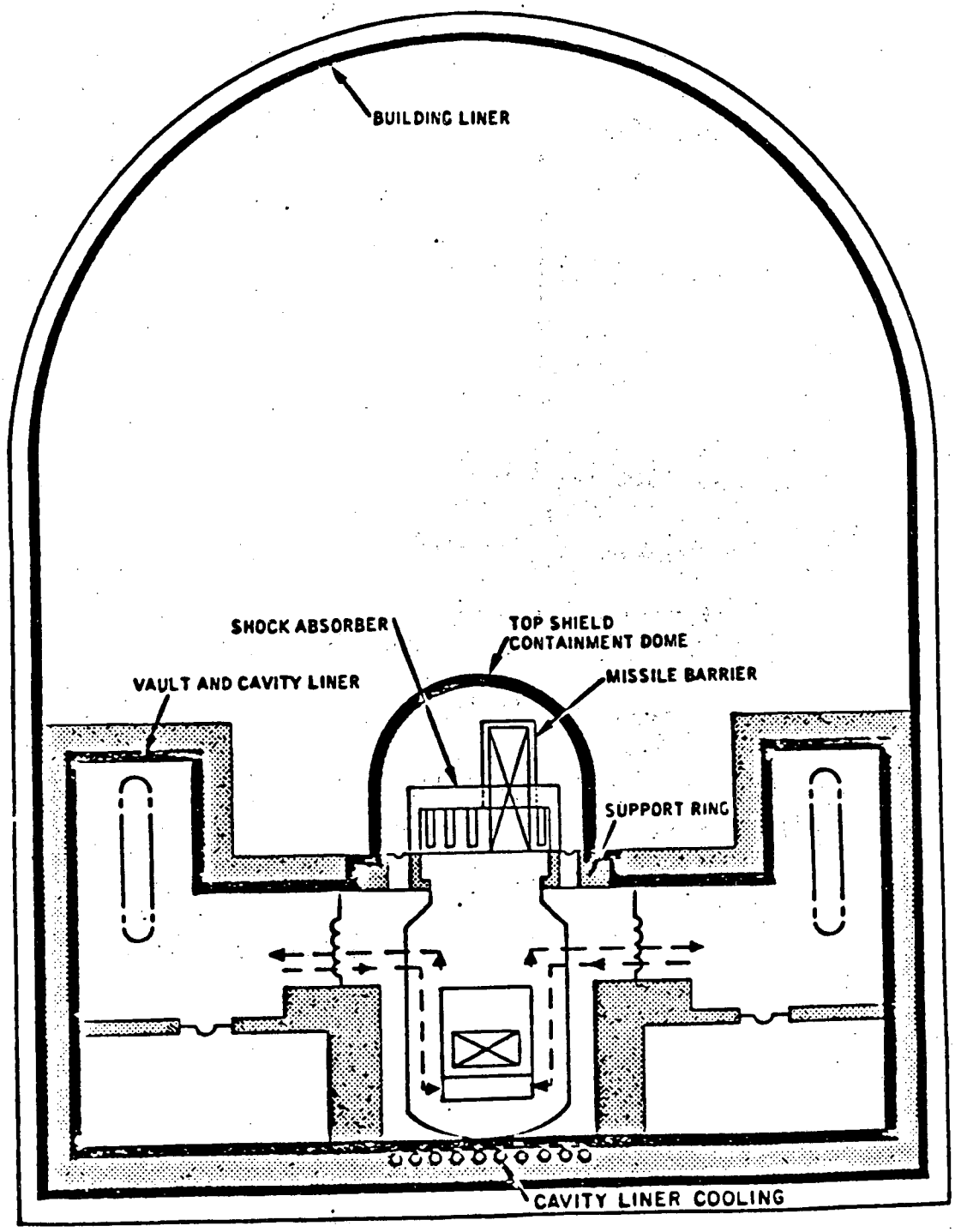
CORE CATCHERS

A NUMBER OF CONCEPTUAL DESIGNS FOR CORE CATCHERS HAVE BEEN DESCRIBED DURING THE PAST TEN YEARS.

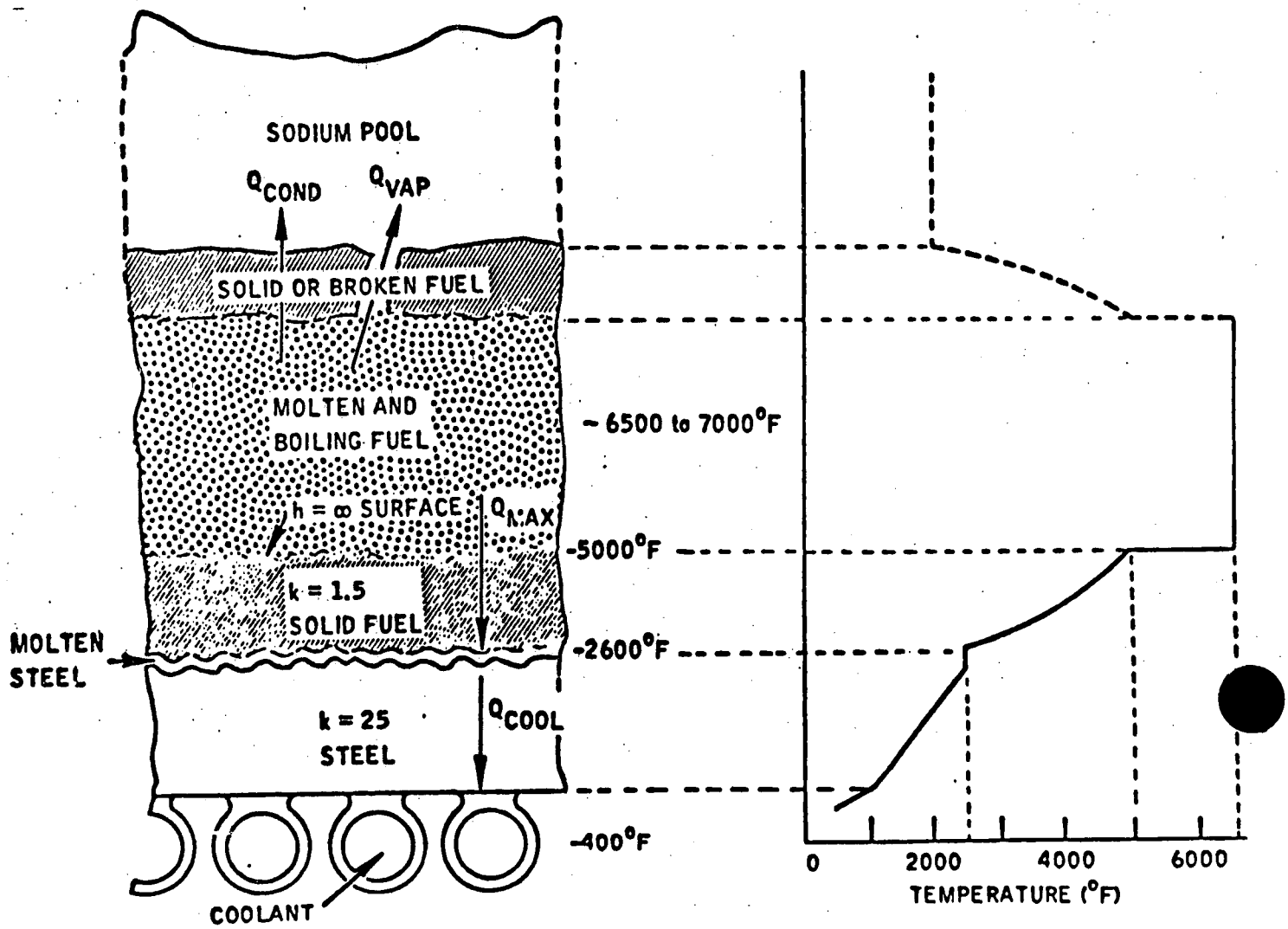
A NUMBER OF DIFFERENT MATERIALS HAVE BEEN CONSIDERED FOR CONSTRUCTION OF A CORE CATCHER.

OUR KNOWLEDGE OF MOLTEN POOL HEAT TRANSFER HAS INCREASED DURING THIS SAME PERIOD.

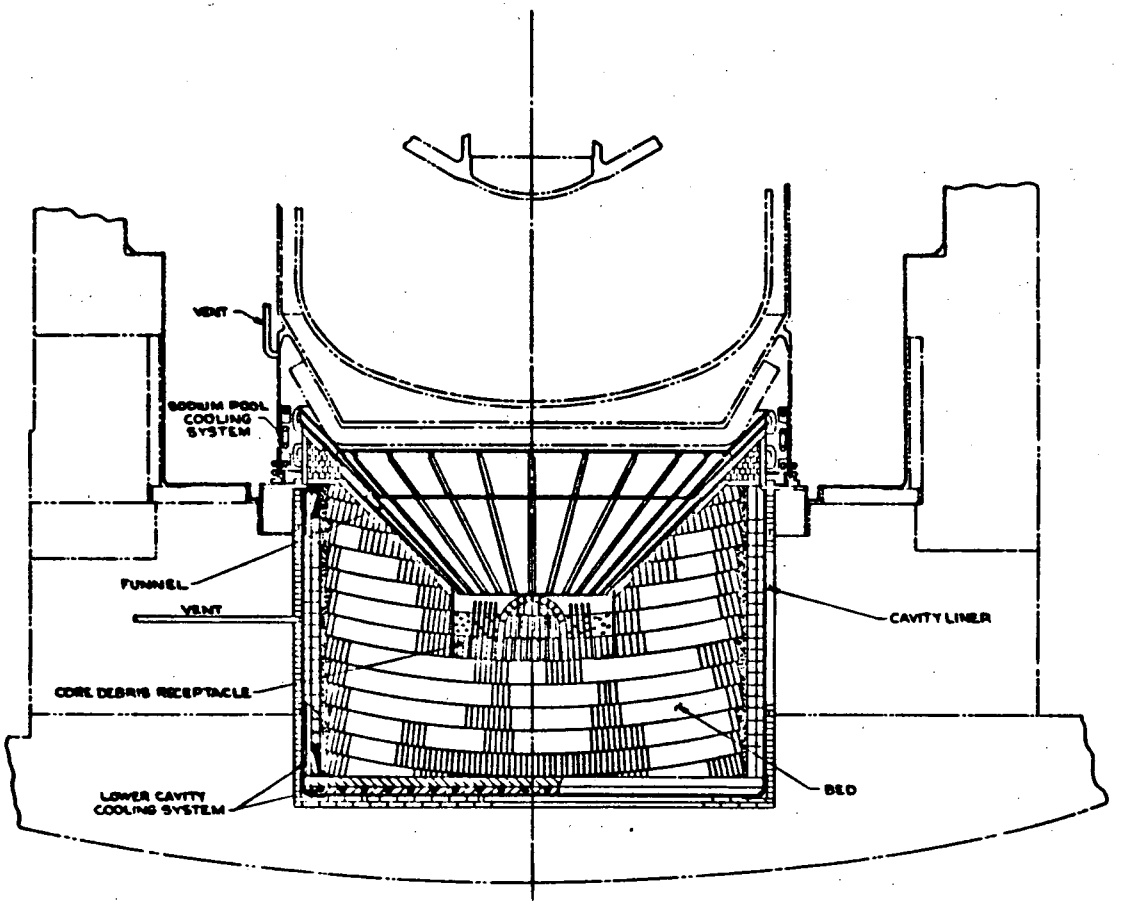
THE GERMANS PLAN TO USE A DEPLETED UO_2 CORE CATCHER WITH ACTIVE COOLING AS A PART OF THE SNR-300 DESIGN.



Atomics International 500 Mwe Plant Containment Features.



Atomics International Molten Fuel Model.



DATA

U. S. ATOMIC ENERGY COMMISSION

WESTINGHOUSE ELECTRIC CORP.

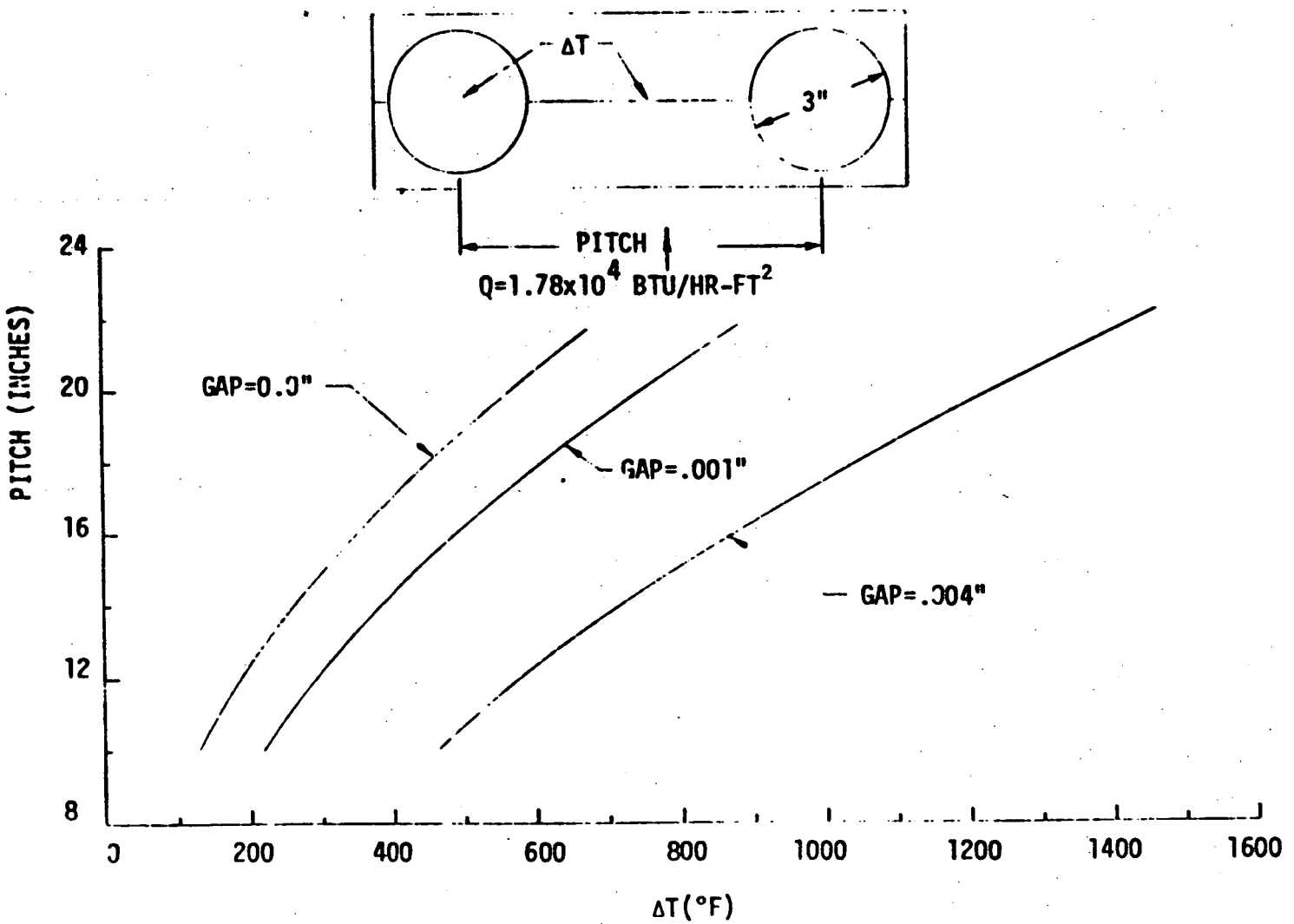
EX-VESSEL CORE CATCHER (EVCC) OVERALL ASSEMBLY

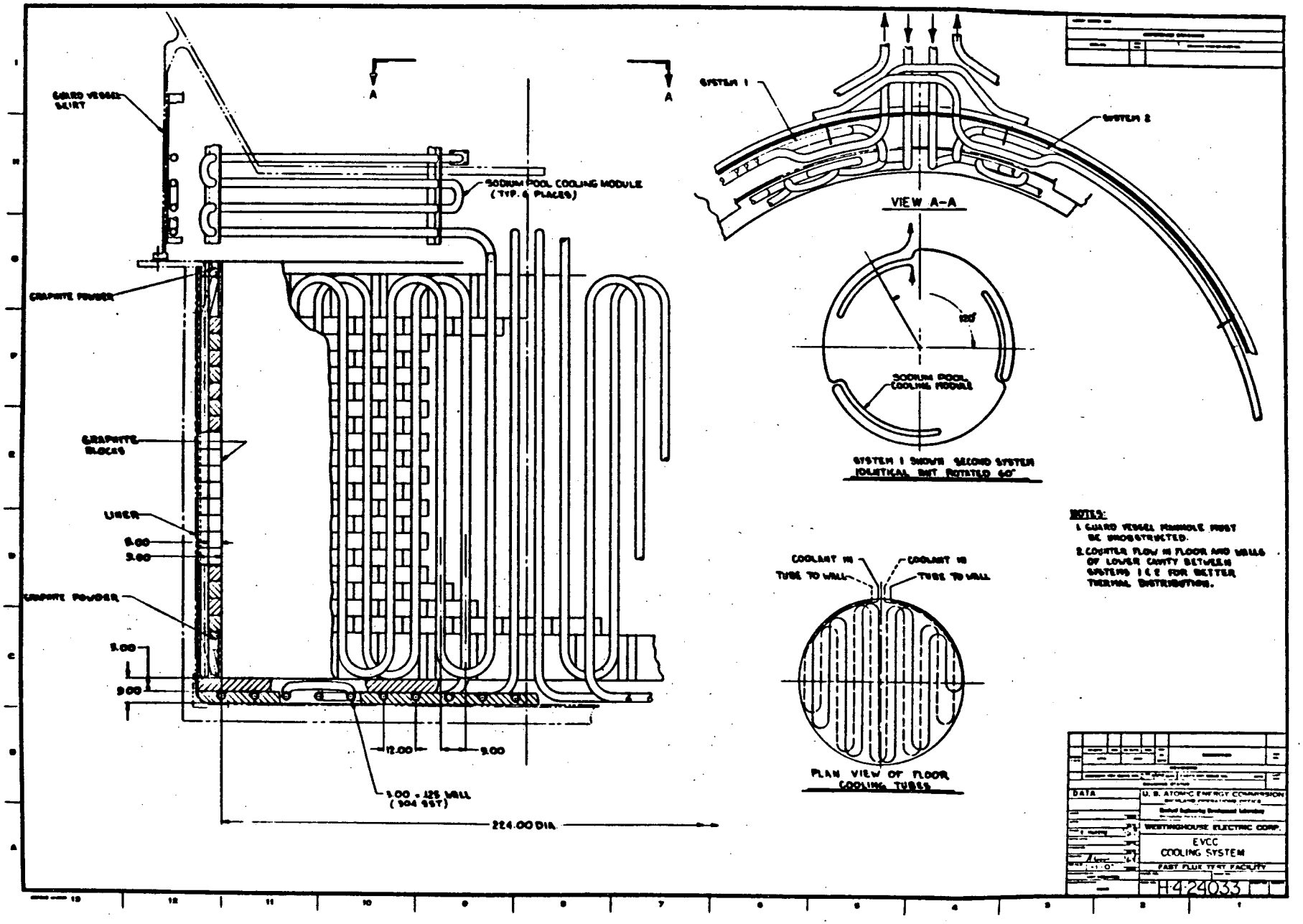
FAST FLUX TEST FACILITY

H424029

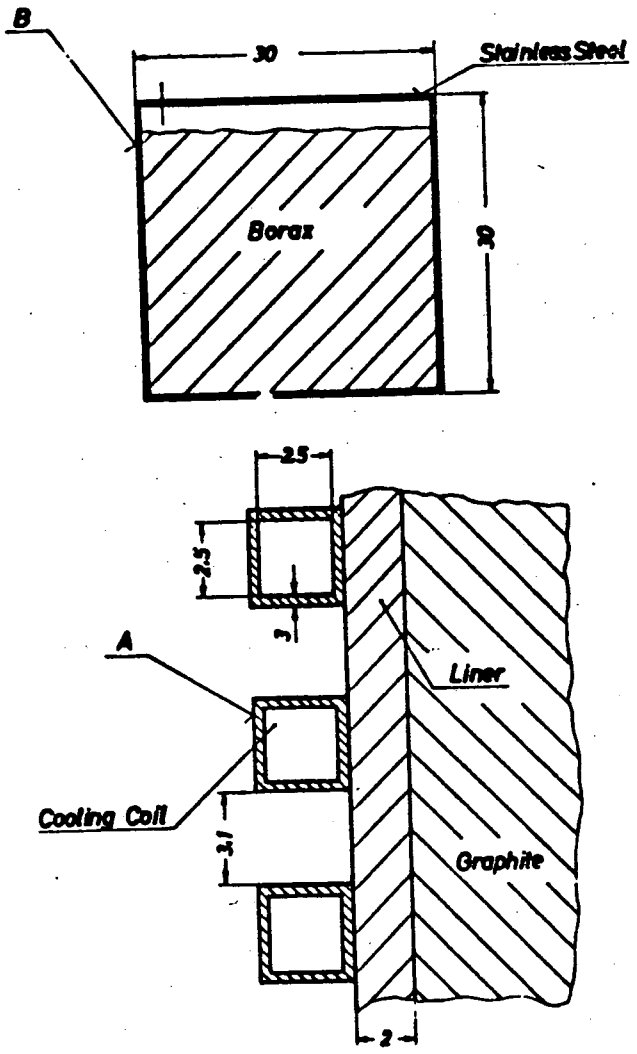
185

COOLING PIPE PITCH VS TEMPERATURE DIFFERENCE AS A FUNCTION OF GAP SIZE

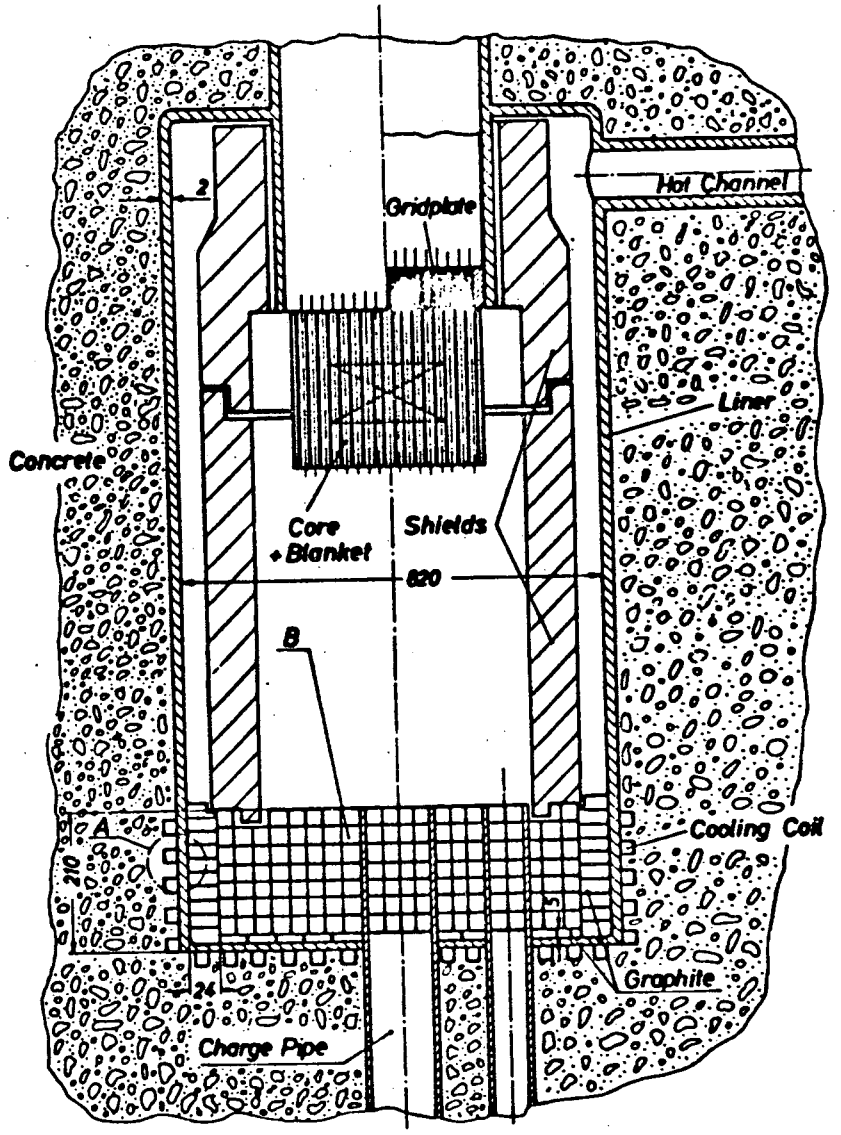



GUARD VESSEL SKIRT
SODIUM POOL COOLING MODULE (TYP. 6 PLACES)
GRAPHITE POWDER
GRAPHITE BLOCKS
LINER
5.00
3.00
GRAPHITE POWDER
5.00
3.00
12.00
5.00
5.00 x .125 WALL (304 SST)
224.00 DIA.
A
A
SYSTEM 1
SYSTEM 2
VIEW A-A
120°
SODIUM POOL COOLING MODULE
SYSTEM 1 SHOWN SECOND SYSTEM IDENTICAL BUT ROTATED 60°
COOLANT IN
TUBE TO WALL
COOLANT IN
TUBE TO WALL
PLAN VIEW OF FLOOR COOLING TUBES
NOTES:
1. GUARD VESSEL MANHOLE MUST BE UNOBSTRUCTED.
2. COUNTER FLOW IN FLOOR AND WALLS OF LOWER CAVITY BETWEEN SYSTEMS 1 & 2 FOR BETTER THERMAL DISTRIBUTION.
DATA
U. S. ATOMIC ENERGY COMMISSION
WESTINGHOUSE ELECTRIC CORP.
EVCC
COOLING SYSTEM
FAST FLUX TEST FACILITY
H-24033

187



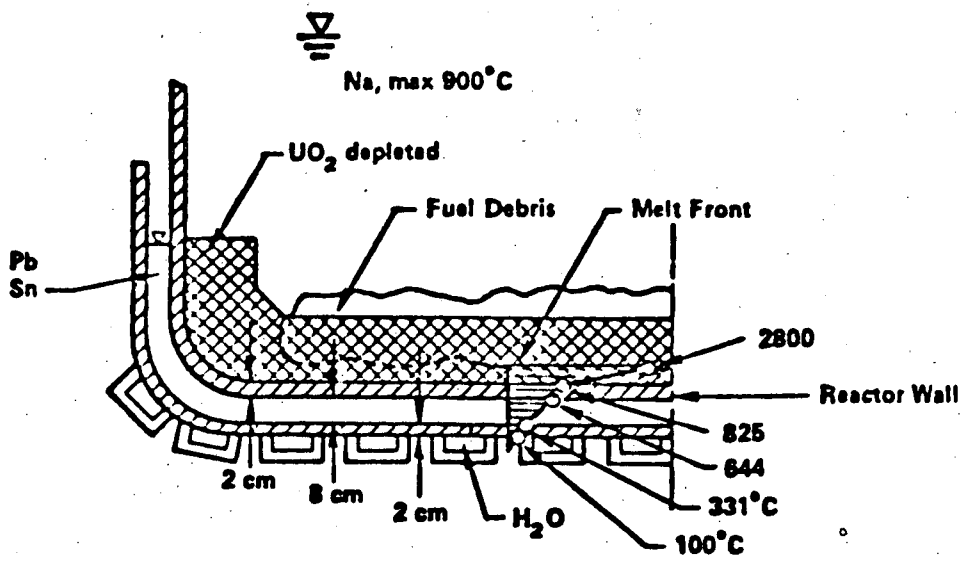
Dimensions in Centimeters



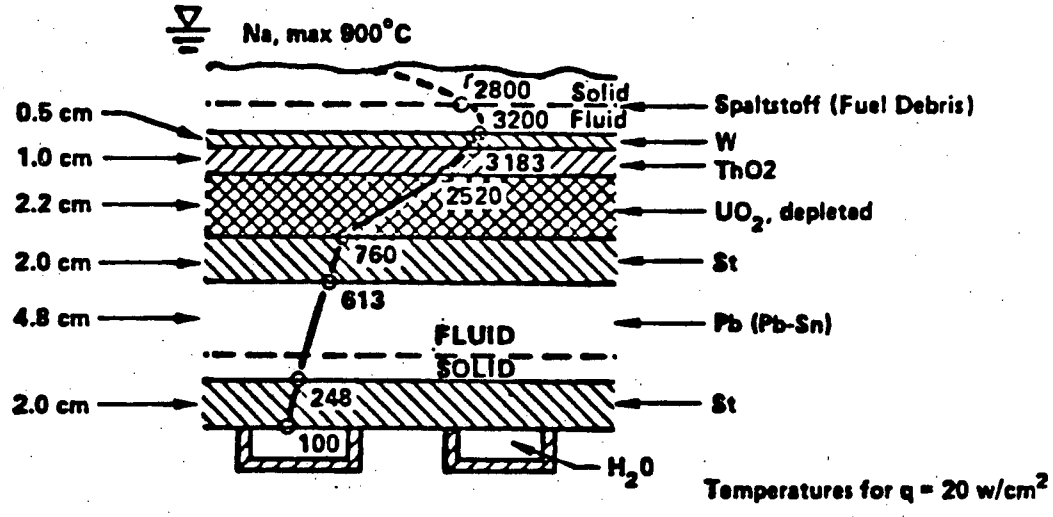
Dimensions in Centimeters

Core-catcher lay-out inside the reactor cavity of the Prestressed Concrete Reactor Vessel.

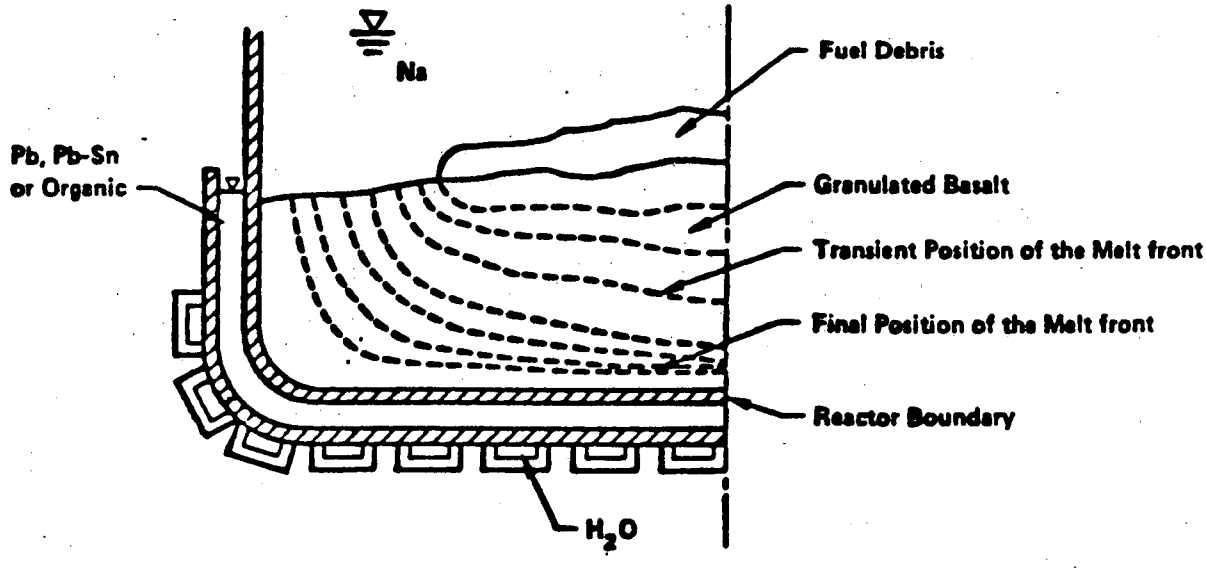
188



(a) Depleted Uranium Dioxide Sacrificial Layer

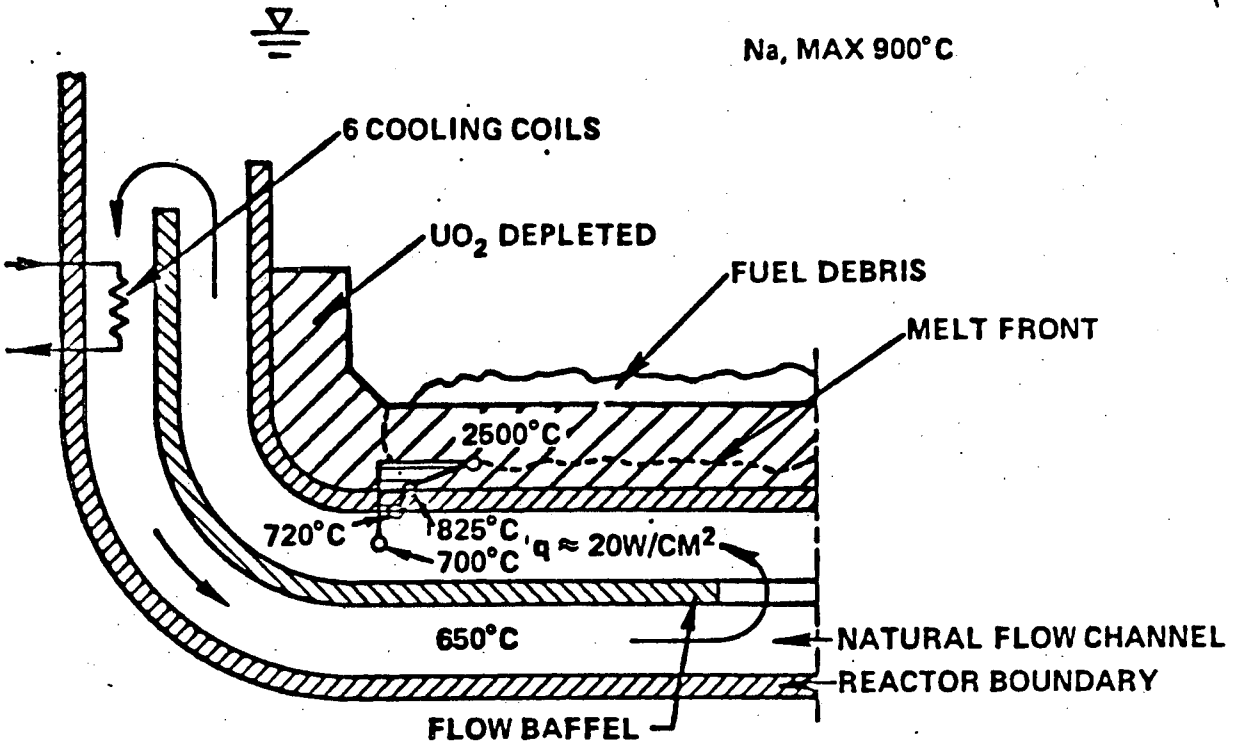


(b) Multilayered Sacrificial Bed With Tungsten Protection

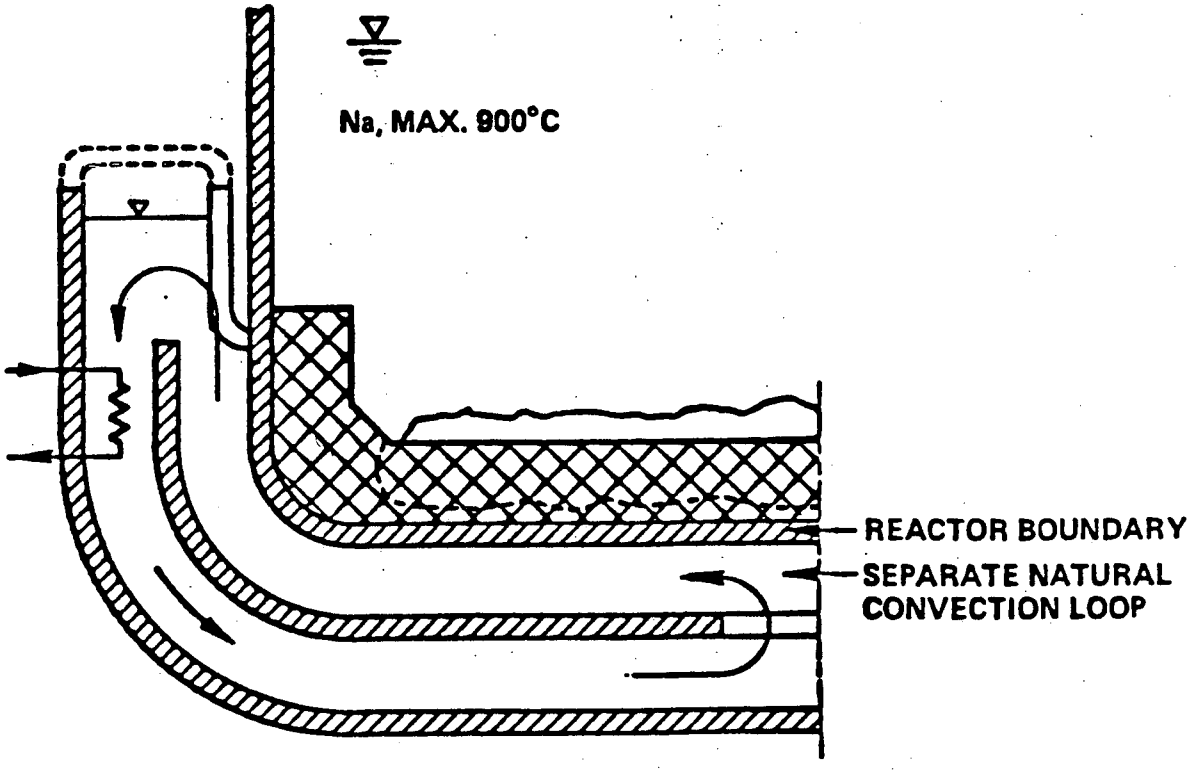


(c) Granulated Basalt Sacrificial Layer

PAHR Concepts Using External Forced Convection Water Loop and a Sacrificial Layer.



(a) INTERNAL COOLING LOOP



(b) EXTERNAL COOLING LOOP

PAHR Concepts Using Sodium Natural Convection Loop and a Sacrificial Layer.

HEAT ABSORBING CAPACITY AND THERMOPHYSICAL PROPERTIES OF SACRIFICIAL BED MATERIALS*

Material	Density (lbm/ft^3)	Specific Heat (BTU/lbm-°F)	Thermal Conductivity (BTU/hr-ft-°F)	Melting Point (°F) / Eutectic or Lowest Solidus Point	Heat of Fusion (BTU/lb)	Heat Capacity (Melting/Eutectic) (10^3 BTU/ft^3)
MgO	212	0.32	4.11	5070/4170	826	512/451
Al_2O_3	243	0.30	4.60	3720/3500	500	385/369
ZrO_2	374	0.14	1.33	4850/4700	304	362/354
UO_2	624	0.09	1.69	5160	121	360
ThO_2	580	0.079	1.45	5920/5200	146	351/318
Basalt	162	0.24	0.968	2190	126	102

* Material properties evaluated at about one half their melting point.

INTERIM APPROACH

1. ASSUME THAT PARTICLE DISTRIBUTION CAN BE REPRESENTED BY A LOWER BOUND TO THE ANL M-SERIES EXPERIMENTS.

2. USE LE RIGOLEUR'S RECOMMENDED FORM FOR A MEAN DIAMETER IGNORING PARTICLES WITH DIAMETERS LESS THAN 50 μm. THE ASSUMPTION THAT $d < 50$ μm CAN BE IGNORED IS PROBABLY CONSERVATIVE BASED ON DHIR'S EXPERIMENTS.

3. PREPARE A GRAPH OF A DEBRIS BED HEIGHT AS A FUNCTION OF DECAY HEAT USING DHIR'S EXPRESSION IN THE LAMINAR REGIME AND LIPINSKI'S EXPRESSION IN THE TURBULENT REGIME (VERY DEEP BEDS) WITH A VOID FRACTION OF 40% ($\varepsilon = 0.4$). THE VALUE OF ε RECOMMENDED IS ON THE LOW SIDE OF WHAT IS OBSERVED AND IS CONSERVATIVE.

4. ASSUME THE ENTIRE CORE HAS MELTED AND IS MIXED WITH AN APPROPRIATE AMOUNT OF STEEL AND ZIRCALOY, THEN ALLOW IT TO BE SPREAD OVER THE ENTIRE CAVITY FLOOR. THE OUTER PORTIONS OF THE CORE AND ALL OF THE STEEL WILL PROBABLY NOT MELT AND CERTAINLY WILL NOT ALL FRAGMENT.

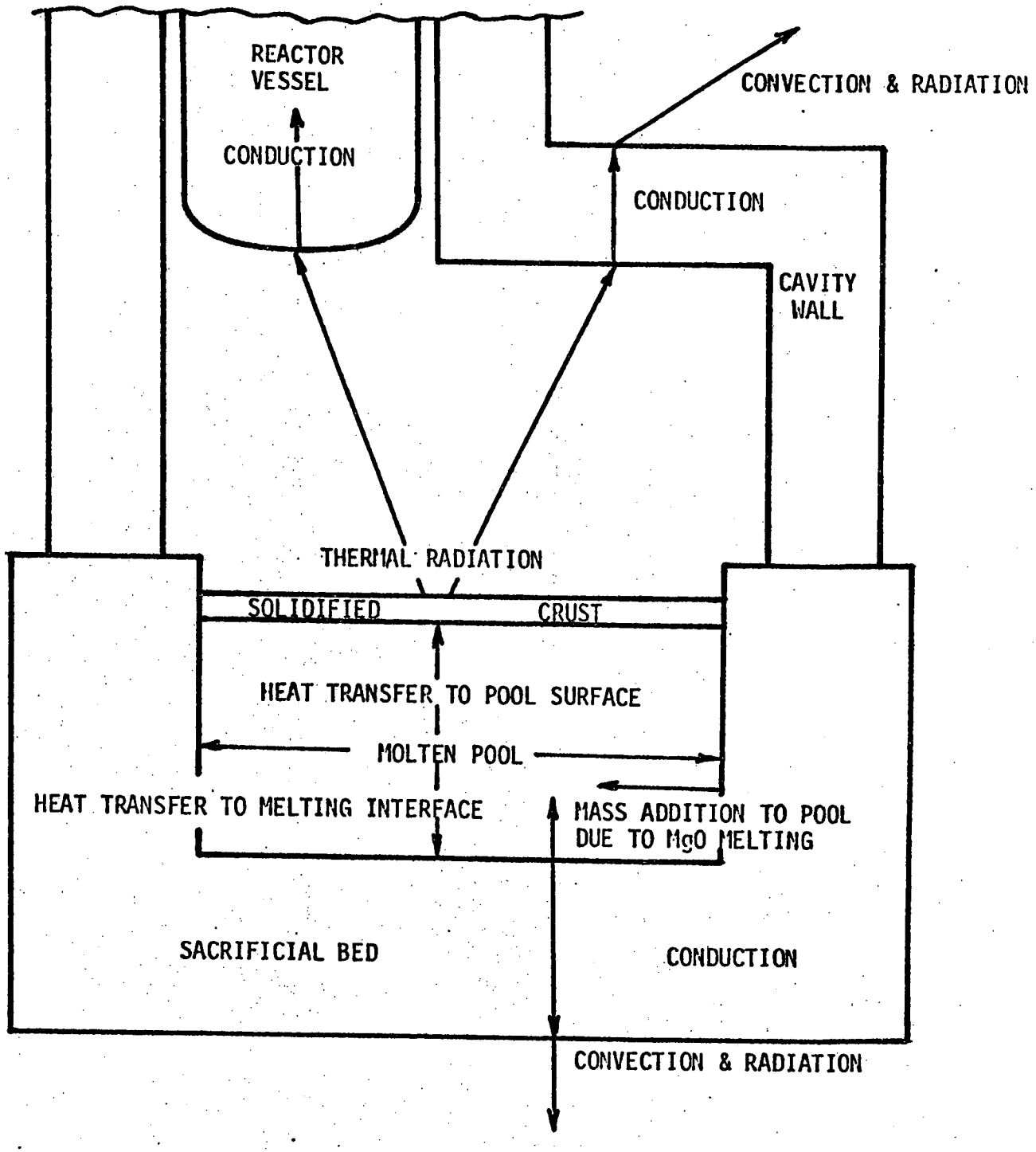
5. IF THE DEBRIS BED HEIGHT FOUND IN STEP 4 IS GREATER THAN THAT CALCULATED IN STEP 3, REMELTING AND THE NEED FOR A MITIGATING DEVICE MUST BE CONSIDERED OR THE CONSERVATISM IN THE APPROACH MUST BE BETTER QUANTIFIED.

BNL STUDY OF Z/IP CORE RETENTION DESIGN CONCEPTS

- MELSAC CODE ASSUMPTIONS
- MODIFICATIONS TO MELSAC FOR Z/IP
- CORE RETENTION DESIGN CONCEPTS

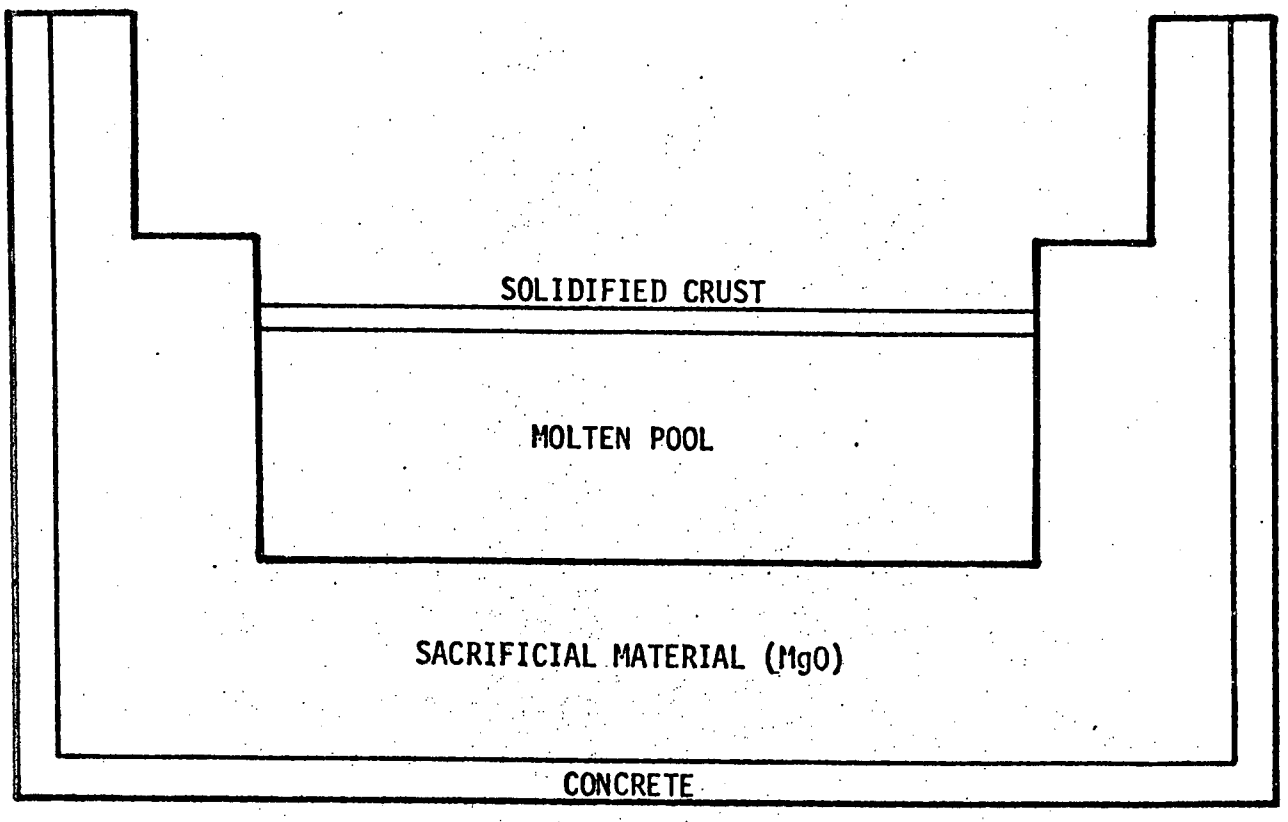
THE MELSAC COMPUTER CODE (FNP APPLICATION)

- ASSUMES MOLTEN POOL ABOVE MgO.
- AS MgO MELTS, POOL DILUTED WITH MgO.
- CONDUCTION AHEAD OF MELT FRONT MODELED.
- THERMAL RADIATION FROM POOL SURFACE TO REACTOR VESSEL AND CAVITY WALLS.
- CRUST CAN FORM ON UPPER POOL SURFACE.

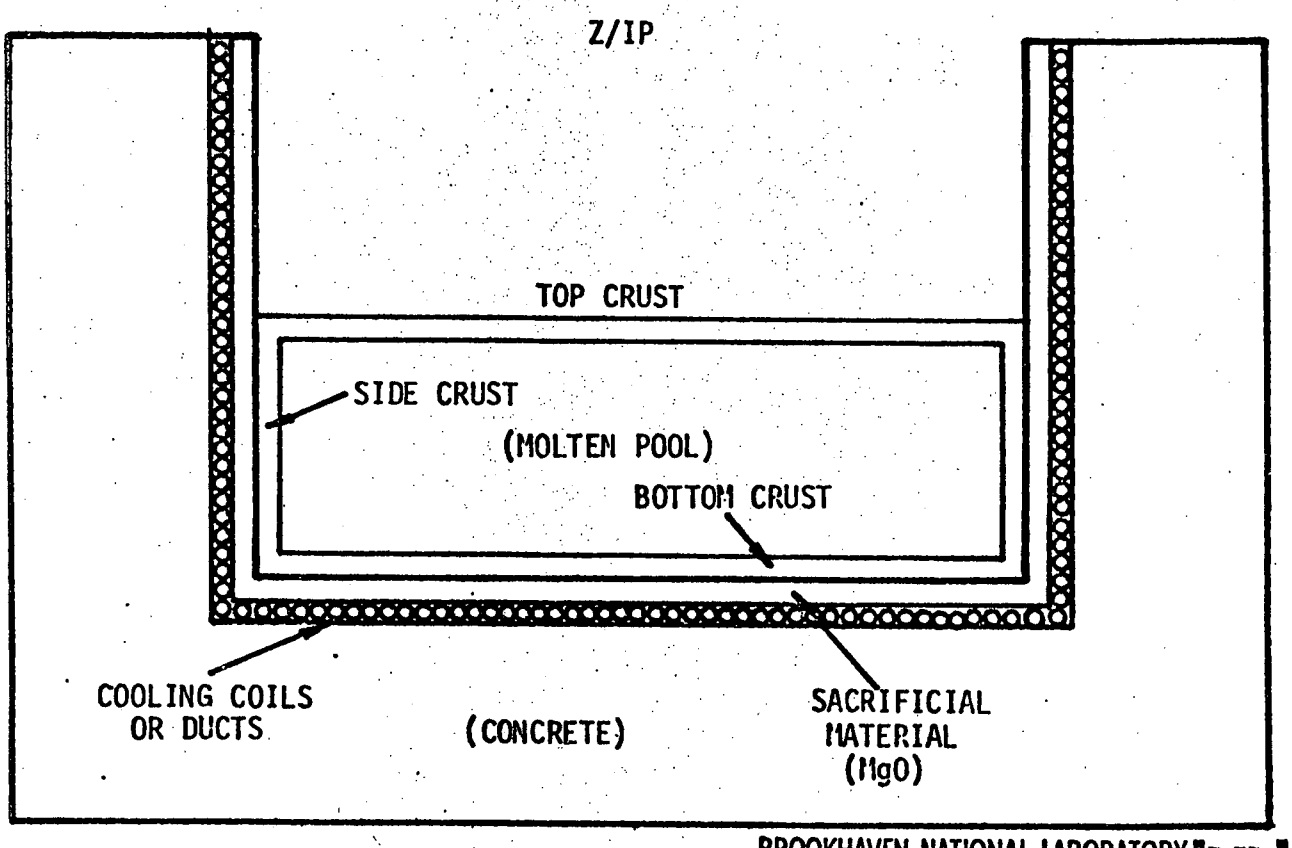


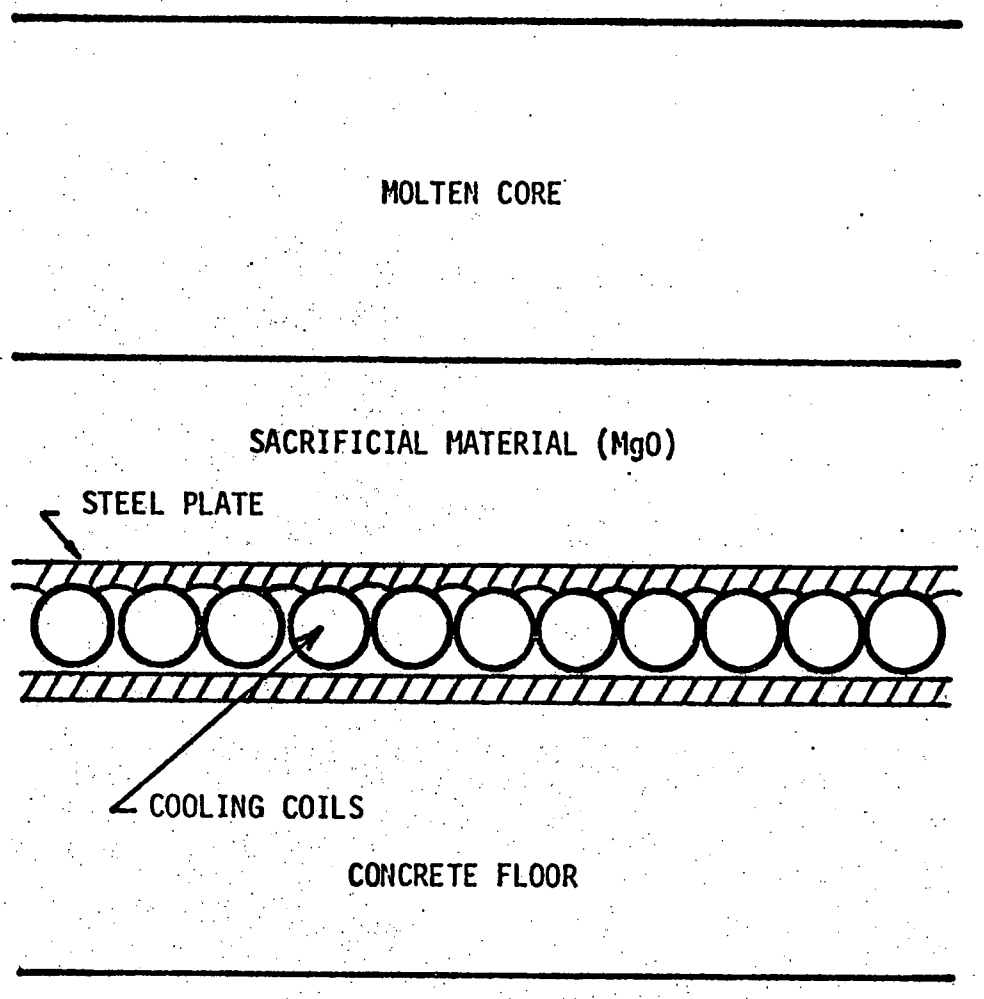
HEAT AND MASS TRANSFER IN REACTOR CAVITY
AS MODELED IN THE FNP ANALYSIS

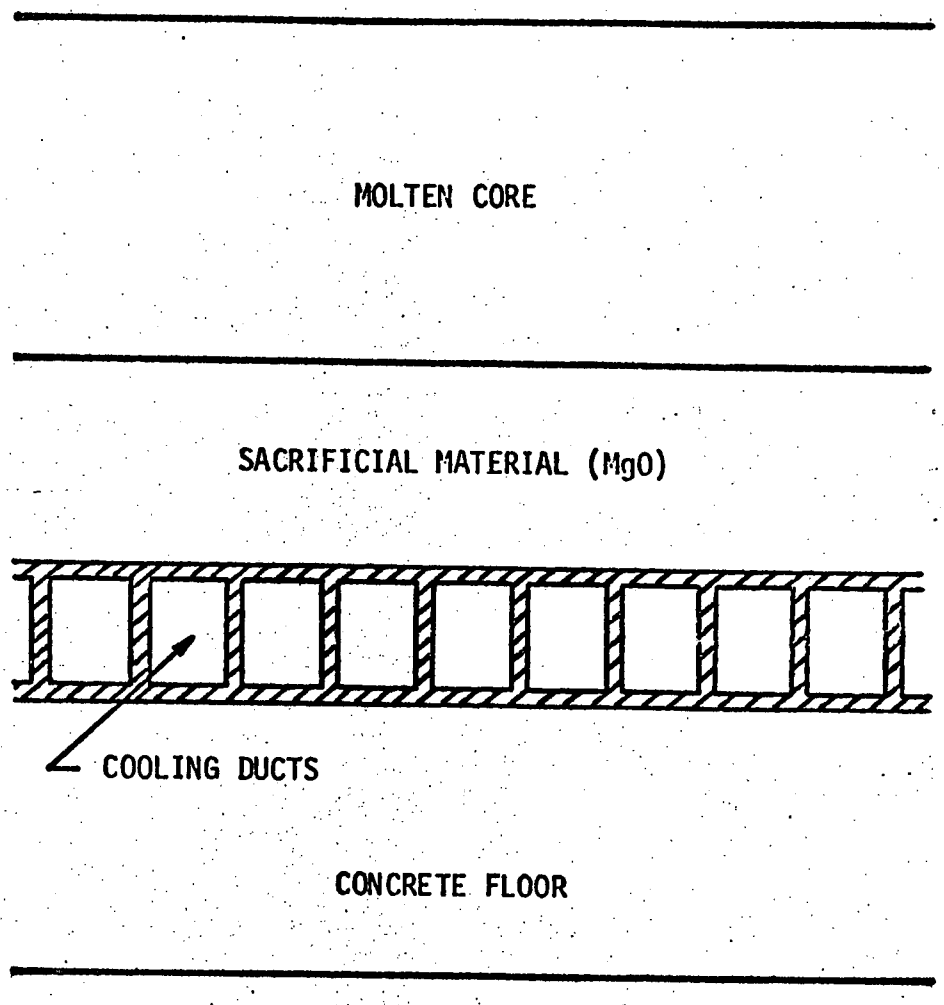
FNP


SOLIDIFIED CRUST
MOLTEN POOL
SACRIFICIAL MATERIAL (MgO)
CONCRETE

Z/IP


TOP CRUST
SIDE CRUST
(MOLTEN POOL)
BOTTOM CRUST
COOLING COILS
OR DUCTS
(CONCRETE)
SACRIFICIAL
MATERIAL
(MgO)


MOLTEN CORE
SACRIFICIAL MATERIAL (MgO)
STEEL PLATE
COOLING COILS
CONCRETE FLOOR


MOLTEN CORE
SACRIFICIAL MATERIAL (MgO)
COOLING DUCTS
CONCRETE FLOOR

CRITERIA FOR CANDIDATE MATERIALS

- o CHEMISTRY COMPATIBLE WITH CORE DEBRIS
  - INSIGNIFICANT GAS/VAPOR GENERATION
- o LAYER THICKNESS
  - LIMIT DOWNWARD THERMAL GRADIENT
  - LIMIT UPWARD RADIATION

200

FUTURE WORK

- ALTERNATIVE CORE RETENTION MATERIALS.
- PHYSICALLY MODELED COOLING SYSTEMS.
- REPLACE UO_2 POOL WITH CORIUM.
- INCLUDE MOLTEN STEEL IN POOL.
- ASSESS IMPACT OF WATER IN CAVITY.

VIEWGRAPHS ACCOMPANYING PRESENTATION

BY D. SWANSON

ASAI

June 3, 1980

MATERIALS SELECTION CONSIDERATIONS

- MELTING POINT
- BOILING POINT
- DENSITY
- EASE OF FABRICATION
- TOXICITY
- COST

Table I: Elements and Compounds with Densities Greater than 11.0 g/cc

Compound or element	Density (g/cc)	Melting Point (°C)	Boiling Point (°C)
Gold	19.32	1064	2807
Hafnium	13.31	2227	4602
Hafnium Carbide	12.2	3890	----
Lead	11.34	327.5	1740
Mercury	13.59	-38.87	356.6
Mercuric Oxide	11.1	d(500)	----
Osmium	22.48	3045	5027
Osmium Dioxide	11.37	d(500)	----
Palladium	12.02	1552	3140
Rhenium	20.53	3180	5627
Rhenium Oxide	11.4	d(1000)	----
Rhodium	12.4	1966	2727
Ruthenium	12.3	2310	3900
Tantalum	16.6	2996	5425
Tantalum Boride	11.15	3000	----
Tantalum Carbide	13.9	3880	5500
Tantalum Nitride	16.3	3360	----
Thallium	11.85	303.5	1457
Thorium	11.7	1750	----
Tungsten	19.35	3410	5660
Tungsten Carbide	15.63	2870	6000
Tungsten Dicarbide	17.15	2860	6000
Tungsten Dioxide	12.11		800 (sub)

Uranium	18.95-19.05	1132	3818
Uranium Boride	12.7	2365	
Uranium Dicarbide	11.28	2350-2400	4370
Uranium Hydride	11.4	Unstable	
Uranium Nitride	14.31	2630	
Uranium Dioxide	10.96	2878	3880

Table II: High Density, High Melting Point Compounds

Compound or element	Density	Melting Point (°C)	Boiling Point (°C)
Hafnium Carbide	12.2	3890	?
Tantalum	16.6	2996	5425
Tantalum Boride	11.15	3000	?
Tantalum Carbide	13.9	3880	5500
Tantalum Nitride	16.3	3360	?
Tungsten	19.35	3410	5660
Tungsten Carbide	15.63	2870	6000
Tungsten Dicarbide	17.15	2860	6000
Uranium Dioxide	10.96	2860	3880

Table III: Enthalpies of High Density, High Melting Point Materials

Material	cc melted/kcal	Melting point (°C)	Density
TaC	1.6	3927	14.5
MgO	2.4	2853	3.5
ZrO_2	2.3	2760	5.7
UO_2	3.7	2860	8.7 (liquid)
ThO_2	4.1	3300	9.95

SOME ZIP ALTERNATIVES

- WHERE RADIATION IS A PROBLEM AND SPACE EXISTS:
  - POUR DENSE, HIGH MELTING GRANULES ON THE CONCRETE FLOOR
  - POUR ALTERNATE LAYERS OR A SANDWICH OF MATERIALS (EXAMPLE: W OR UO_2 ON MgO)
- WHERE RADIATION AND SPACE ARE NOT PROBLEMS:
  - INSTALL A CORE LADLE (INVERTED ARCH OF MgO, ETC.)
- WHERE SPACE IS A PROBLEM AND RADIATION IS NOT:
  - RELOCATE INSTRUMENTATION AND INSTALL A CORE LADLE
  - INSTALL A THIN LAYER OF REFRACTORY COVERING AN ACTIVE COOLING SYSTEM
  - INSTALL A DEVICE TO CHANNEL AWAY THE MOLTEN CORE DEBRIS TO ANOTHER LOCATION
- WHERE SPACE AND RADIATION ARE PROBLEMS:
  - TUNNEL UNDER THE PLANT FROM OUTSIDE
    - INSTALL PASSIVE CORE LADLE
    - INSTALL COOLING, EITHER ACTIVELY OR BY NATURAL CONVECTION

208

VIEWGRAPHS ACCOMPANYING PRESENTATION

BY D. POWERS

SANDIA

June 3, 1980

PURPOSE

* STOP BASEMAT PENETRATION :
  A) LIQUID PATHWAY RELEASE
  B) PUBLIC CONFIDENCE

* AVOID NON-CONDENSABLE GAS GENERATION

* AVOID HYDROGEN AND CO PRODUCTION

DESIGN CONCEPTS

A) REFRACTORY -
(CRBR PARALLEL, FNP)

B) SACRIFICIAL -
(GERMAN GAS COOLED)

C) ACTIVE SYSTEM -
(SNR 300)

D) HYBRID SYSTEM -
(POWER REQUIRED IN TIME)

Figure 112-1

!! NEEDED !!

A SYSTEMS ANALYSIS TO DETERMINE IMPROVEMENTS THAT ARE PROVIDED BY A CORE RETENTION DEVICE.

CORE RETENTION MATERIALS

SACRIFICIAL MATERIALS :

* BORAX
* BASALT
* METALS

REFRACTORY MATERIALS :

* MgO
* HIGH-ALUMINA-CEMENT
* URANIA
* FIREBRICK

MgO

* DESIGN IS FEASIBLE.
* EROSION PROCESS IS DIFFERENT THAN CONCRETE
* DESIGN EVALUATION IS DIFFICULT.

CRITICAL DESIGN FEATURES OF A REFRACTORY RETENTION DEVICE

* BRICK STABILITY.
* ANCHOR DEVICES.
* THERMAL EXPANSION ACCOMODATION.
* SUPPORT STRUCTURE STABILITY.
* DELAY TIME.

REFRACTORY ISSUES

1) ATTACK MECHANISM

2) EROSION RATE

3) HEAT TRANSFER PROCESSES

4) AEROSOL GENERATION

5) BRICK FLOATATION

6) FRACTURE & SHOCK BEHAVIOR

7) CRACK PENETRATION

RETROFIT POSSIBILITY

A THIN (<2') DESIGN PROVIDES ONLY A SMALL DELAY.

A THICKER DEVICE REQUIRES PLANT MODIFICATIONS.

POWER REQUIRED FOR ACTIVE DEVICES

HYBRID DEVICES REQUIRE ROOM AND POWER AFTER THE DESIGN DELAY.

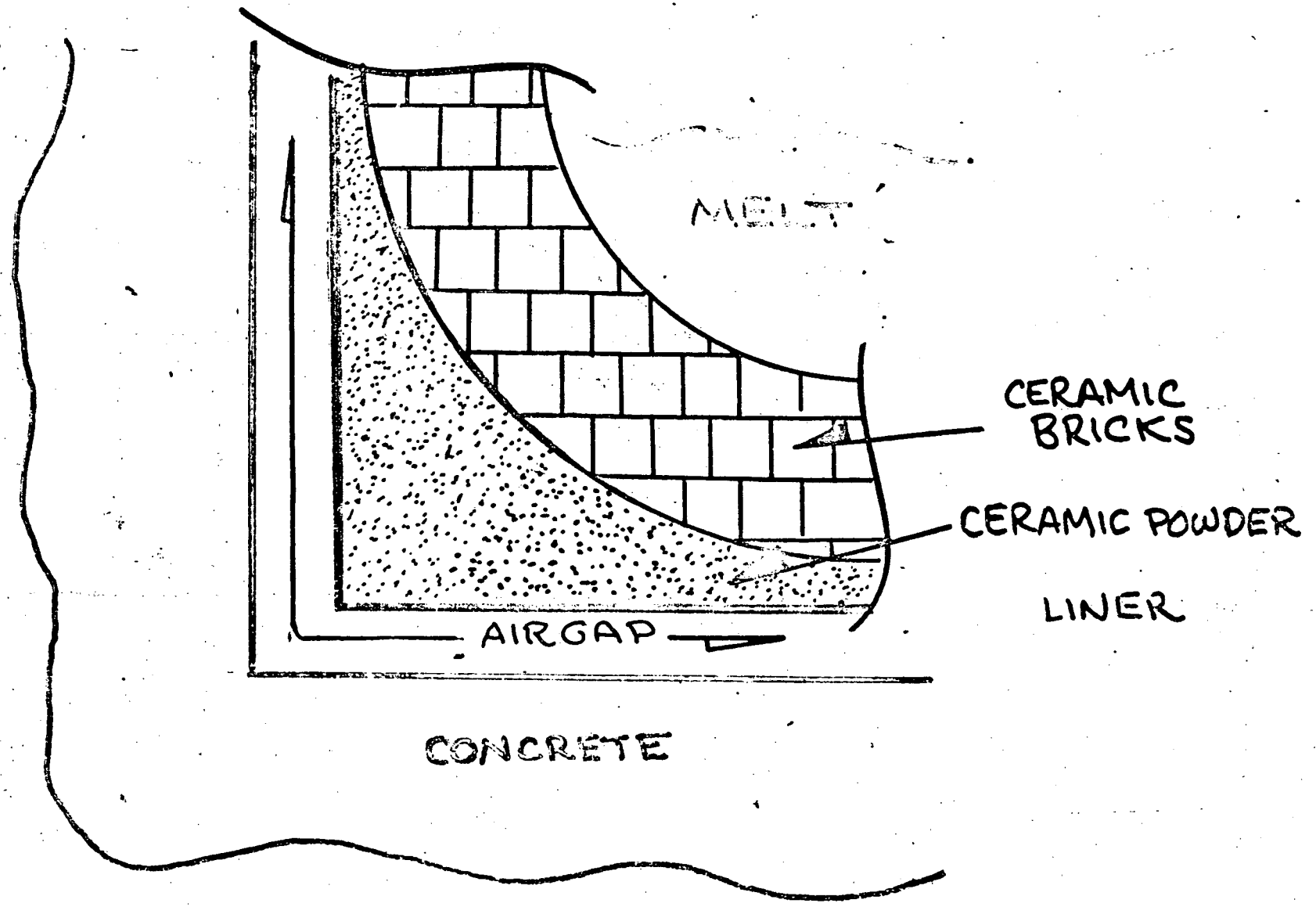
CONCLUSIONS FROM MODEL

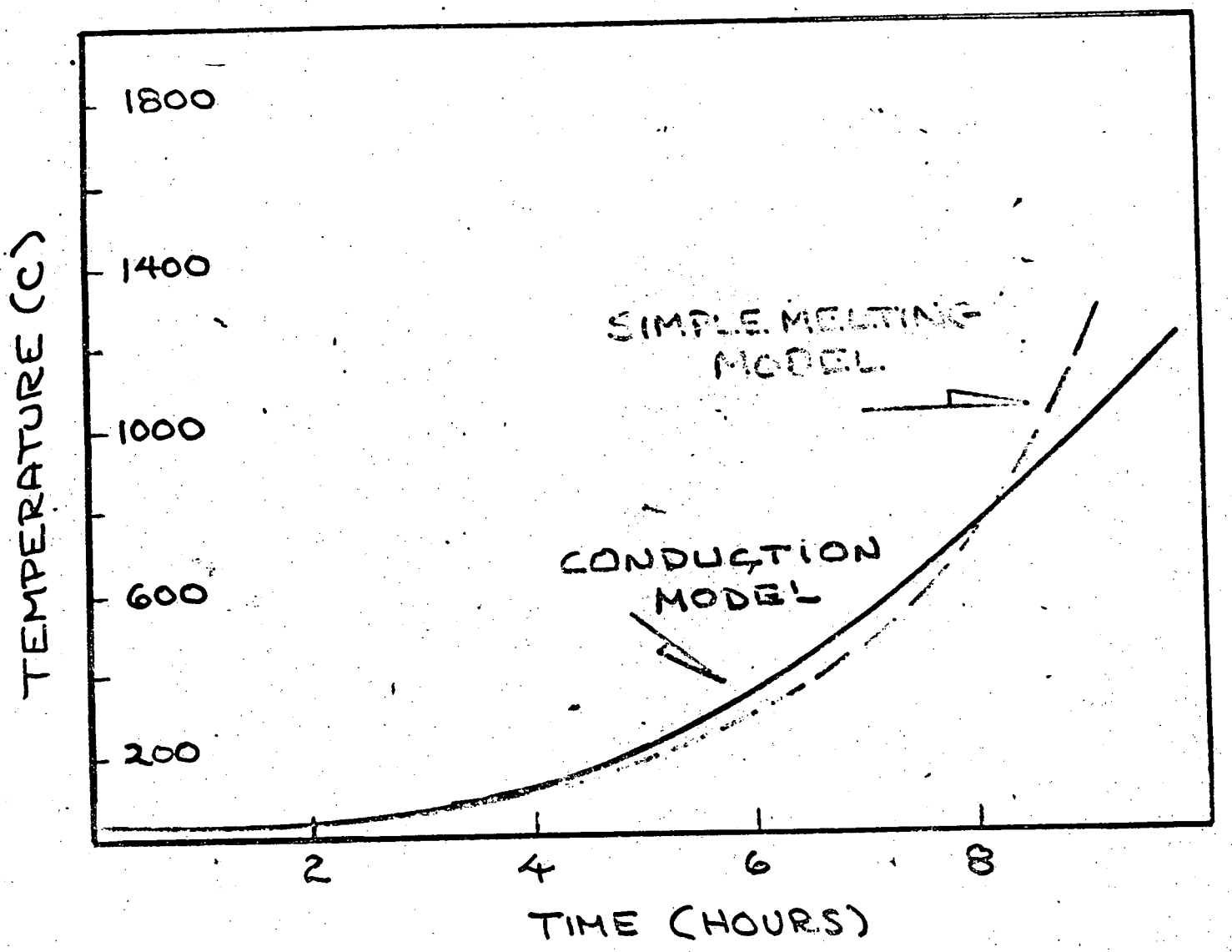
* FEW FEATURES MAY BE CONTROLLED BY DESIGN OF DEVICE

  * MELT STAYS HOTTER ON MgO THAN ON CONCRETE

    * WATER HAS LITTLE IMPACT

      * MECHANISM OF ATTACK IS MOST IMPORTANT


MELT
CERAMIC BRICKS
CERAMIC POWDER LINER
AIRGAP
CONCRETE

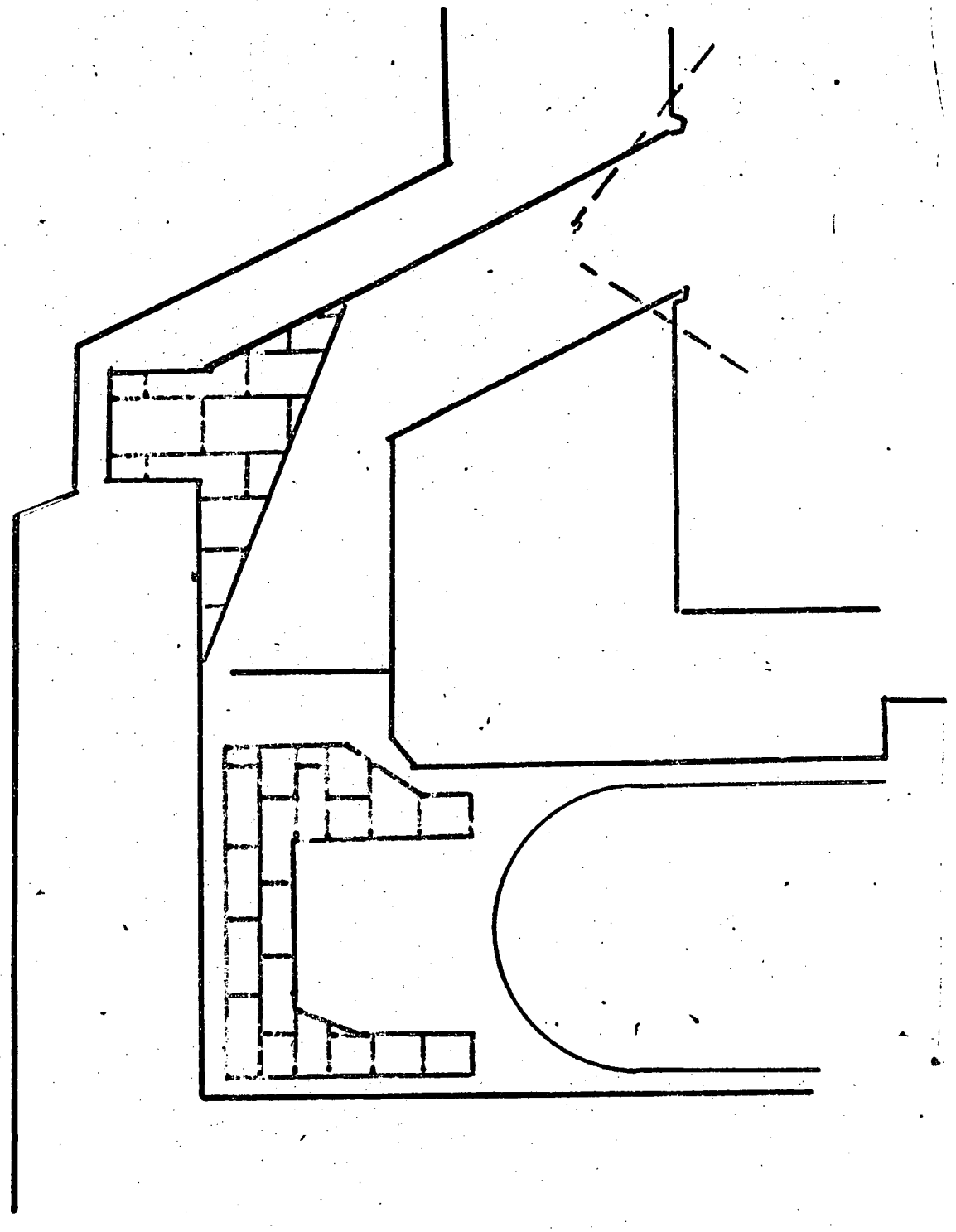

TEMPERATURE (C)
1800
1400
1000
600
200
SIMPLE MELTING MODEL
CONDUCTION MODEL
2
4
6
8
TIME (HOURS)

A PASSIVE NATURAL CIRCULATION SCHEME IS POSSIBLE IF :

*) MODIFICATIONS FOR A 2' THICK DEVICE CAN BE MADE.

*) CONDENSATION WATER SUPPLY IS ADEQUATE.

*) WATER IS DIVERTED AROUND THE DEVICE.



CURRENT EFFORTS

1) LARGE-SCALE FUEL MELT TESTS

2) SUSTAINED CORIUM TESTS

3) TESTS WITH CORE RETENTION MATERIALS

4) IN-PILE/OUT-OF-PILE DEBRIS BEHAVIOR COMPARISONS

5) CODE COMPARISON TESTS

6) COOLANT-DEBRIS-CONCRETE TESTS

INNATE :

$MgO(c) \rightarrow Mg(g) + 1/2\ O_2(g)$

$MgO(c) + UO_2(c) \rightarrow Mg(g) + UO_3(g)$

GRAIN BOUNDARY :

$SiO_2(c) \rightarrow SiO(g) + 1/2O_2(g)$

$Fe_3O_4(c) \rightarrow 3FeO(c) + 1/2O_2(g)$

IMPURITY :

$Mg(OH)_2(c) \rightarrow MgO(c) + H_2O(g)$

CUTTING FLUIDS

OTHER CORE RETENTION MATERIAL RESEARCH

* *CASTABLE REFRACTORIES*
* *SACRIFICIAL MATERIALS*