Enclosure 6

SCRUBBING OF AEROSOLS BY WATER POOLS UNDER SEVERE ACCIDENT CONDITIONS

by

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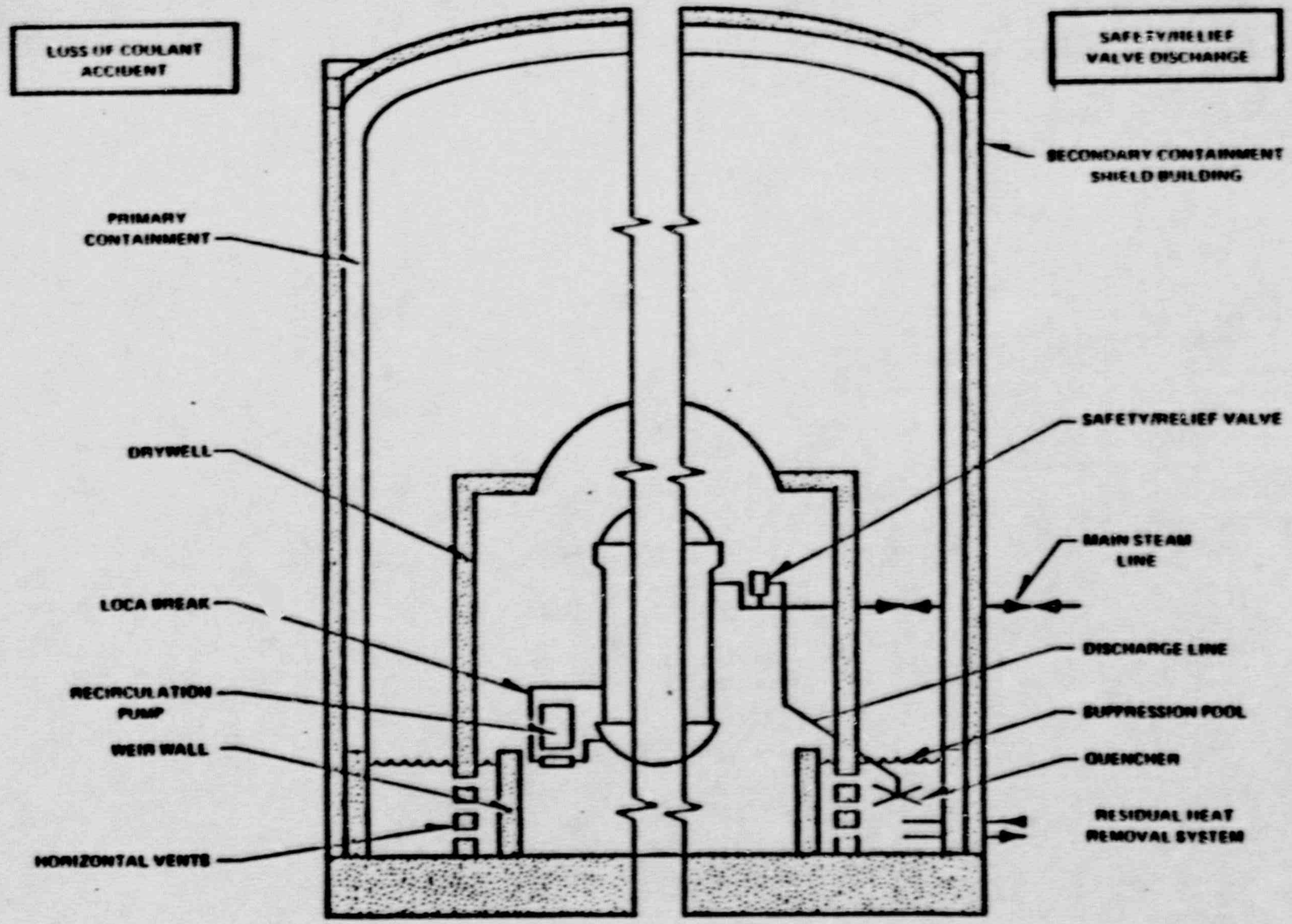
April 9, 1986

Bethesda, MD

EPRI
Electric Power
Research Institute


LOSS OF COOLANT ACCIDENT
SAFETY/RELIEF VALVE DISCHANGE
SECONDARY CONTAINMENT SHIELD BUILDING
PRIMARY CONTAINMENT
DRYWELL
SAFETY/RELIEF VALVE
MAIN STEAM LINE
LOCA BREAK
DISCHARGE LINE
RECIRCULATION PUMP
SUPPRESSION POOL
WEIR WALL
QUENCHER
RESIDUAL HEAT REMOVAL SYSTEM
HORIZONTAL VENTS

OBJECTIVES

- TO DETERMINE THE FRACTION OF FISSION PRODUCT AEROSOL WHICH ARE SCRUBBED FROM A GAS STREAM BY PASSING THROUGH POOLS OF WATER

- TO DEVELOP AND VALIDATE A PREDICTIVE CAPABILITY FOR POOL SCRUBBING (SUPRA) APPLICABLE TO SEVERE ACCIDENT CONDITIONS.

VARIABLES AFFECTING THE SCRUBBING OF AEROSOLS

1. INJECTOR GEOMETRY

- SPARGERS/ORIFICES
- DOWNCOMERS
- HORIZONTAL VENTS

2. POOL CHARACTERISTICS

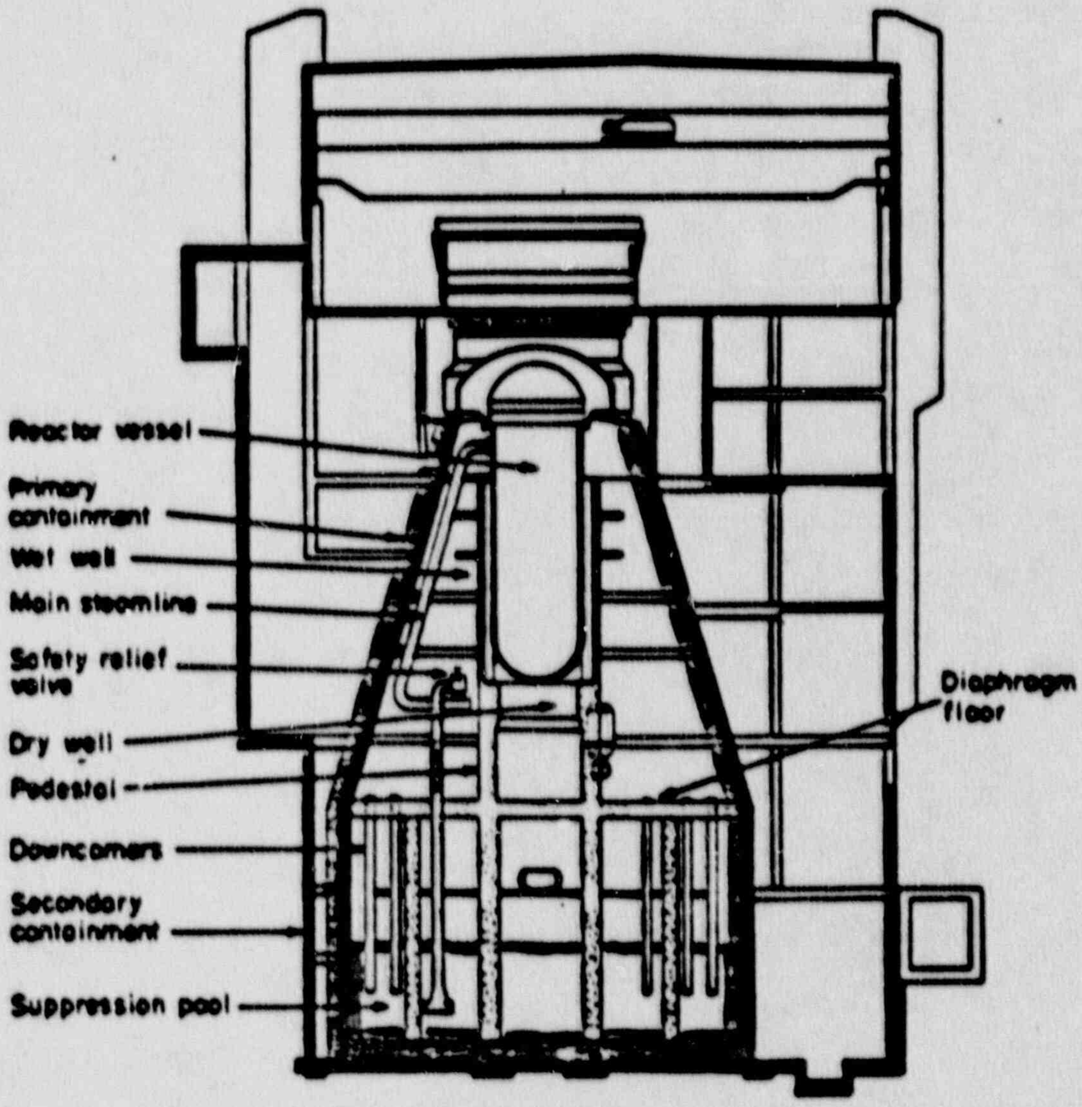
- SUBCOOLING
- SUBMERGENCE
- IMPURITIES

3. CARRIER GAS

- COMPOSITION
- FLOWRATE

4. AEROSOL CHARACTERISTICS

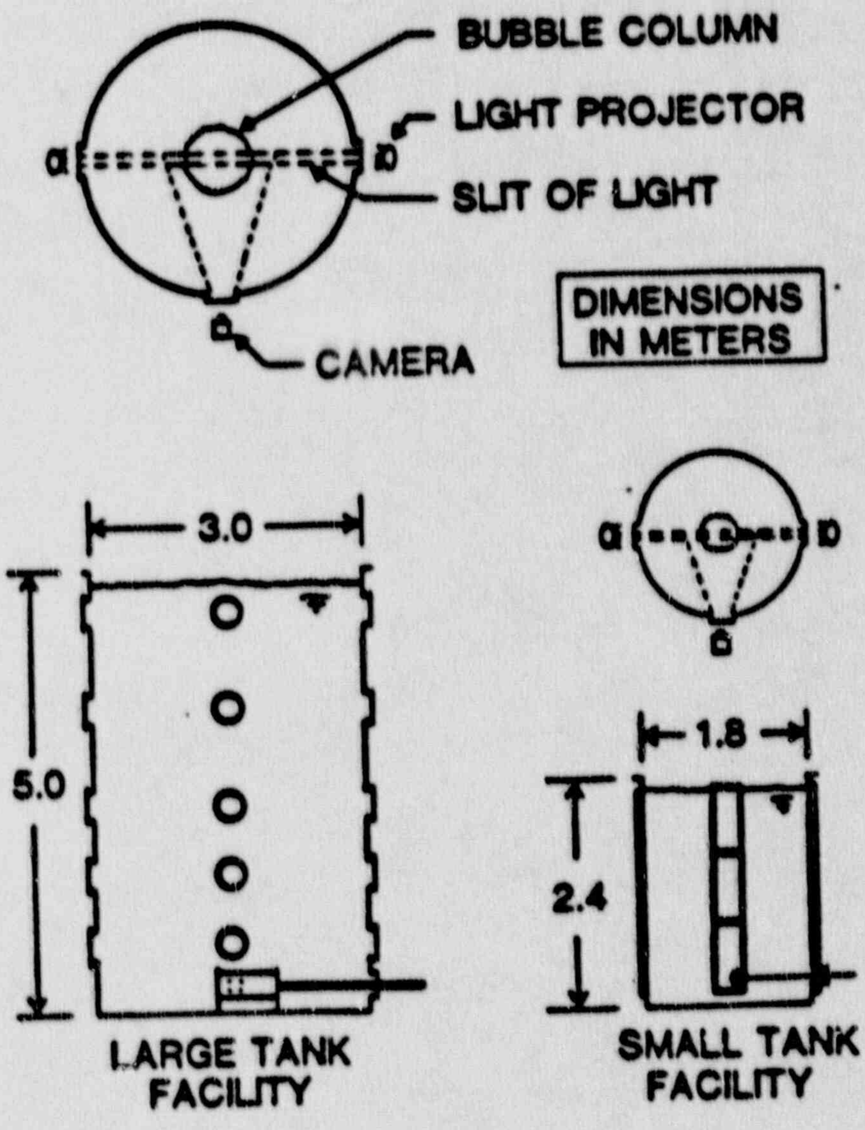
- SIZE
- MORPHOLOGY
- SOLUBILITY

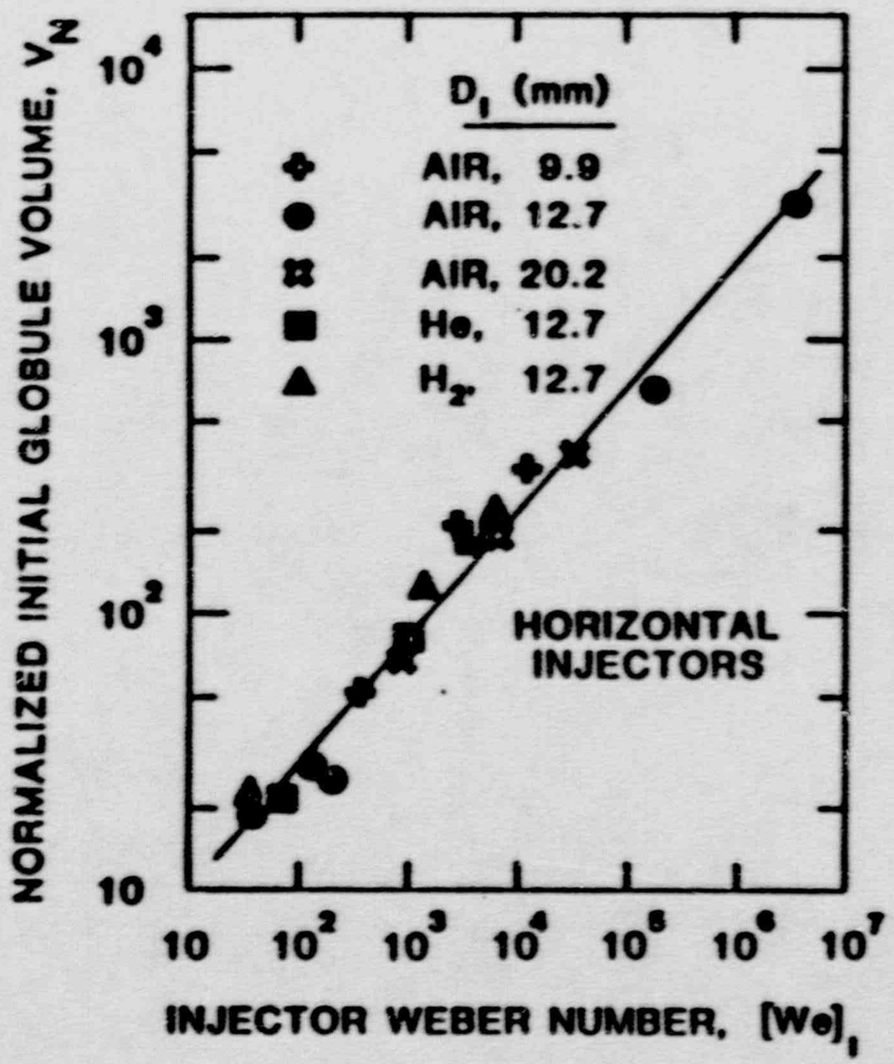


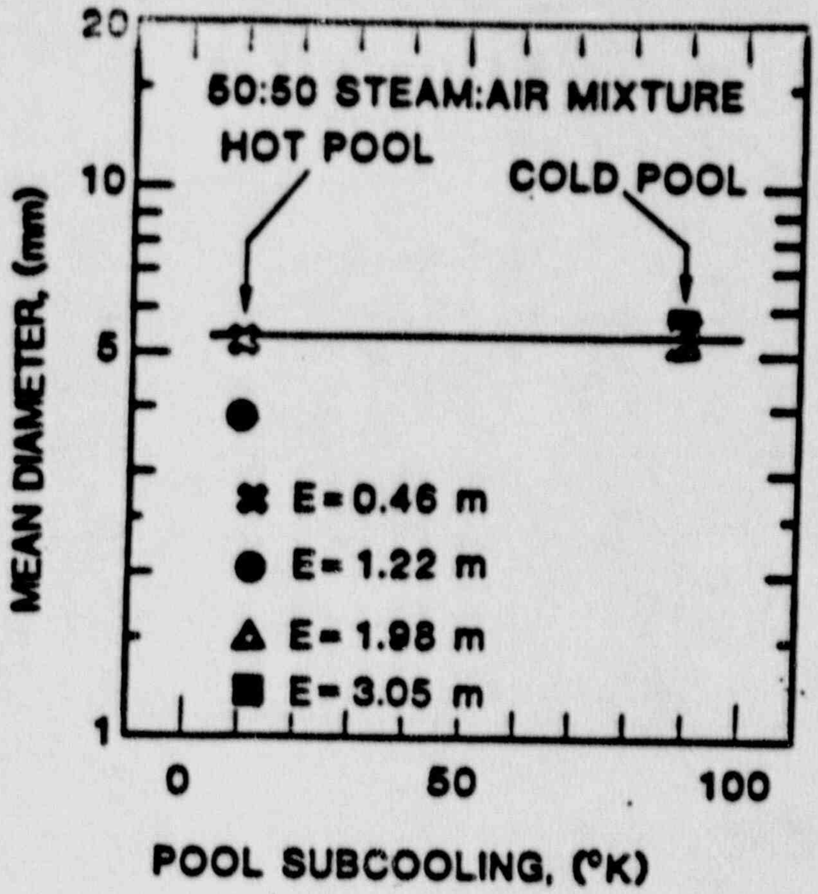
BWR, Mark-II primary and secondary containment

EXPERIMENTAL FACILITY

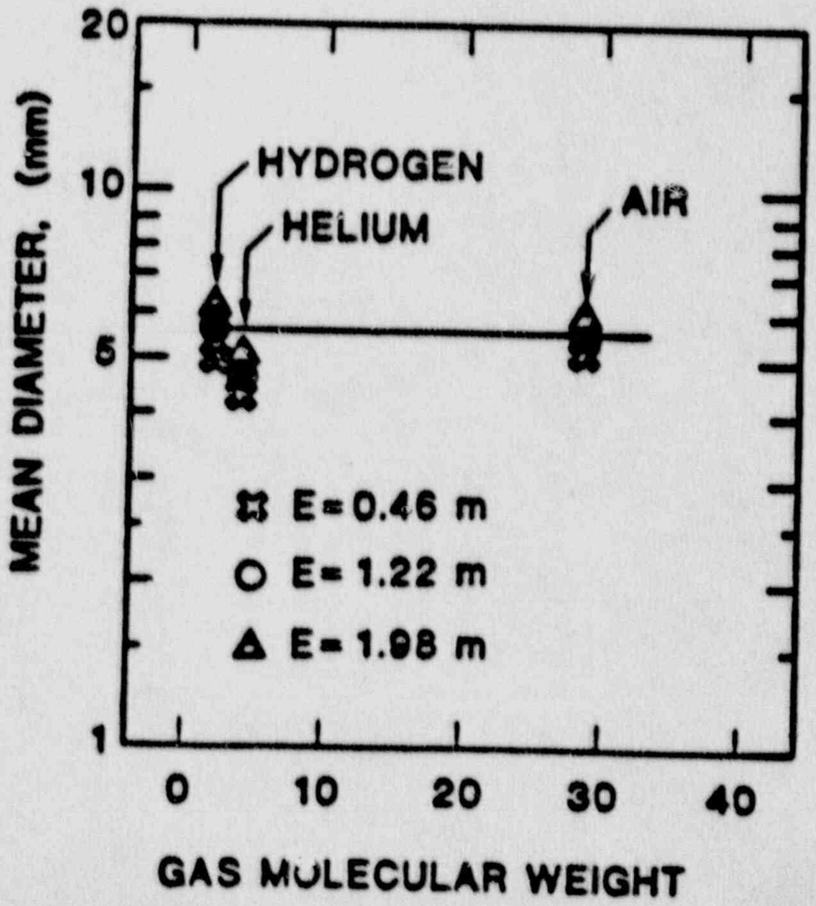
- AEROSOL GENERATION SYSTEM
- WATER TANK AND INJECTION SYSTEM
- MEASUREMENT SYSTEM


BUBBLE COLUMN
LIGHT PROJECTOR
SLIT OF LIGHT
CAMERA
DIMENSIONS IN METERS
3.0
5.0
1.8
2.4
LARGE TANK FACILITY
SMALL TANK FACILITY


NORMALIZED INITIAL GLOBULE VOLUME, V_N
10^4
10^3
10^2
10
D_I (mm)
AIR, 9.9
AIR, 12.7
AIR, 20.2
He, 12.7
H_2, 12.7
HORIZONTAL INJECTORS
10
10^2
10^3
10^4
10^5
10^6
10^7
INJECTOR WEBER NUMBER, $[We]_I$



50:50 STEAM:AIR MIXTURE
HOT POOL
COLD POOL
E=0.46 m
E=1.22 m
E=1.98 m
E=3.05 m
MEAN DIAMETER, (mm)
POOL SUBCOOLING, (°K)
20
10
5
1
0
50
100



HYDROGEN
HELIUM
AIR
E=0.46 m
E=1.22 m
E=1.98 m
MEAN DIAMETER, (mm)
GAS MOLECULAR WEIGHT
20
10
5
1
0
10
20
30
40

EXPERIMENTAL OBJECTIVES

TO MEASURE:

1. THE INJECTED MASS, M_I
2. THE SCRUBBED MASS, M_S
3. THE ESCAPED MASS, M_O

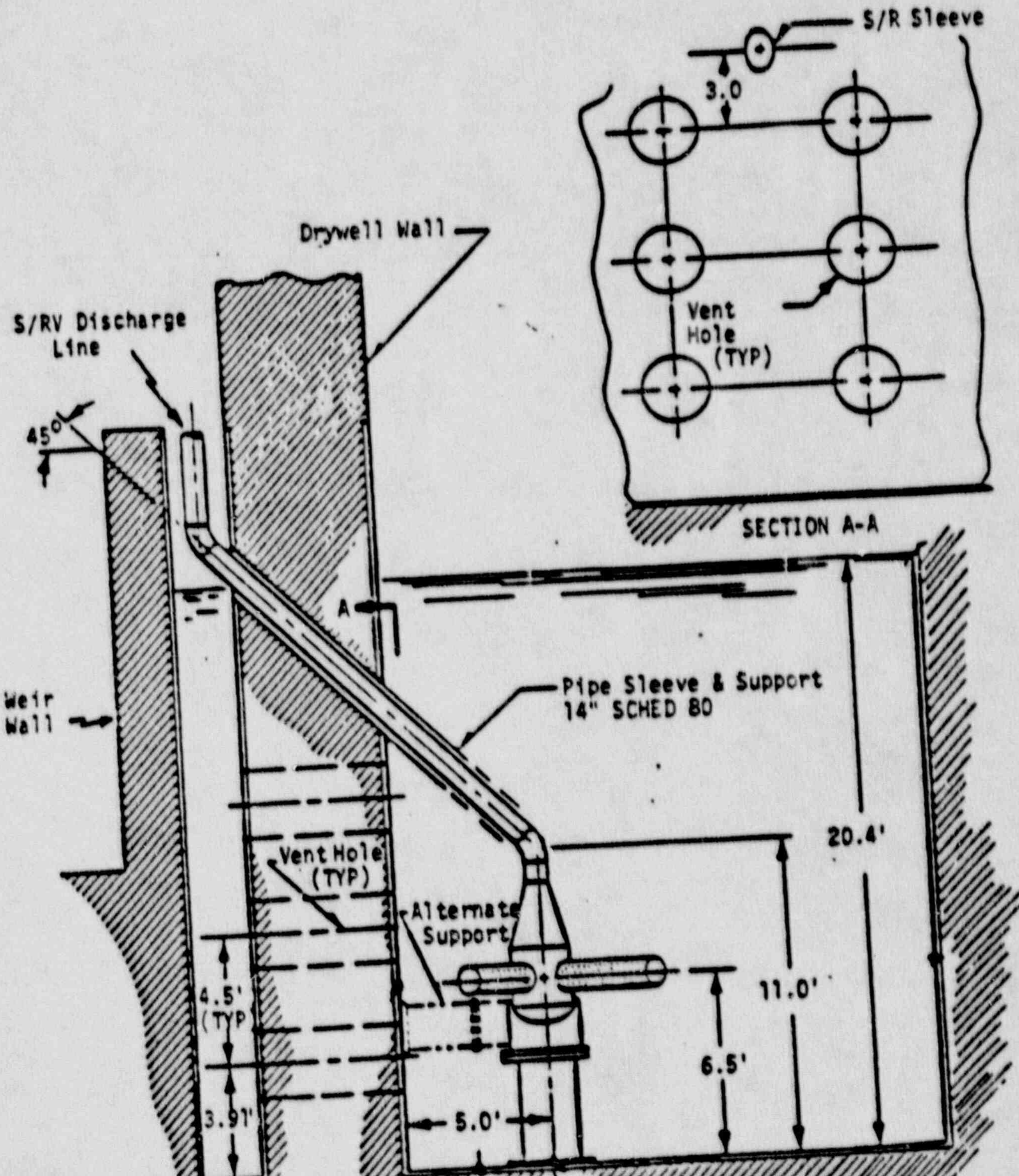
AS A FUNCTION OF THE PARTICLE SIZE AND OTHER PARAMETERS OF THE SYSTEM.

DEFINITION: DECONTAMINATION FACTOR, DF

$$\boxed{DF = \frac{M_I}{M_O} = \frac{M_S + M_O}{M_O} = \frac{M_I}{M_I - M_S}}$$

SUMMARY OF THE PHASE I SCRUBBING TEST MATRIX

Parameter	Experimental Range
Injection velocity	0.24 - 7.1 m/s
Submergence	0.152 - 1.65 m
Pool temperature	293 - 373 K
Gas temperature	293 - 395 K
Orifice diameter	Fixed (1.27 cm)
Injector orientation	Fixed (horizontal)
Condensible/noncondensible ratio	0 - 0.95 (mass fraction)
Aerosol density	4.5 - 6.0 (g/cc)
Aerosol size (mass median diameter)	0.2 - 3.0 μm

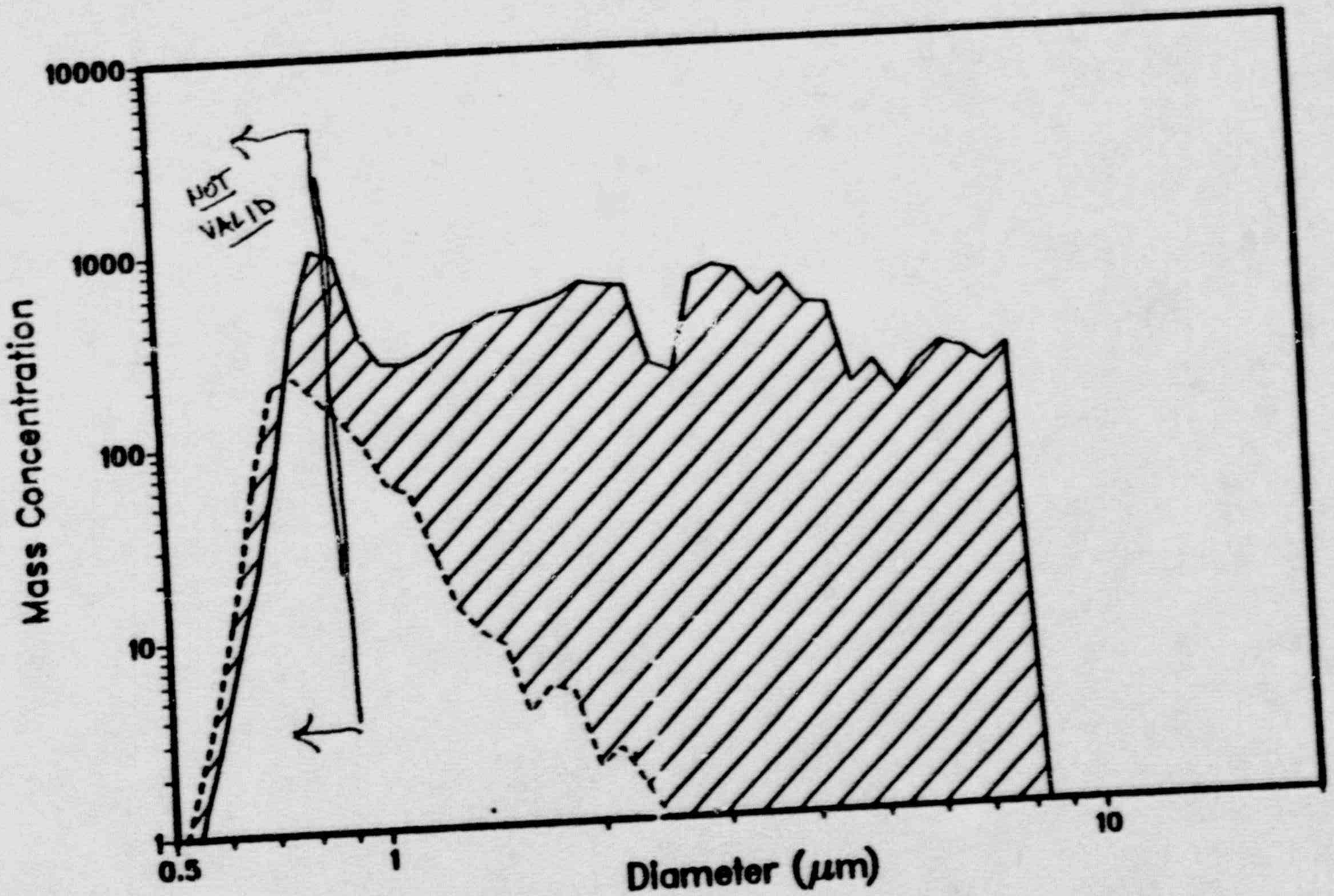


S/R Sleeve
3.0
Vent
Hole
(TYP)
SECTION A-A
Drywell Wall
S/RV Discharge
Line
45°
A
Weir
Wall
Pipe Sleeve & Support
14" SCHED 80
Vent Hole
(TYP)
Alternate
Support
20.4'
11.0'
4.5'
(TYP)
6.5'
3.91'
5.0'
2.17'

Temperature	60°C			20°C
Submergence	8'		4'	8'
Aerosol Material	CsI	Sn	CsI	CsI
Flow Rate				
20 CFM		X(A)		
50 CFM	X	X	X	X
100 CFM		X		

(A) As low a flow as is practical

PHASE IIIA. SCRUBBING MATRIX



INJECTED (———) AND ESCAPED (-----) AEROSOL SIZE DISTRIBUTIONS FOR TEST S41M AS DETERMINED BY THE APS (Mass Concentration Expressed in ng/m^3)

Aerosol Material	Submergence, Ft.	C_4 Orifice Arrangement		Line Source	
		15 CFM	25 CFM	37 CFM	62 CFM
CsI	1.5	--	--	X	X
	5.5	X	X	X	X
	11	X	X	X	X
Sn	11	--	--	X	X

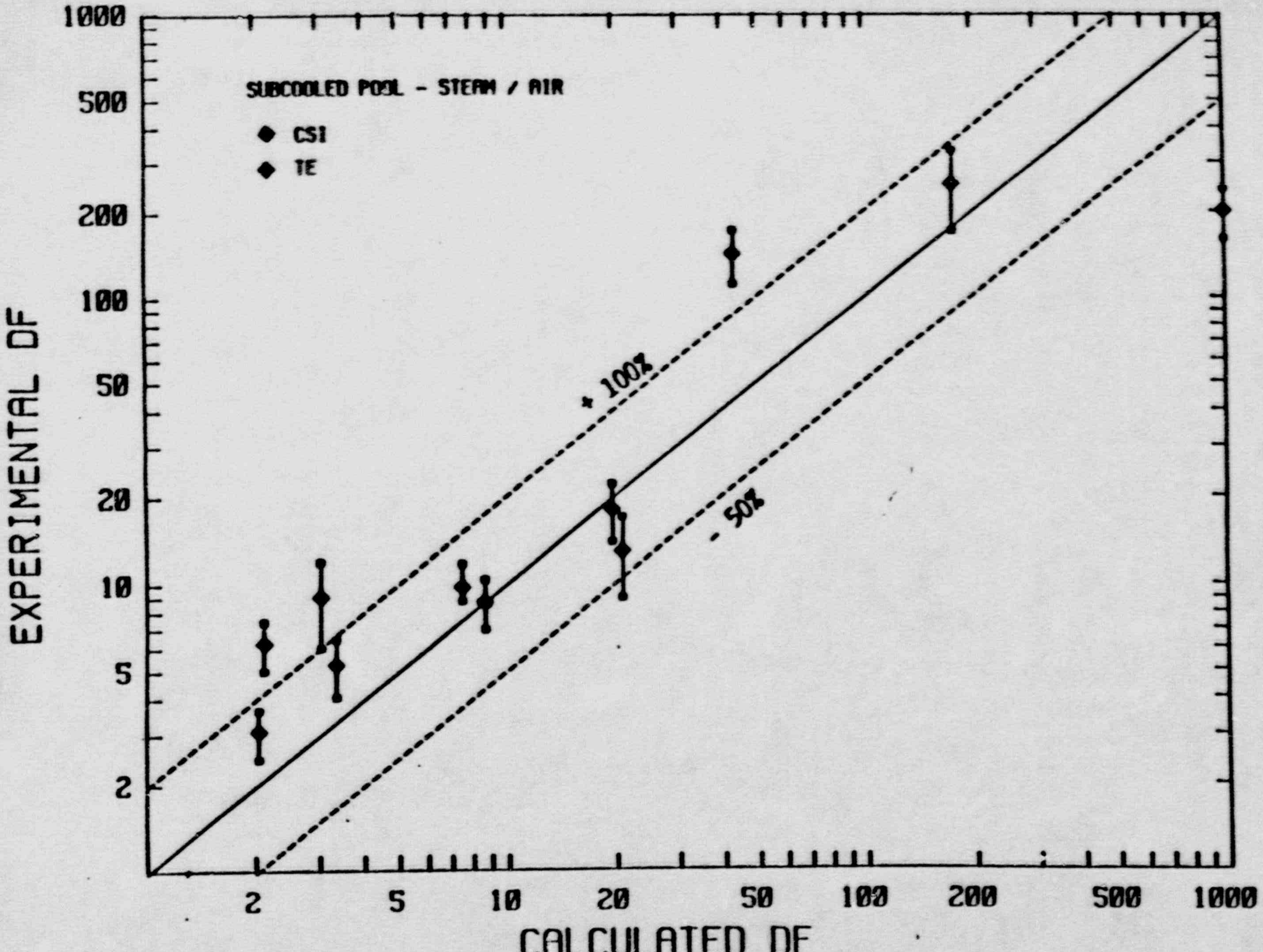
PHASE II SCRUBBING TEST MATRIX

CONFIGURATION/SPECIES CONSIDERED

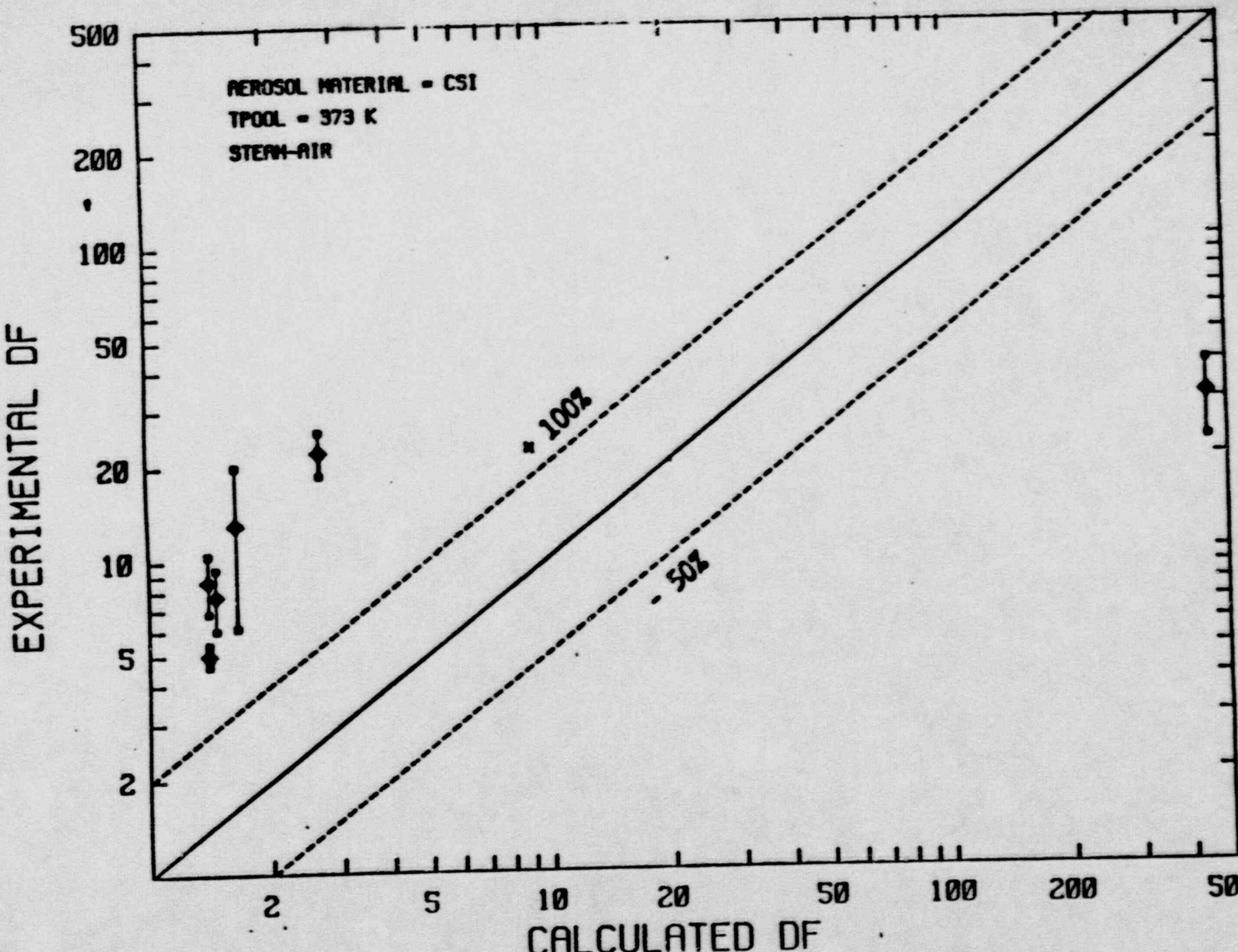
- INJECTION CONFIGURATION:
  - ORIFICE TYPE (T-, X-QUENCHER, ETC.)
  - DOWNCOMER
  - SIDE VENT
- SPECIES:
  - CONDENSIBLE: STEAM (H_2O)
  - NONCONDENSIBLE: AIR (A), HYDROGEN (H_2), CARBON DIOXIDE (CO_2) OR HELIUM (HE)
  - TRACE SPECIES: ELEMENTAL IODINE (I_2)
METHYL IODIDE (CH_3I)
  - AEROSOL: 20 SIZE BINS OF SINGLE MATERIAL OR LOG NORMAL SIZE DISTRIBUTION
- POOL CONDITIONS: SUBCOOLED
SATURATED

AEROSOL REMOVAL MECHANISMS IN SUPRA

MECHANISM	INJECTION ZONE	BUBBLE RISE ZONE	UPPER COMPARTMENT
SEDIMENTATION		X	X
BROWNIAN DIFFUSION	X	X	X
DIFFUSIOPHORESIS		X	X
CONVECTIVE DEPOSITION		X	X
THERMOPHORESIS		X	X
INERTIAL DEPOSITION			
- INTERNAL CIRCULATION	X	X	
- JET IMPACTION	X		

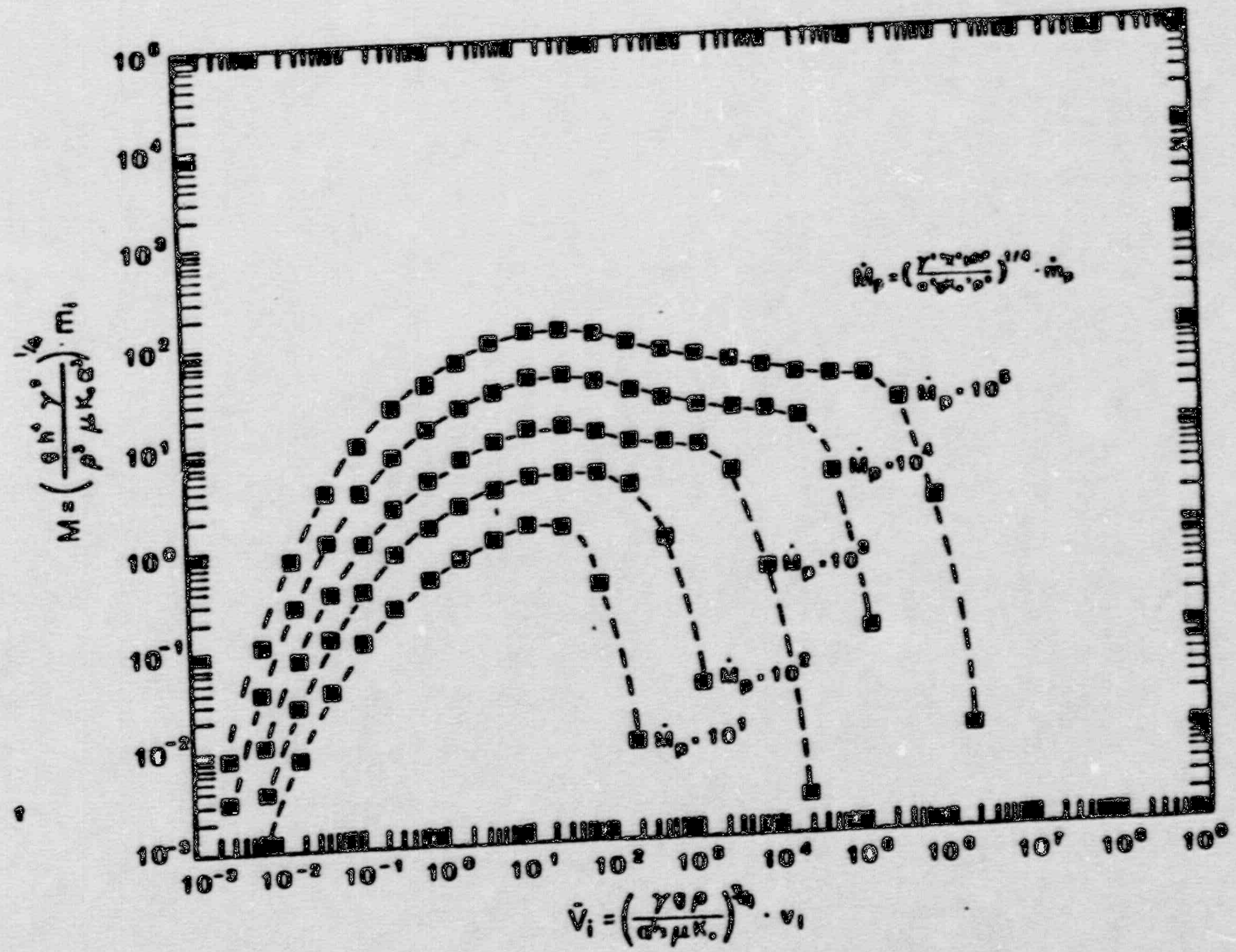


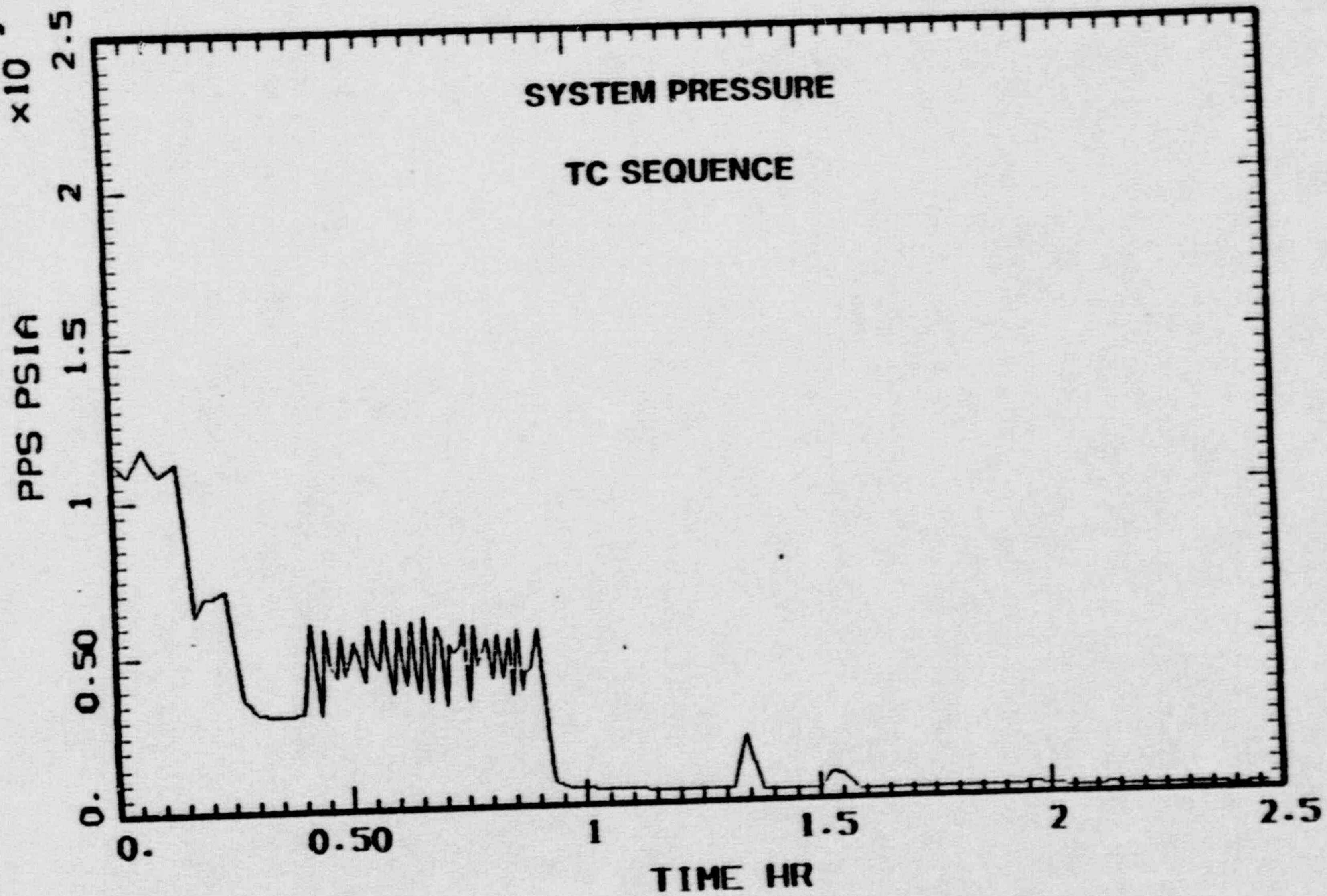
COMPARISON BETWEEN CALCULATED AND EXPERIMENTALLY INFERRED INTEGRAL DECONTAMINATION FACTORS FOR SUBCOOLED POOL AND STEAM-AIR MIXTURE



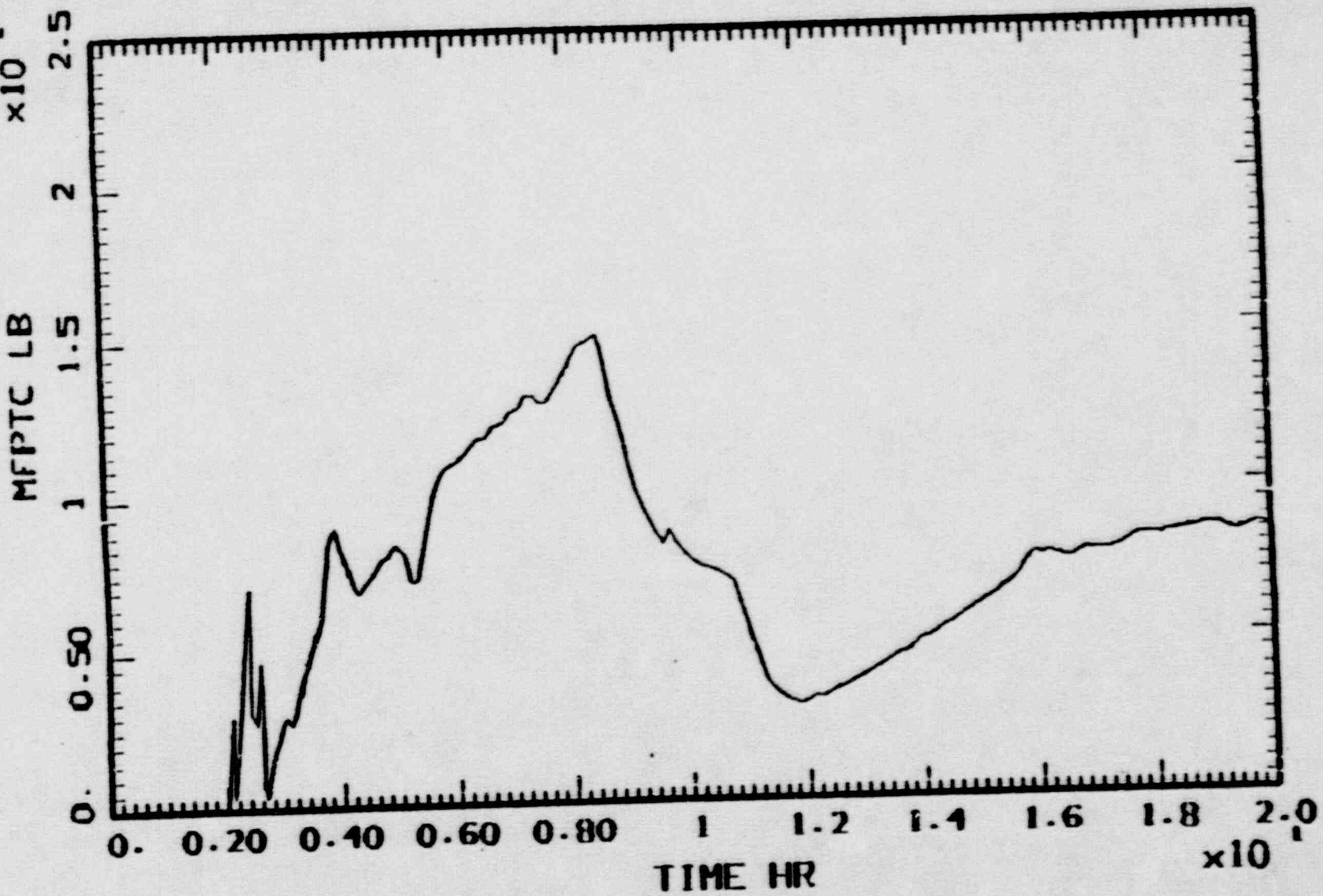
EXPERIMENTAL VS CALCULATED DF FOR HOT POOL

COMPARISON BETWEEN CALCULATED AND EXPERIMENTALLY INFERRED INTEGRAL DECONTAMINATION FACTORS FOR HOT POOL AND STEAM-AIR MIXTURE

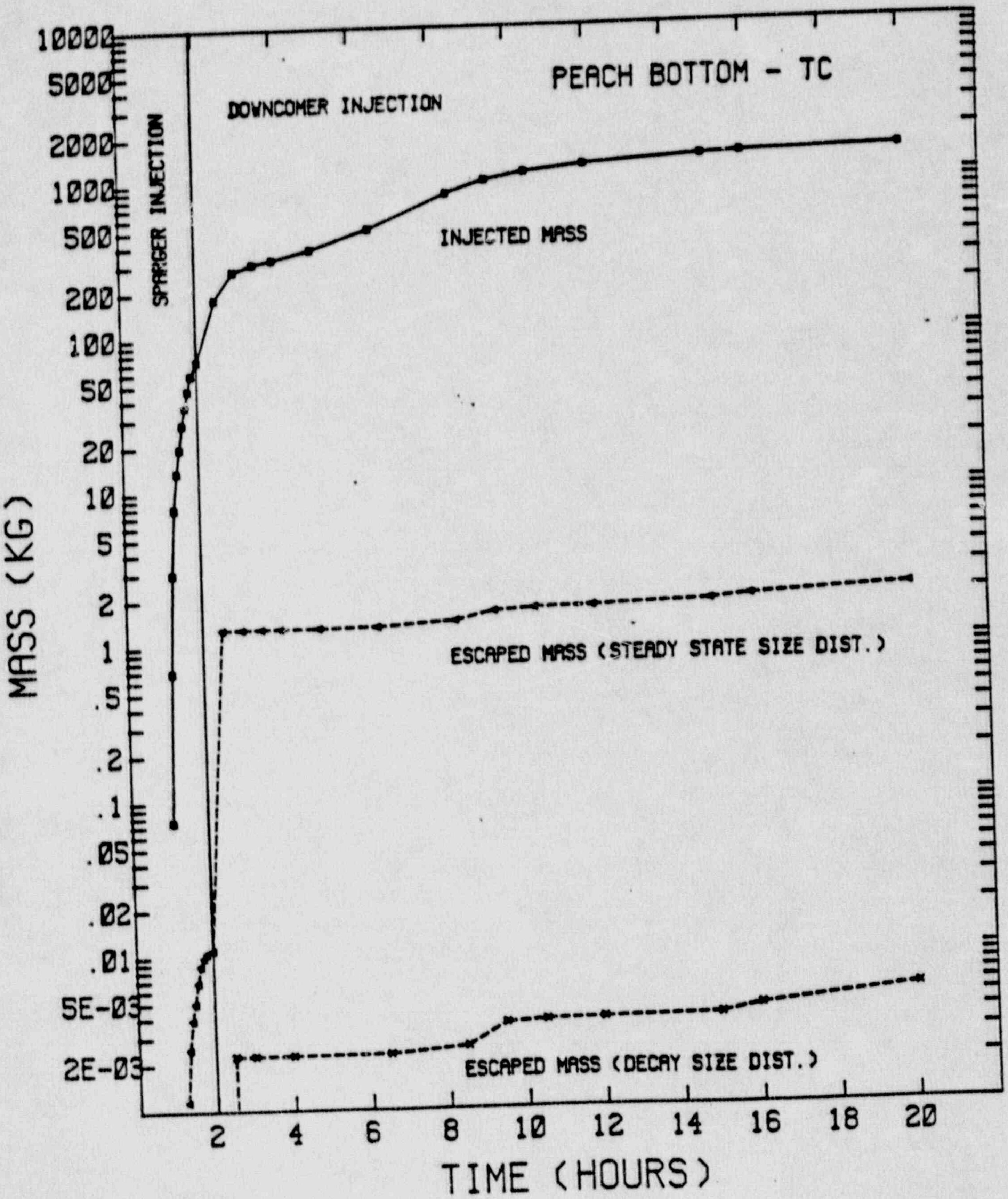

10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-3 10^-2 10^-1 10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9
Ṁp · 10^5
Ṁp · 10^4
Ṁp · 10^3
Ṁp · 10^2
Ṁp · 10^1



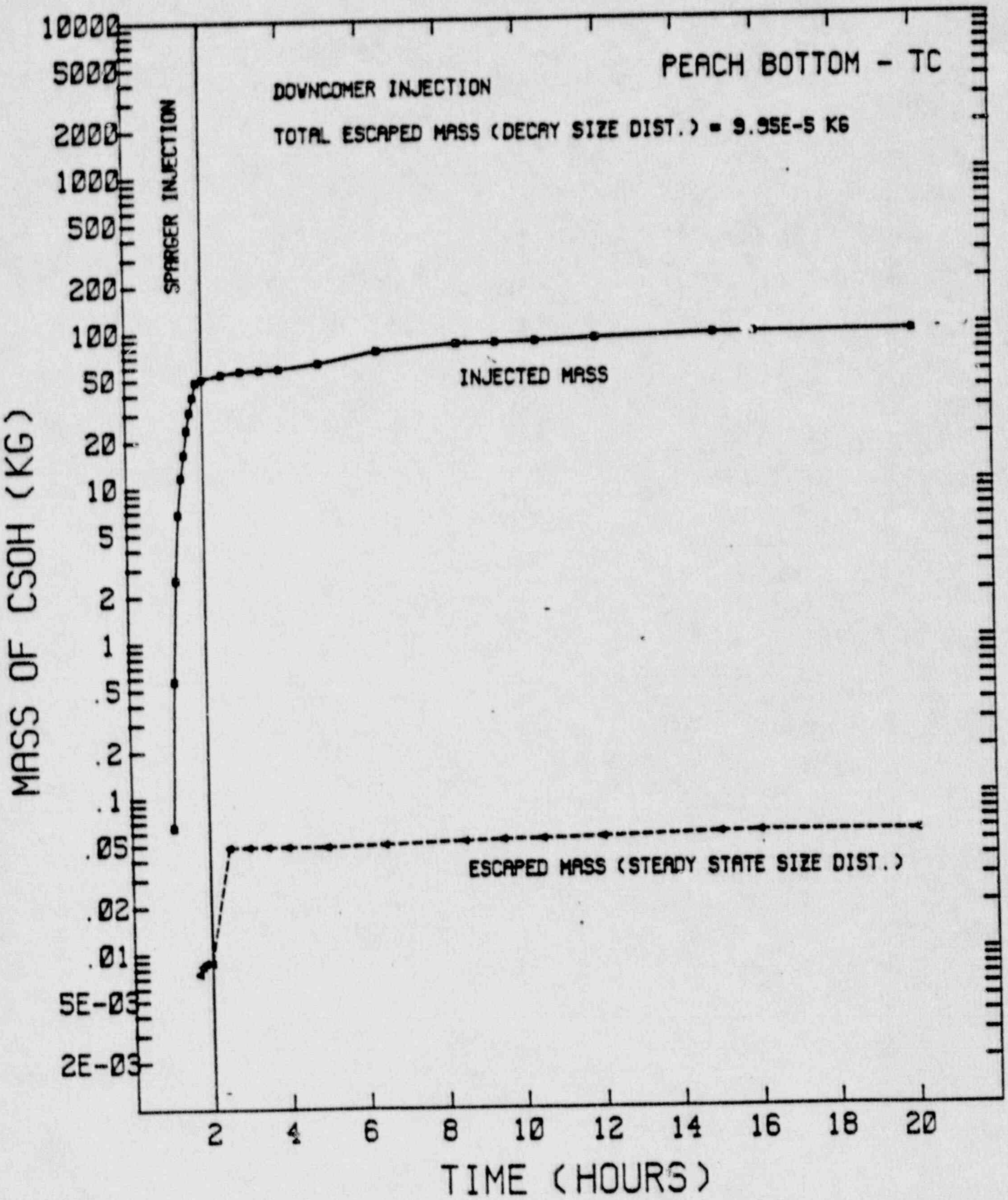
SYSTEM PRESSURE
TC SEQUENCE
PPS PSIA
×10³
0.
0.50
1
1.5
2
2.5
TIME HR



SUSPENDED AEROSOL MASS IN CONTAINMENT



PEACH BOTTOM - TC
DOWNCOMER INJECTION
SPARGER INJECTION
INJECTED MASS
ESCAPED MASS (STEADY STATE SIZE DIST.)
ESCAPED MASS (DECAY SIZE DIST.)
MASS (KG)
TIME (HOURS)
10000
5000
2000
1000
500
200
100
50
20
10
5
2
1
.5
.2
.1
.05
.02
.01
5E-03
2E-03
2
4
6
8
10
12
14
16
18
20



PEACH BOTTOM - TC
DOWNCOMER INJECTION
TOTAL ESCAPED MASS (DECAY SIZE DIST.) = 9.95E-5 KG
SPARGER INJECTION
INJECTED MASS
ESCAPED MASS (STEADY STATE SIZE DIST.)
MASS OF CSOH (KG)
10000
5000
2000
1000
500
200
100
50
20
10
5
2
1
.5
.2
.1
.05
.02
.01
5E-03
2E-03
2
4
6
8
10
12
14
16
18
20
TIME (HOURS)

DECONTAMINATION FACTORS

PEACH BOTTOM SEQUENCE TC

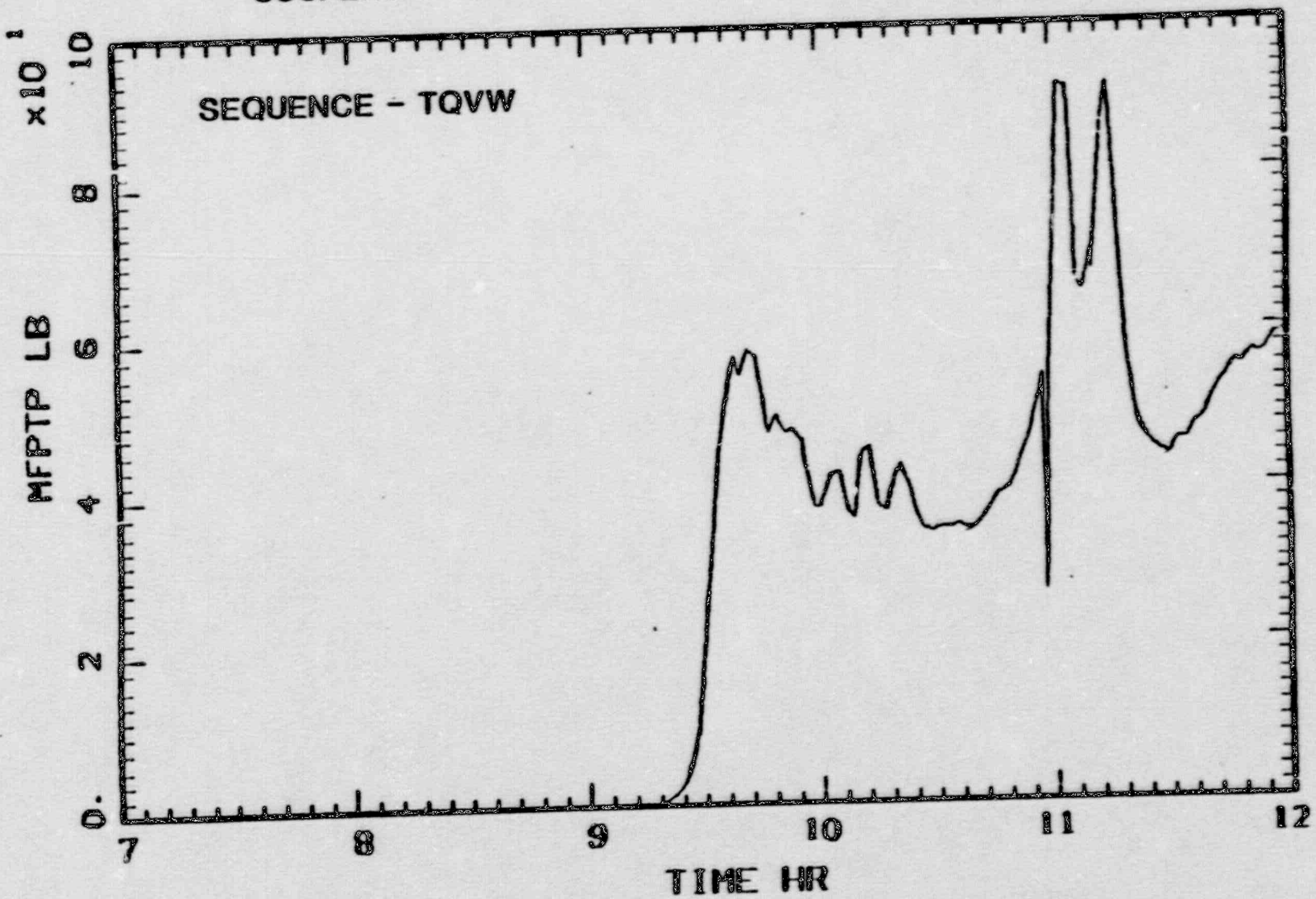
	STEADY STATE			DECAY		
	SPARGERS	DOWNCOMERS	TOTAL	SPARGERS	DOWNCOMERS	TOTAL
STRUCTURAL	4.18×10^{4}	649	654	2.17×10^{7}	2.45×10^{5}	2.47×10^{5}
C_SI	5858	909	1455	6.37×10^{6}	3.23×10^{5}	5.63×10^{5}
T_EO_2		1935	1935		5.07×10^{5}	5.07×10^{5}
C_SOH	5753	853	1601	6.24×10^{6}	4.54×10^{5}	9.25×10^{5}
TOTAL	6778	657	687	7.13×10^{6}	2.50×10^{5}	2.62×10^{5}

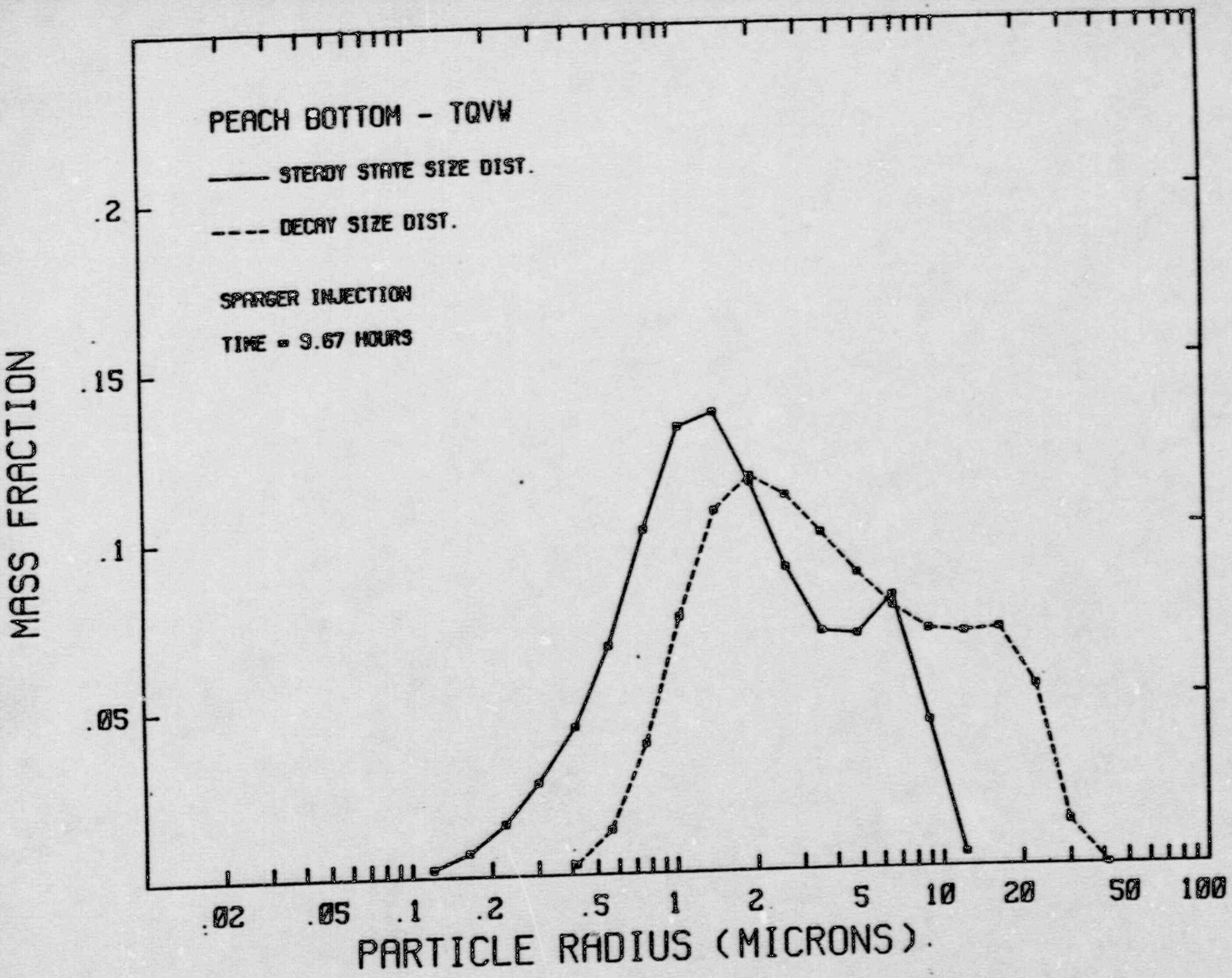
PEACH BOTTOM

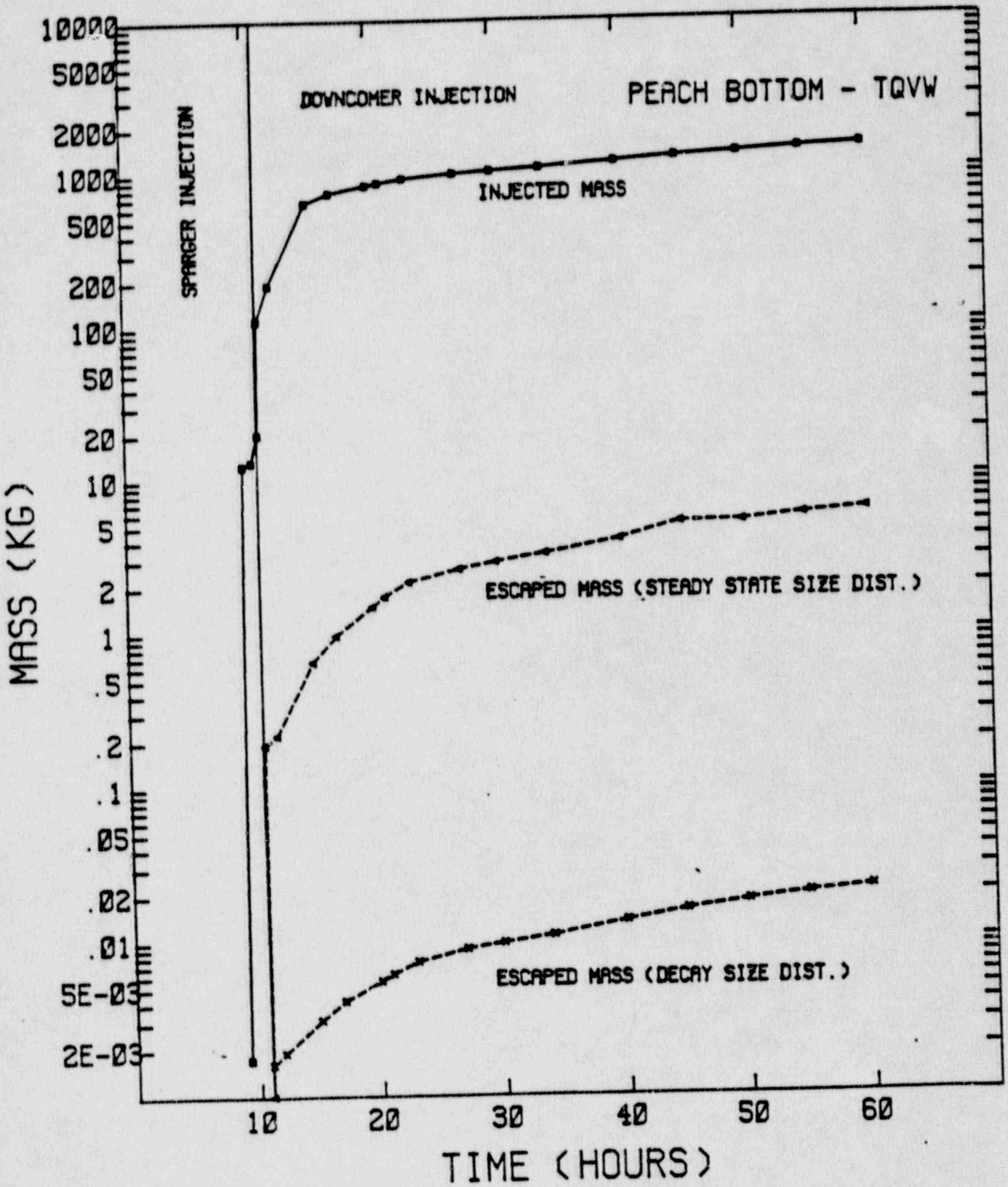
STATION BLACKOUT - TQVW

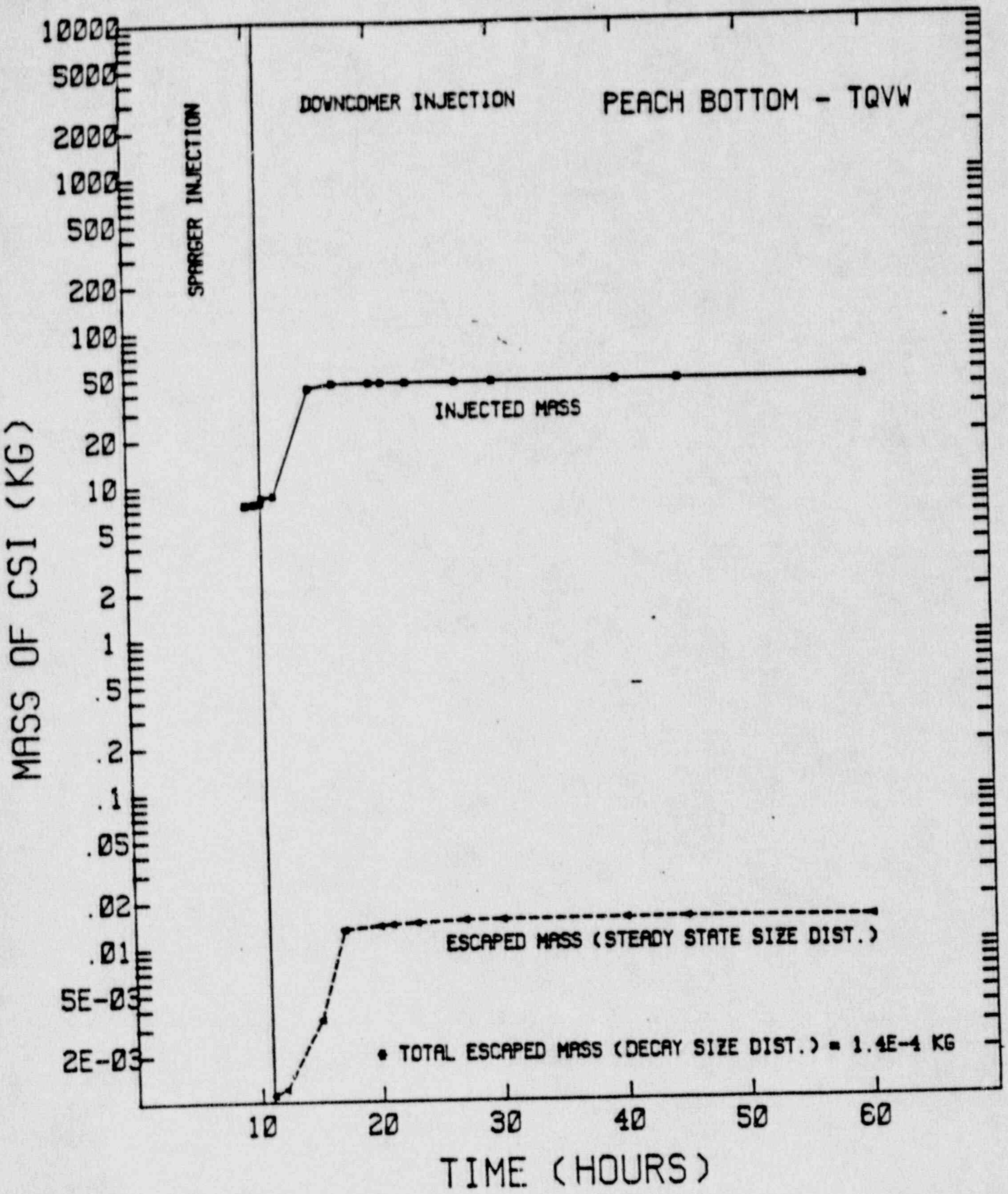
INITIATION	LOSS OF AC POWER
	DIESEL POWER FAILS
4.7 S	REACTOR SCRAMS
	DC POWER CONTROLS STEAM DRIVEN HPCI & RCIC
21,638 S	BATTERY POWER UNAVAILABLE
30,138 S	START OF CORE UNCOVERY
32,500 S	START OF AEROSOL GENERATION IN VESSEL & TRANSPORT THROUGH SPARGERS
39,420 S	VESSEL FAILURE
39,479 S	OPEN WETWELL VENT
	AEROSOL TRANSPORT THROUGH DOWNCOMER
216,000 S (60 HRS)	STOP CALCULATION

SUSPENDED AEROSOL MASS IN THE REACTOR VESSEL




PEACH BOTTOM - TQVW
STEADY STATE SIZE DIST.
DECAY SIZE DIST.
SPARGER INJECTION
TIME = 9.67 HOURS
MASS FRACTION
.2
.15
.1
.05
.02
.05
.1
.2
.5
1
2
5
10
20
50
100
PARTICLE RADIUS (MICRONS)


PEACH BOTTOM - TQVW
DOWNCOMER INJECTION
SPARGER INJECTION
INJECTED MASS
ESCAPED MASS (STEADY STATE SIZE DIST.)
ESCAPED MASS (DECAY SIZE DIST.)
MASS (KG)
TIME (HOURS)
10000
5000
2000
1000
500
200
100
50
20
10
5
2
1
.5
.2
.1
.05
.02
.01
5E-03
2E-03
10
20
30
40
50
60


PEACH BOTTOM - TQVW
DOWNCOMER INJECTION
SPARGER INJECTION
INJECTED MASS
ESCAPED MASS (STEADY STATE SIZE DIST.)
• TOTAL ESCAPED MASS (DECAY SIZE DIST.) = 1.4E-4 KG
MASS OF CSI (KG)
10000
5000
2000
1000
500
200
100
50
20
10
5
2
1
.5
.2
.1
.05
.02
.01
5E-03
2E-03
10
20
30
40
50
60
TIME (HOURS)

DECONTAMINATION FACTORS

PEACH BOTTOM SEQUENCE TQVW

	STEADY STATE			DECAY		
	SPARGERS	DOWNCOMERS	TOTAL	SPARGERS	DOWNCOMERS	TOTAL
STRUCTURAL	1.63×10^5	207	208	3.23×10^8	5.55×10^4	5.58×10^4
C_SI	6.17×10^5	2585	3109	3.85×10^8	2.71×10^5	3.27×10^5
T_EO_2		157	157		36,800	36,800
C_SOH	3.67×10^5	3242	3323	6.68×10^8	3.01×10^5	3.09×10^5
TOTAL	3.04×10^5	233	235	1.49×10^8	6.5×10^4	6.68×10^5

SUMMARY AND CONCLUSIONS

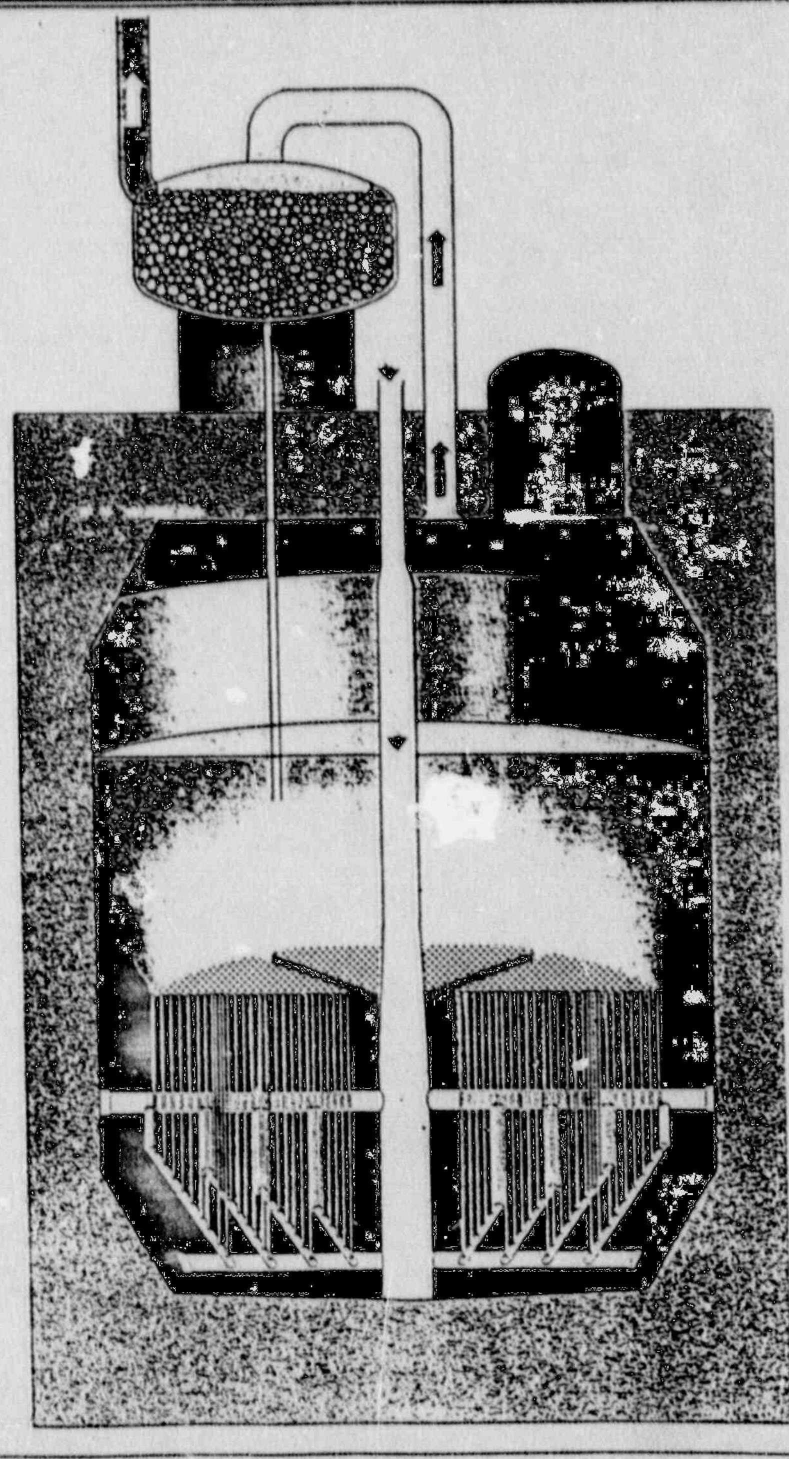
- EXPERIMENTAL PROGRAM HAS SHOWN THAT, FOR SPARGER AND SIDE VENT GEOMETRIES, WATER POOLS ARE EFFECTIVE IN SCRUBBING AEROSOLS
- DOWNCOMER AND MULTIPLE ORIFICE EXPERIMENTS WILL BE COMPLETED THIS SPRING WITH SIMILAR RESULTS EXPECTED
- BEST-ESTIMATE SCENARIO CALCULATIONS INDICATE EXTREMELY HIGH FISSION PRODUCT RETENTION IN THE PEACH BOTTOM SUPPRESSION POOL

BWR SUPPRESSION POOLS
PROVIDE AN EFFECTIVE
BARRIER TO FISSION PRODUCTS

Enclosure 7

ABB PRESENTATION TO THE USNRC STAFF ON THE SWEDISH CONTAINMENT VENTING IMPLEMENTATION PROGRAM

APRIL 25, 1989



FILTRA - MVSS

MULTI VENTURI SCRUBBER SYSTEM

KE 89-04-21

ABB Atom

ABB

FILTRA - MVSS
BWR FILTERED VENTING

FLOW CAPACITY

- MANUAL VENTING DURING WATER FILLING OF CONTAINMENT. FLOW RATE 0,1 - 10 KG/S
- MANUAL VENTING OF DECAY POWER. FLOW RATE 6 KG/S
- AUTOMATIC VENTING DURING WATER FILLING OF CONTAINMENT. FLOW RATE 12 KG/S
- AUTOMATIC VENTING WITHOUT ANY MANUAL ACTIONS. FLOW RATE 12 KG/S

FILTRA - MVSS

PWR FILTERED VENTING FLOW CAPACITY

- AUTOMATIC VENTING WITHOUT ANY MANUAL ACTIONS. FLOW RATE 13 KG/S

FILTRA - MVSS

DESIGN PARAMETERS (BWR AND PWR)

o GAS MASS FLOW RATE	0,1 - 13 KG/S
o GAS COMPOSITION	STEAM, N_2, H_2, O_2
o GAS TEMPERATURE	70 - 150 °C
o RUPTURE DISC OPENING PRESSURE	0,5 - 0,6 MPA
o EARTHQUAKE, GROUND ACCELERATION	0,15 G

FILTRA - MVSS

DESIGN PARAMETERS

	BWR	PWR
o DECONTAMINATION FACTOR		
- REQUIREMENT	100	500
- DESIGN	500	1500
o AEROSOLS		
- TOTAL AMOUNT	90 KG	180 KG
- RADIOACTIVE	20 KG	20 KG
- SIZE DISTRIBUTION	LOG-NORMAL $\sigma_g = 2$	
- MASS MEAN DIAMETER	1,5 μM	
o TOTAL DECAY POWER	400 KW	

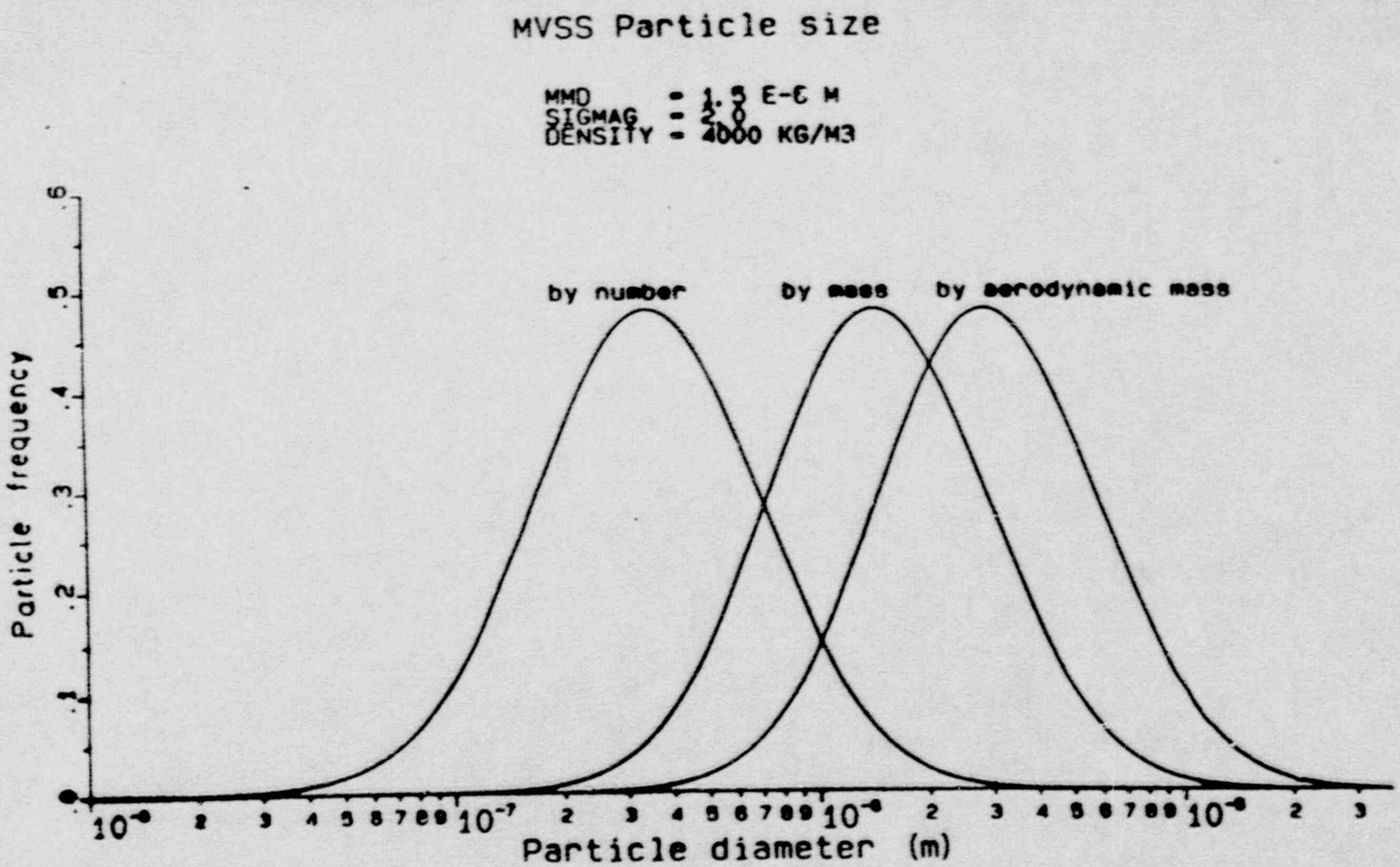

MVSS Particle size
MMD = 1.5 E-6 M
SIGMAG = 2.0
DENSITY = 4000 KG/M3
by number
by mass
by aerodynamic mass
Particle frequency
Particle diameter (m)

ABB Atom

FILTRA - MVSS

MAIN DATA

FILTER VESSEL DATA	BWR	PWR
DESIGN PRESSURE	0,3 MPA + HYDR	0,4 MPA + HYDR
TOTAL VOLUME	250 M^3	400 M^3
WATER VOLUME	180M^3	270 M^3
INSIDE DIAMETER	7 M	7 M
GRAVEL BED VOLUME	8 M^3	9 M^3

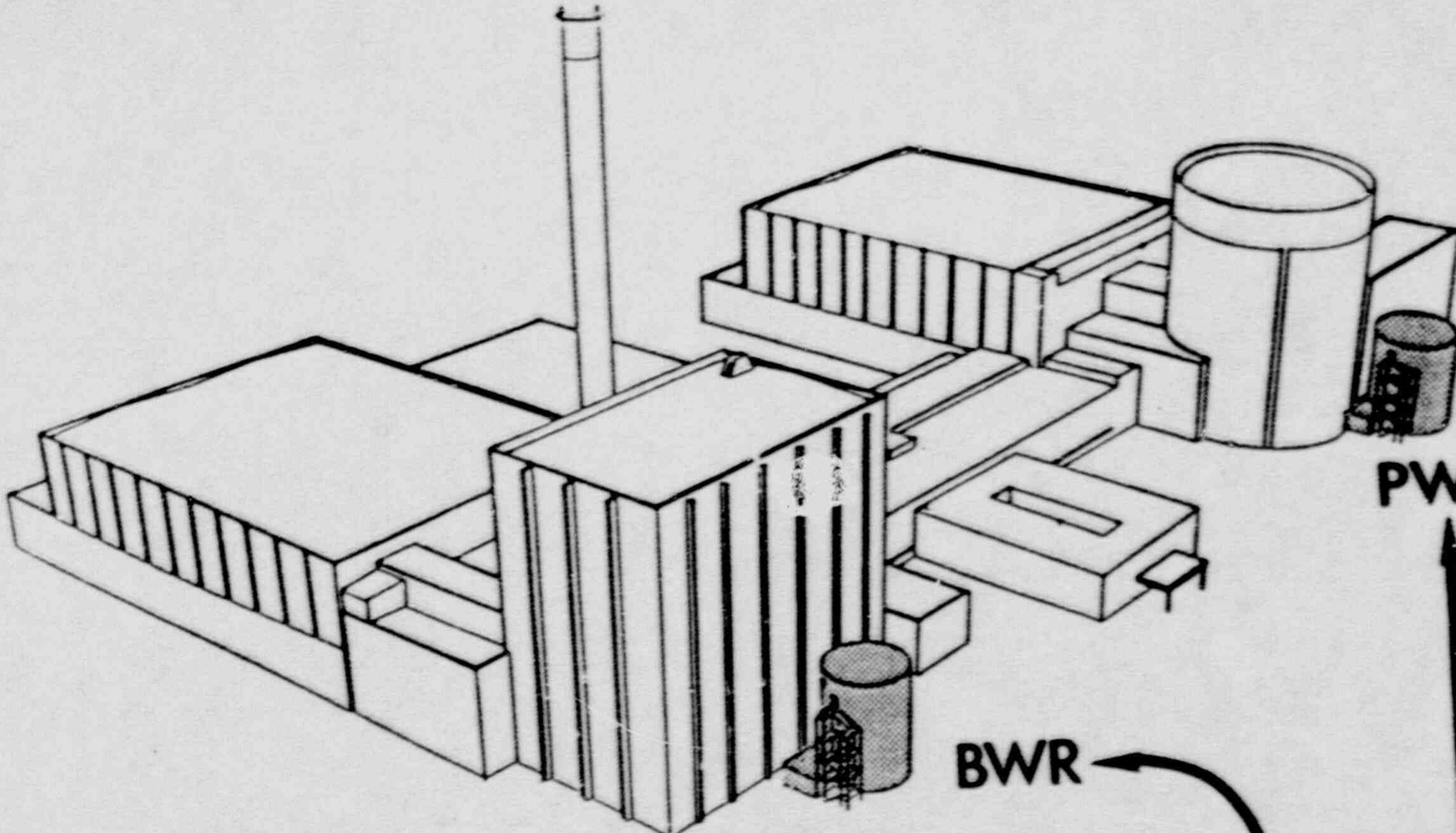
ABB

FILTRA - MVSS SYSTEM

- o PRESSURE RELIEF PIPING
- o VALVES WITH PNEUMATIC OPERATORS
- o RUPTURE DISCS
- o CONCRETE PRESSURE VESSEL
- o POOL WITH A HIGH PH
- o MULTI VENTURI UNIT
- o MOISTURE SEPARATOR
- o SERVICE FUNCTIONS

FILTRA - MVSS
SERVICE FUNCTIONS

- WATER FILLING AND DRAINAGE
- CHEMICAL DOSING
- WATER HEATING / COOLING
- WATER SAMPLING
- NITROGEN BLANKETING



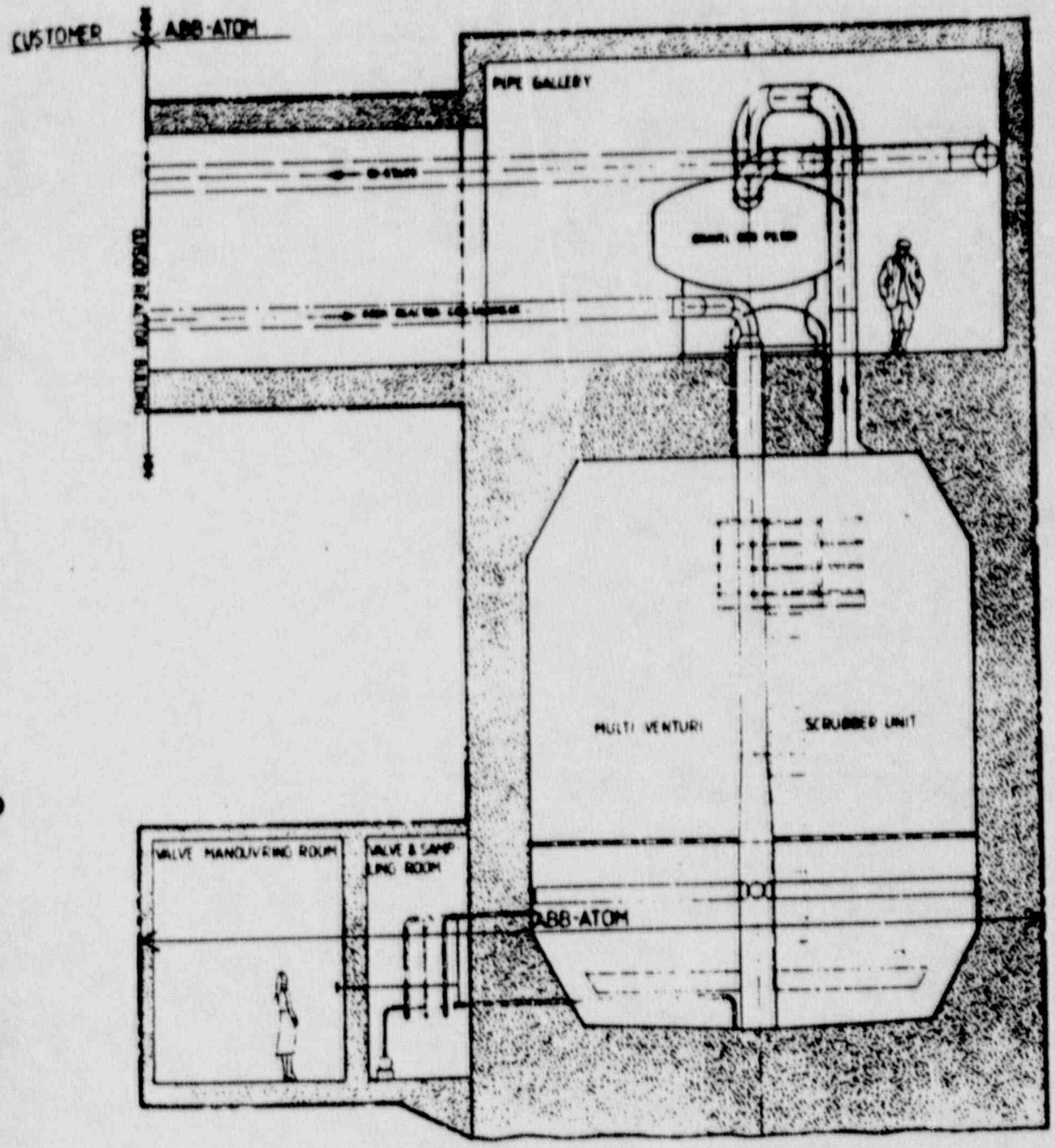
FILTRA - MVSS

ABB Atom

Fläkt
Industri AB

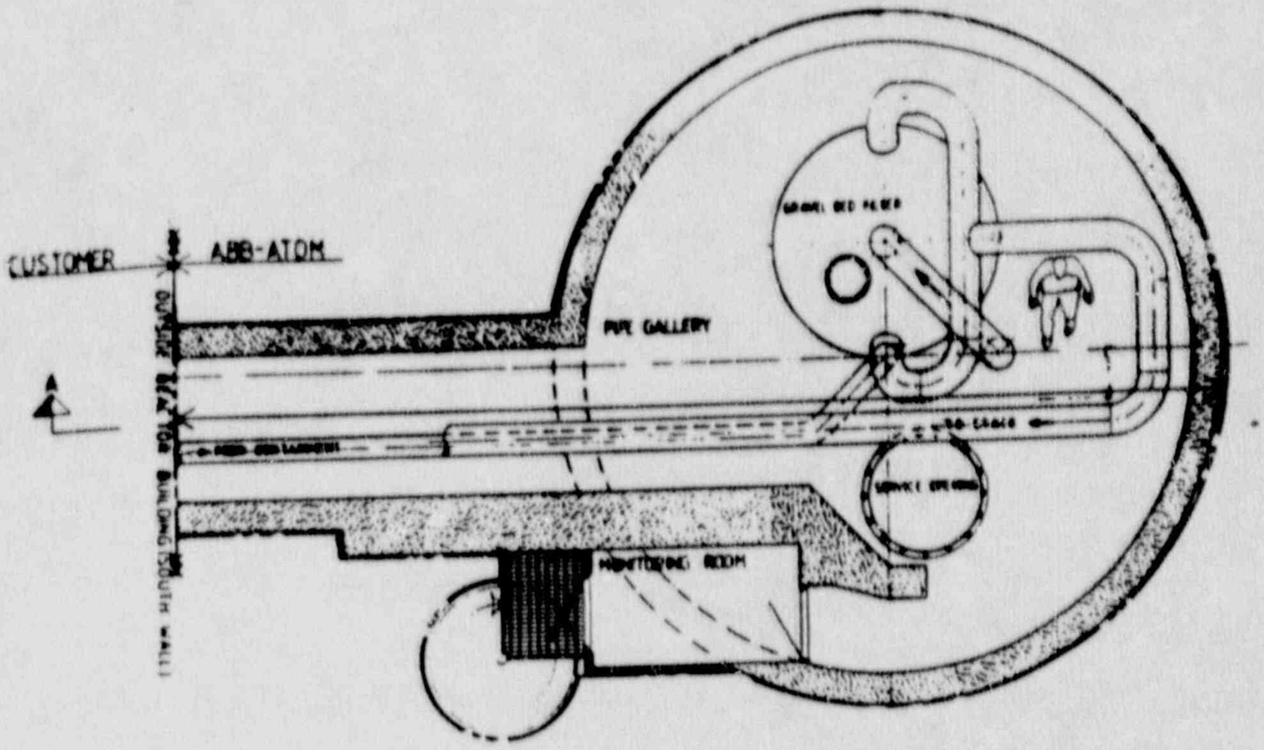
ABB
ASEA BROWN BOVERI

FILTRA / MVSS - BUILDING

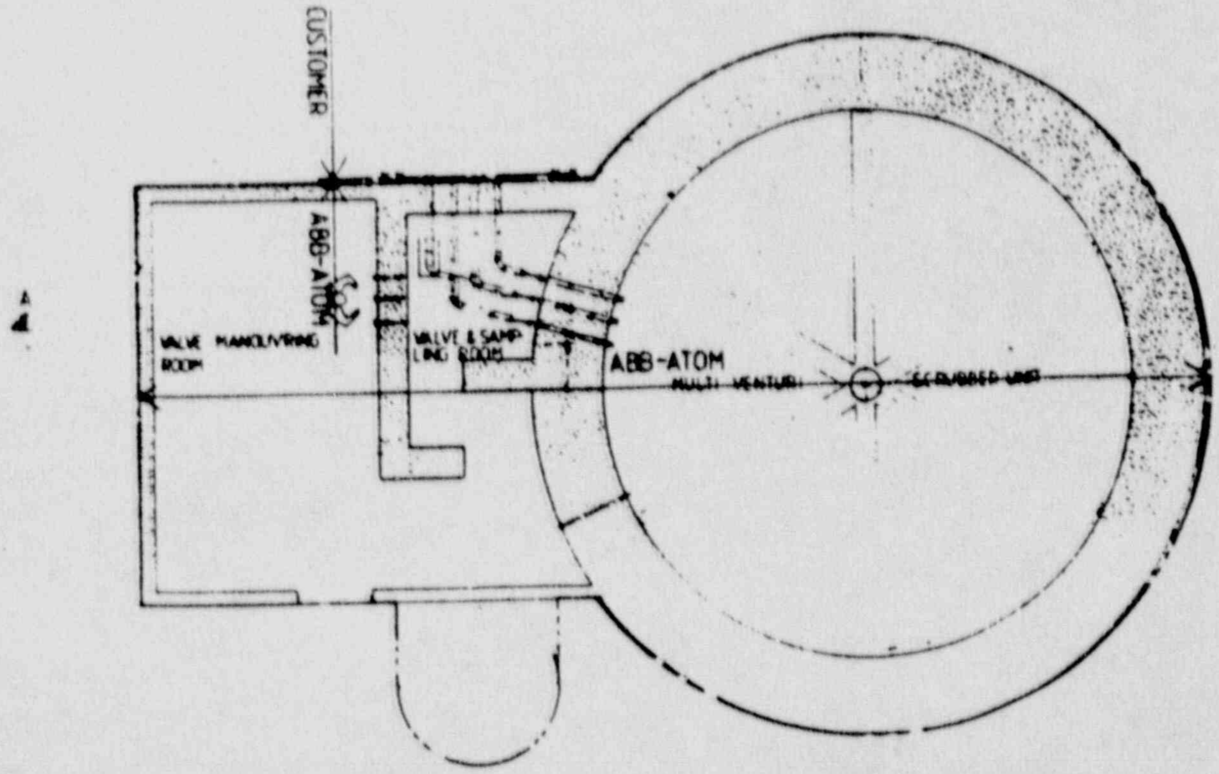


SECTION A-A

FILTRA / MVSS - BUILDING

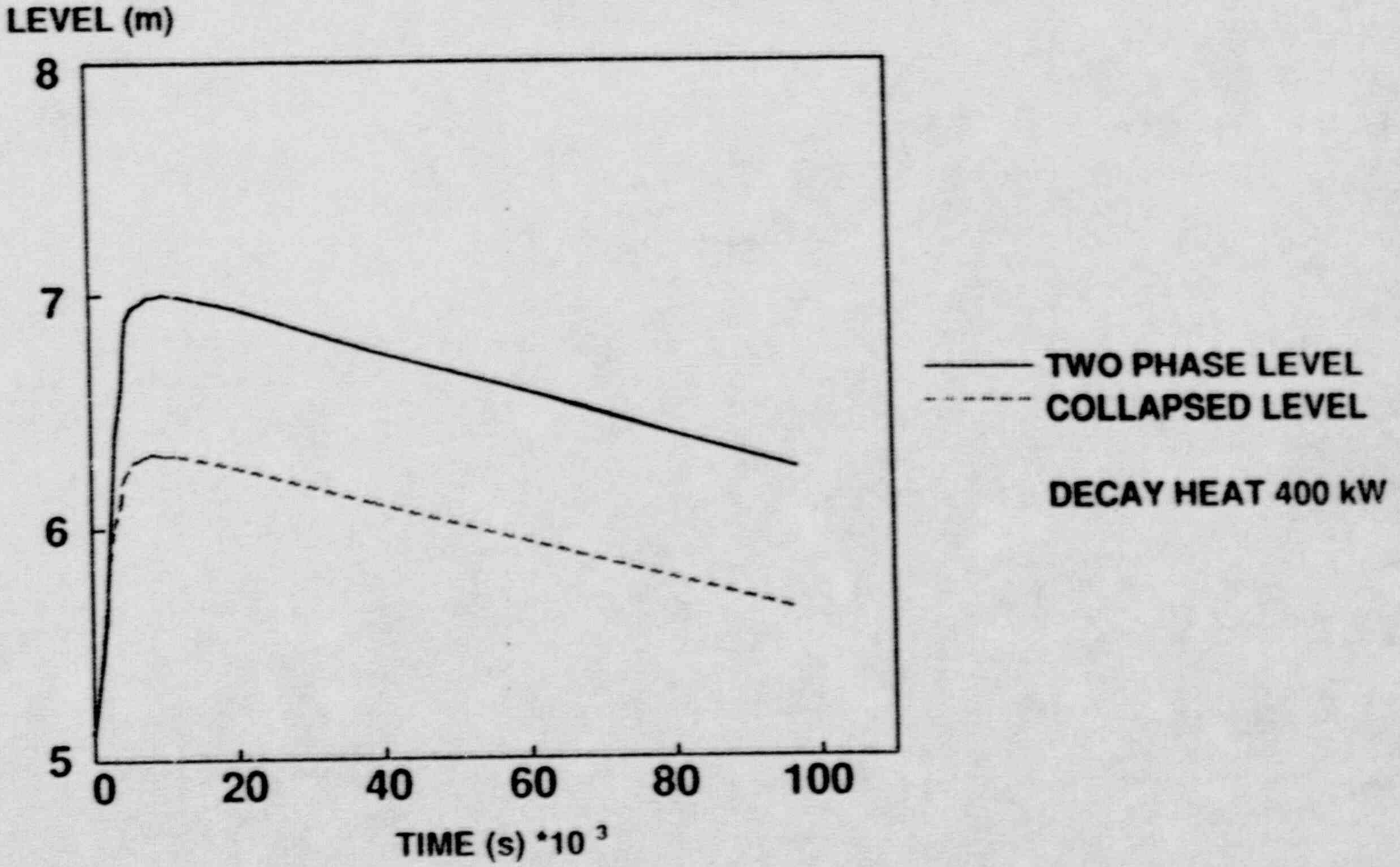


TOP LEVEL

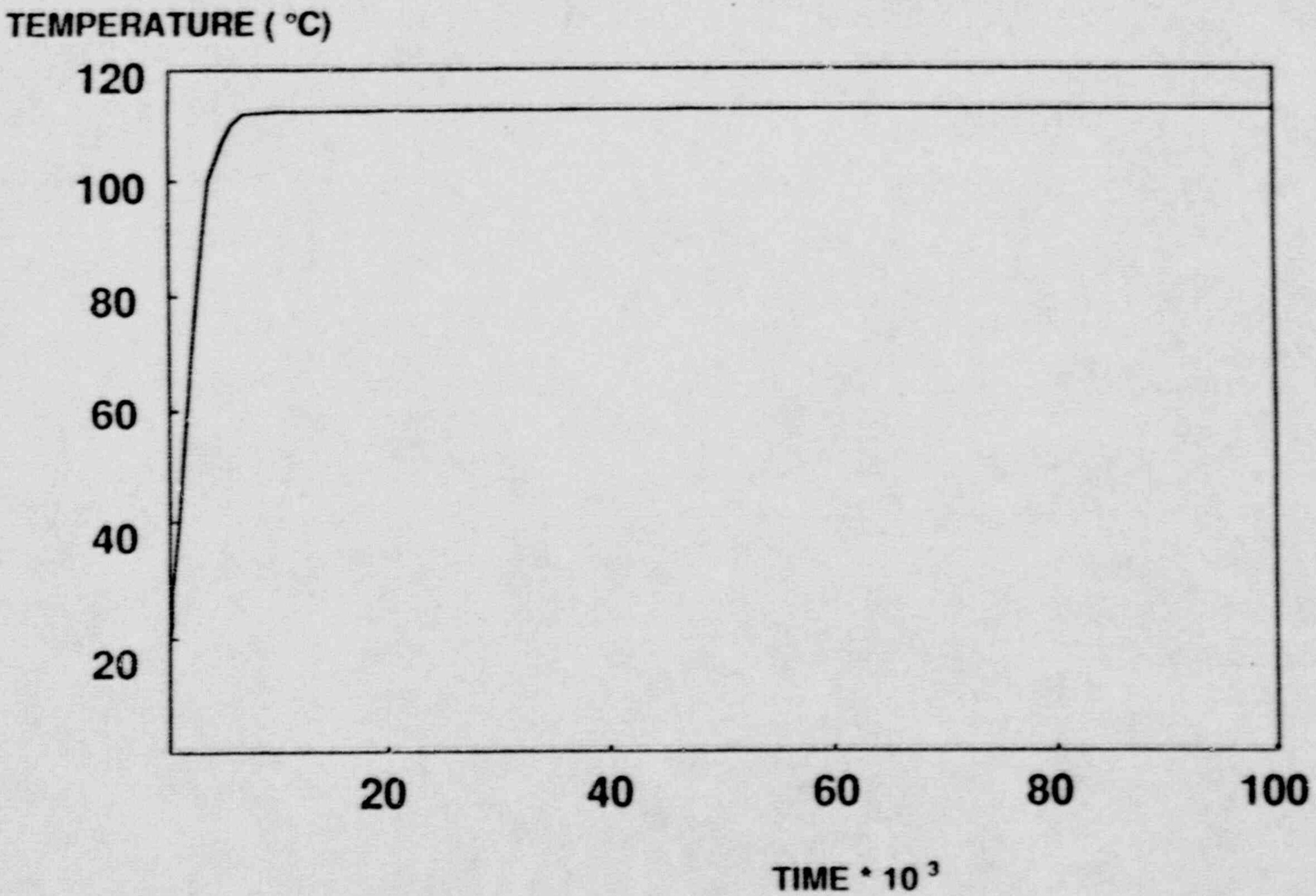


GROUND LEVEL

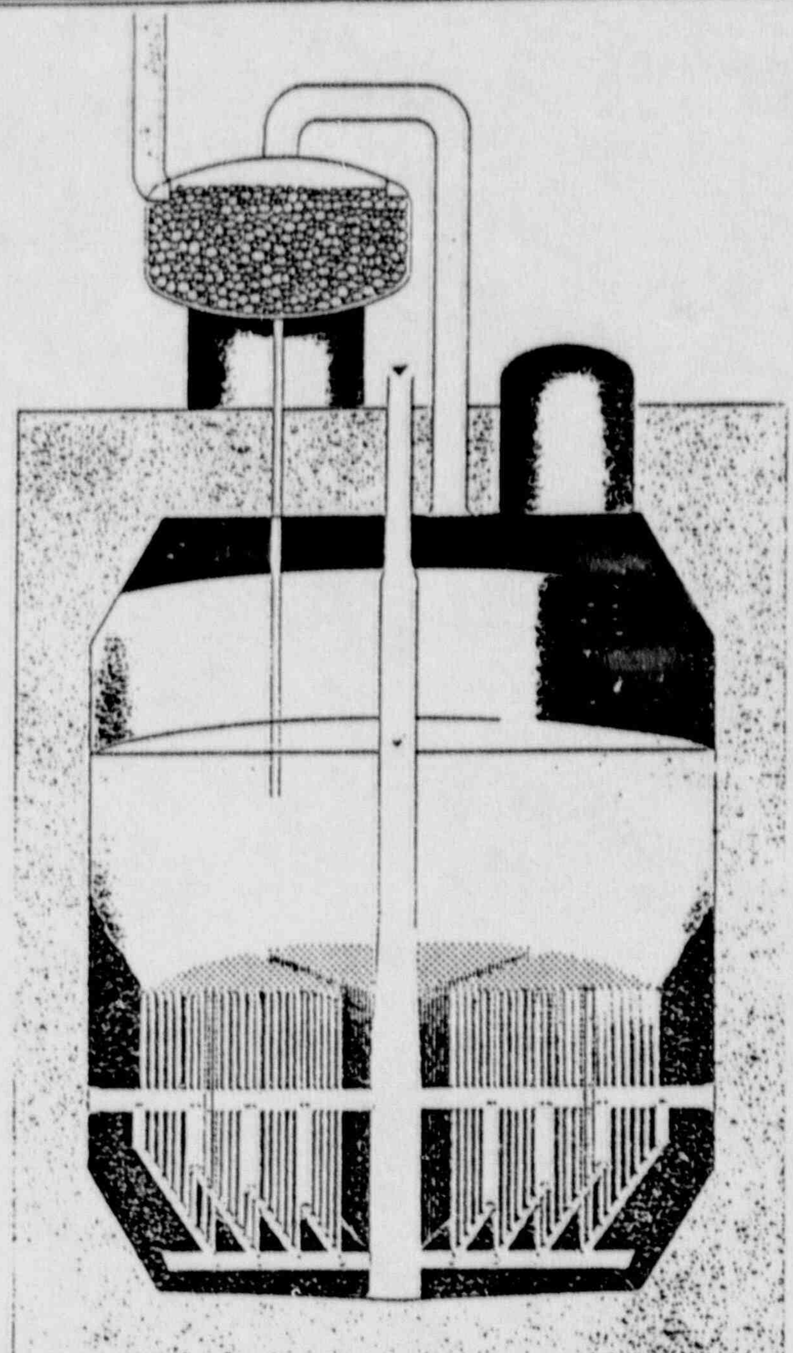
FILTRA-MVSS
WATER LEVEL

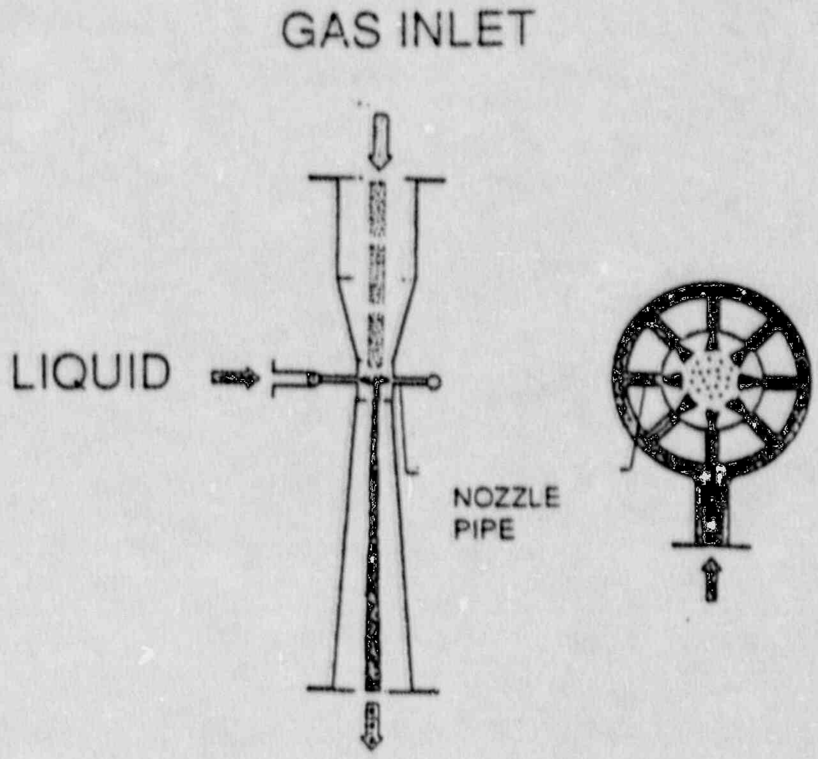


FILTRA-MVSS
TEMPERATURE IN VESSEL



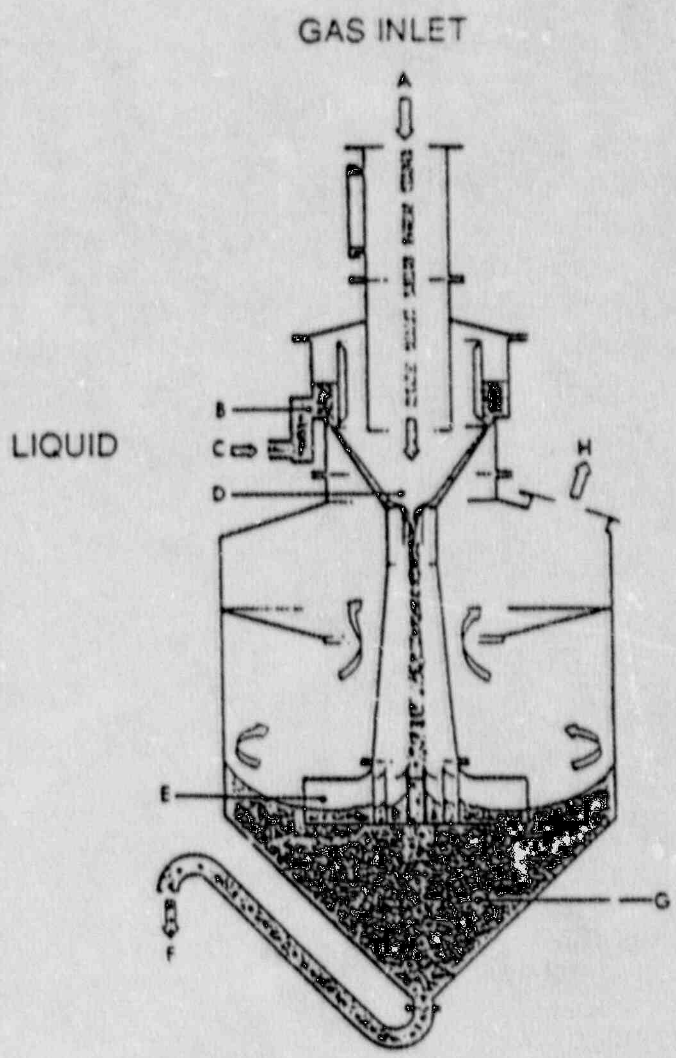
FILTRA - MVSS





VENTURI WITH NOZZLES FOR
WATER INJECTION.

CONSTANT ΔP WITH
- VARIABLE THROAT
- RECIRCULATION OF GAS



VENTURI WITH INTEGRATED
DROP COLLECTOR

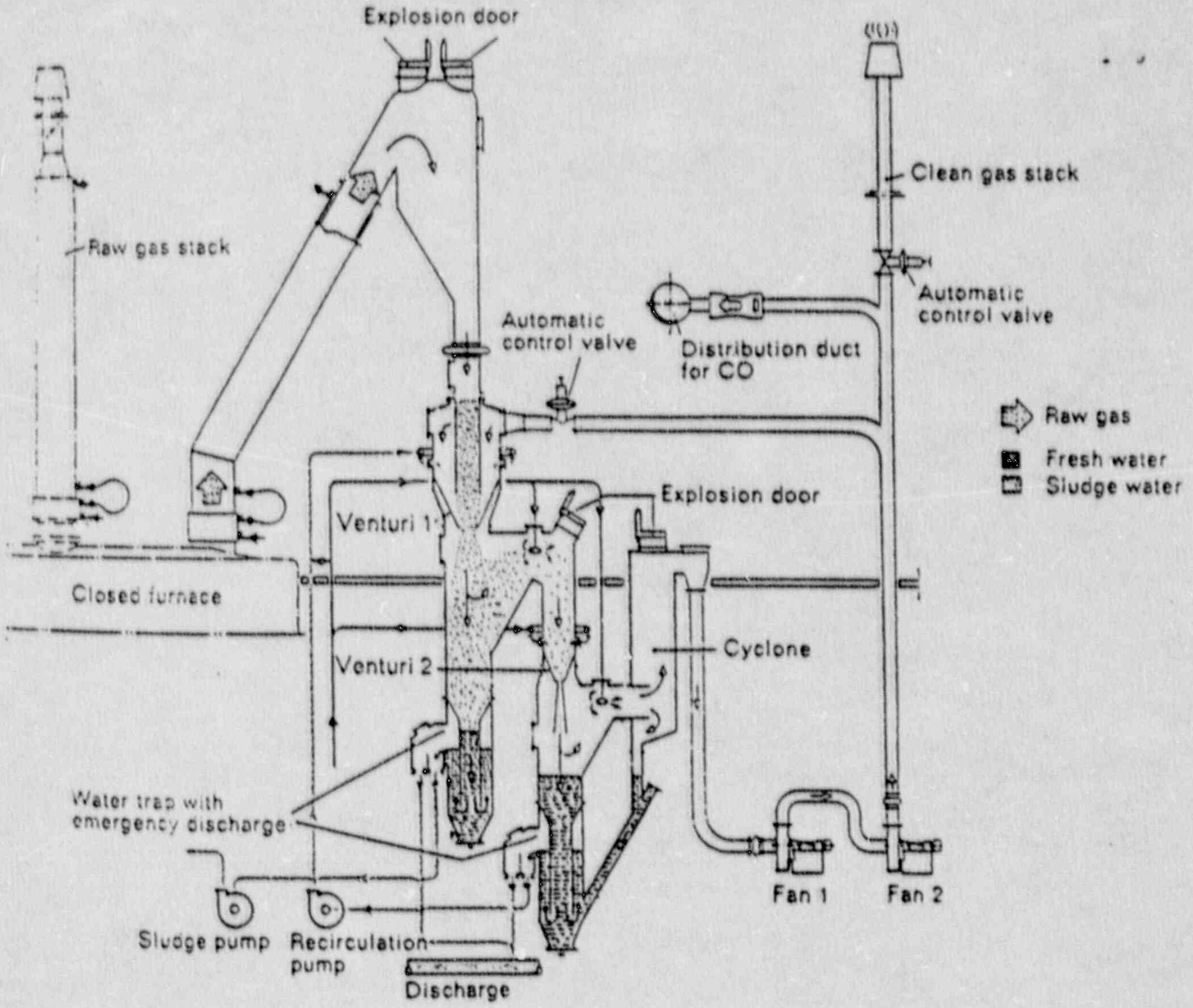
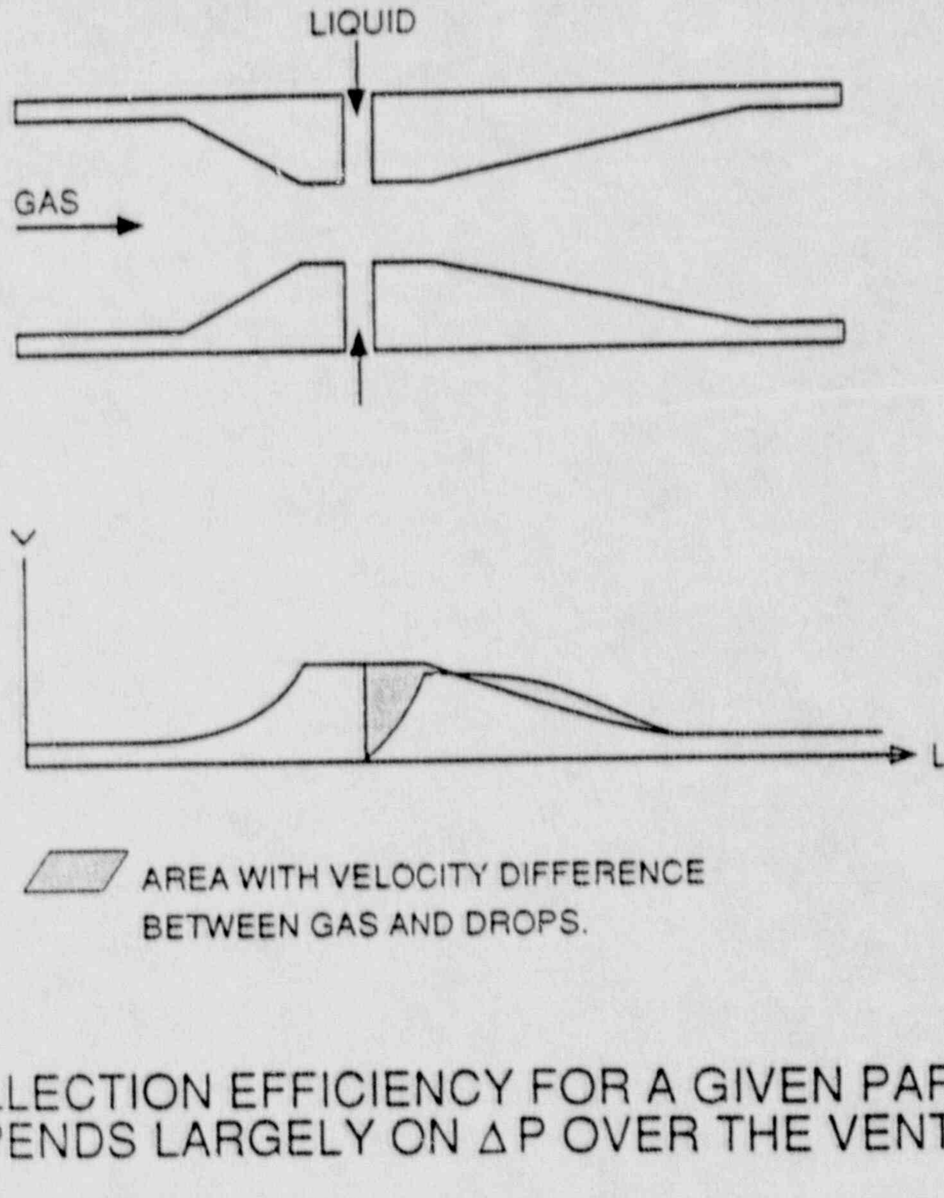


ABB ATOM — Fläkt Industri AB

ABB

VENTURICOLLECTION

OBJECT: TRANSFER OF PARTICLES AND SOLVABLE GASES FROM GAS TO LIQUID.



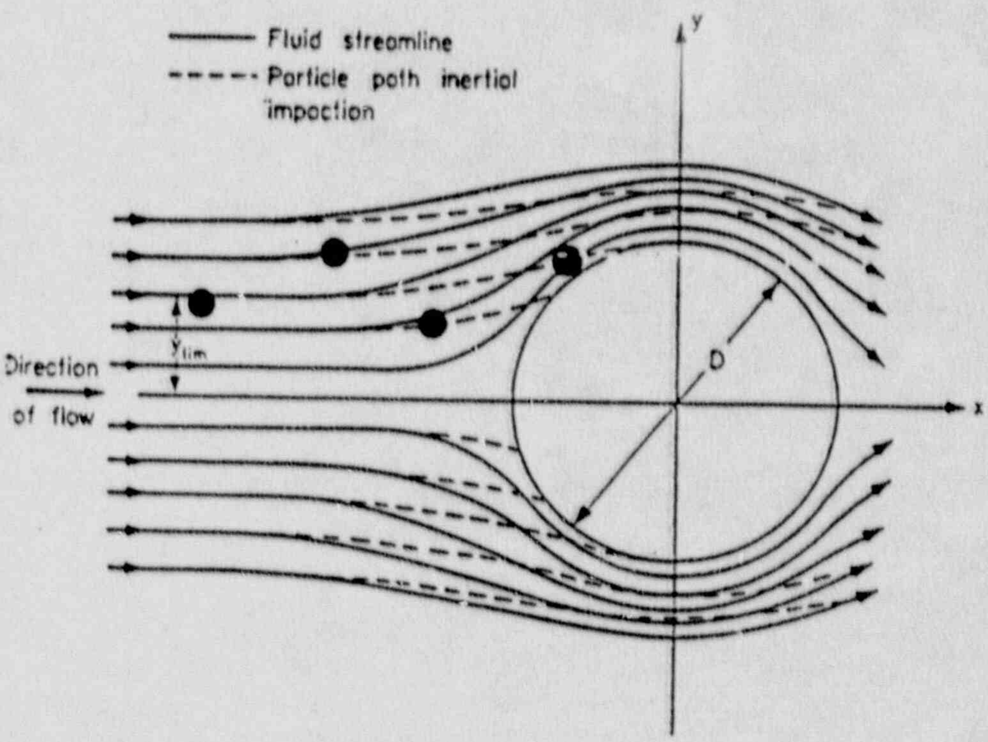
COLLECTION EFFICIENCY FOR A GIVEN PARTICLE DEPENDS LARGELY ON ΔP OVER THE VENTURI.

ABB ATOM – Fläkt Industri AB ABB

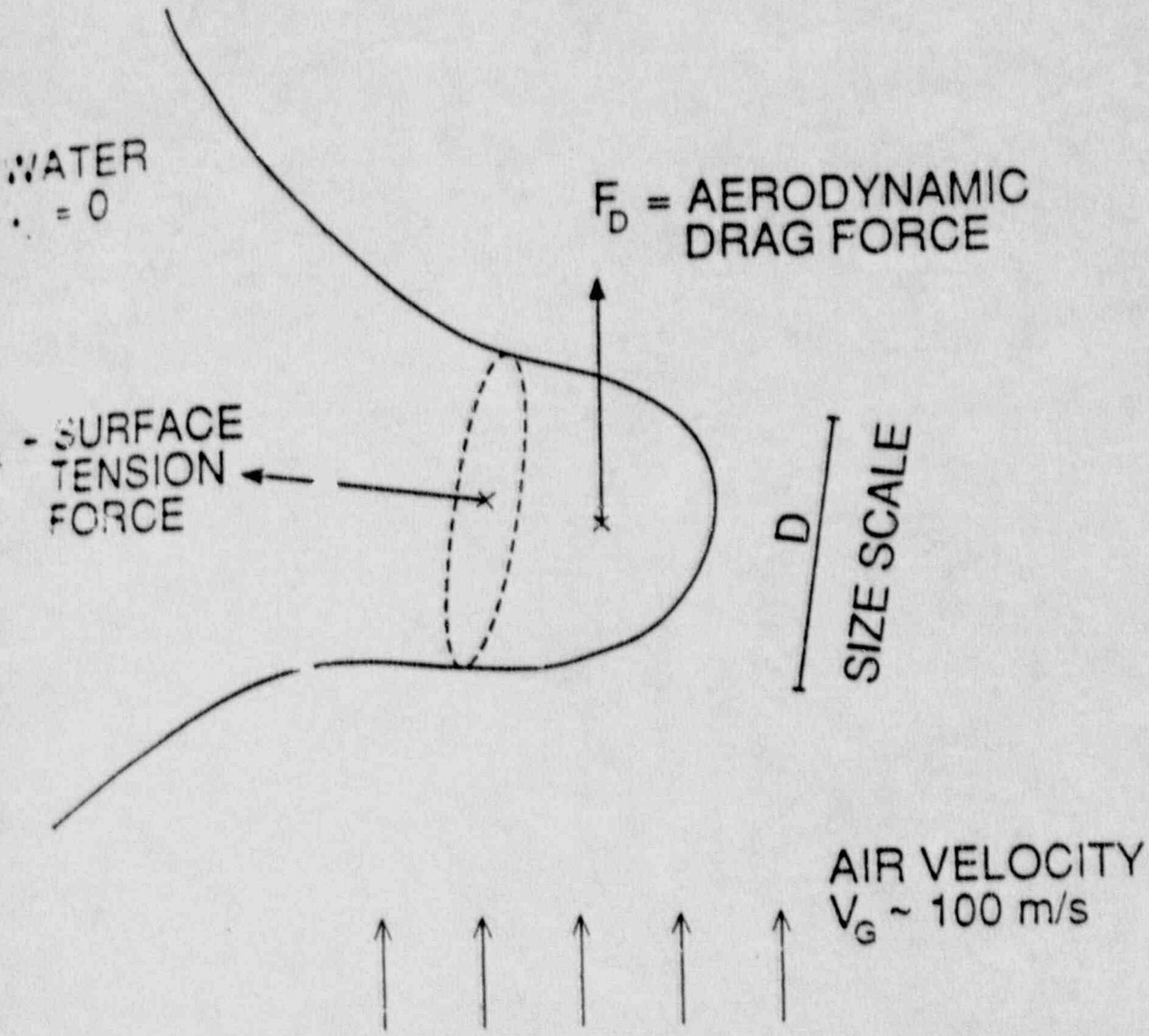
COLLECTION PRINCIPLES

INERTIAL IMPACTION

INTERCEPTION
DIFFUSION
ELECTROSTATIC FORCES



VENTURI ATOMIZATION

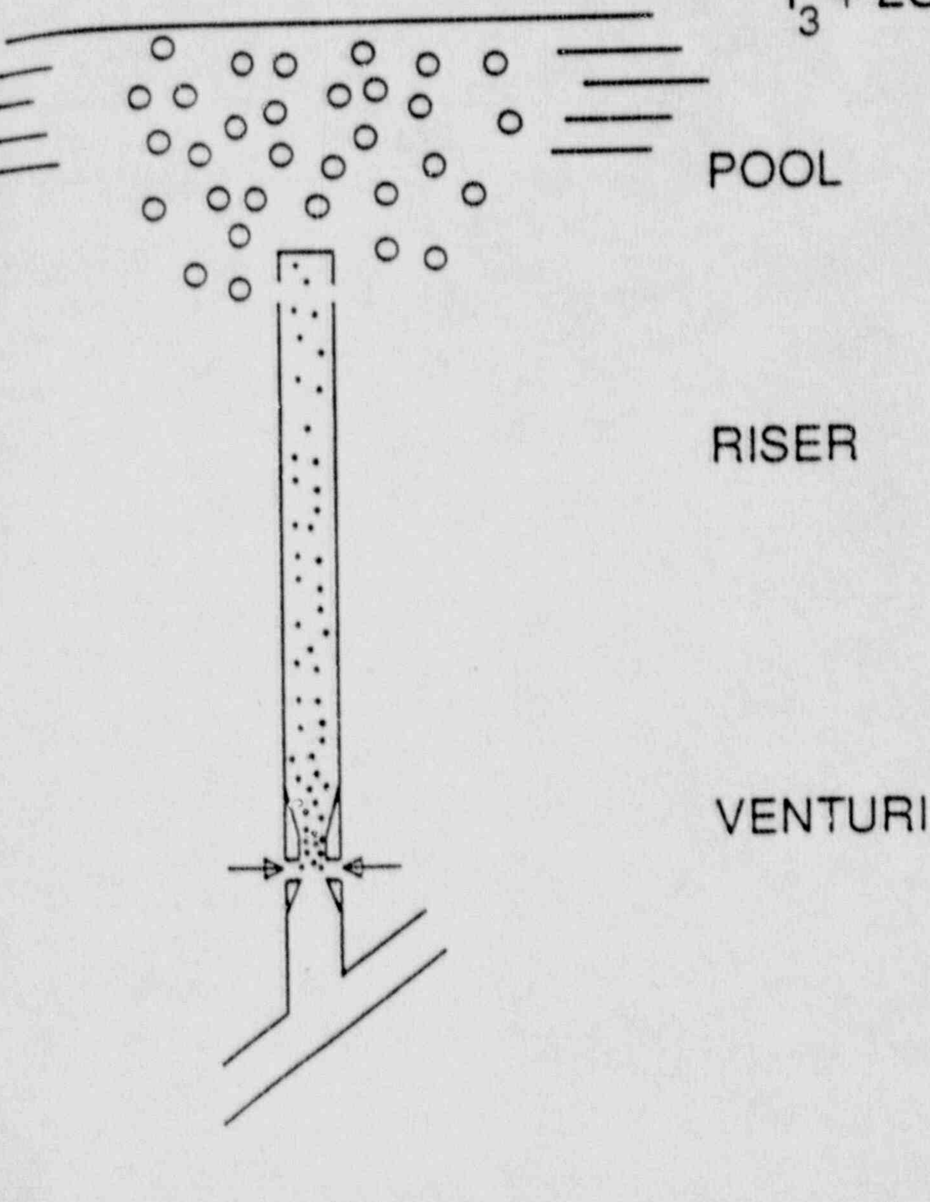


D,µm	10	100	1000
R_e	70	100	1000
F_S, N	2×10^{-6}	2×10^{-5}	2×10^{-4}
F_Δ, N	6×10^{-7}	2×10^{-5}	2×10^{-3}

IODINE ABSORPTION

$$I_2 + I^- \rightarrow I_3^-$$

$$I_3^- + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 3I^-$$



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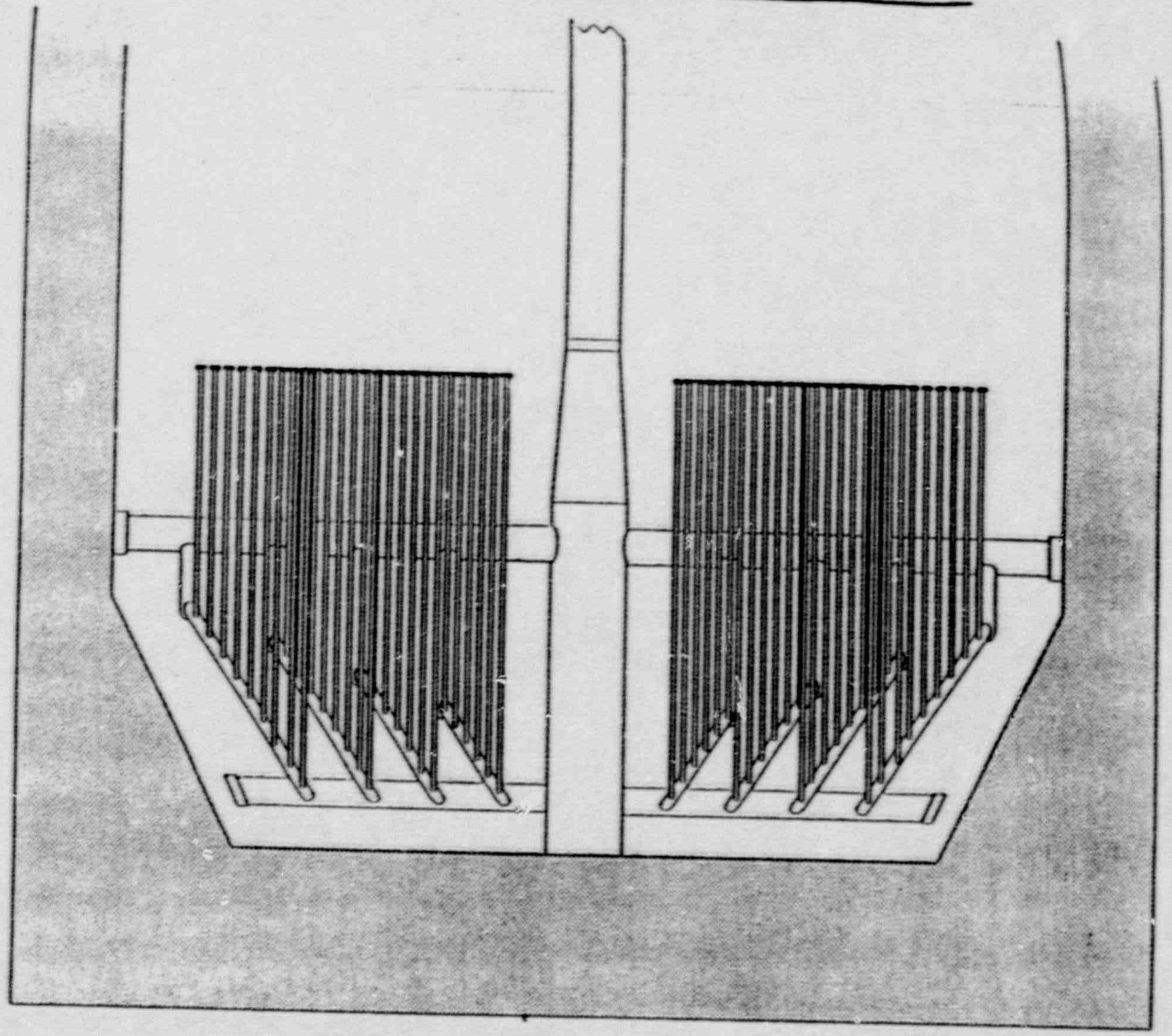
FILTRA - MVSS



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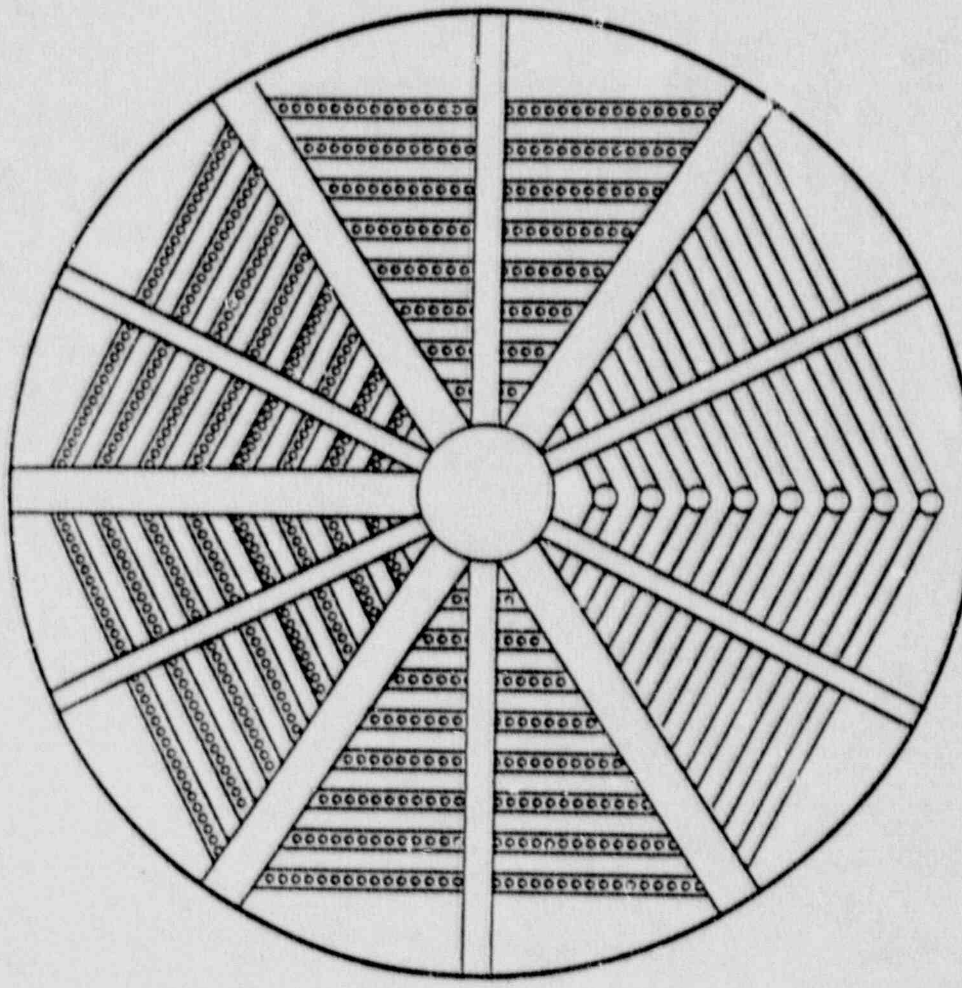
FILTRA - MVSS



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FILTRA - MVSS

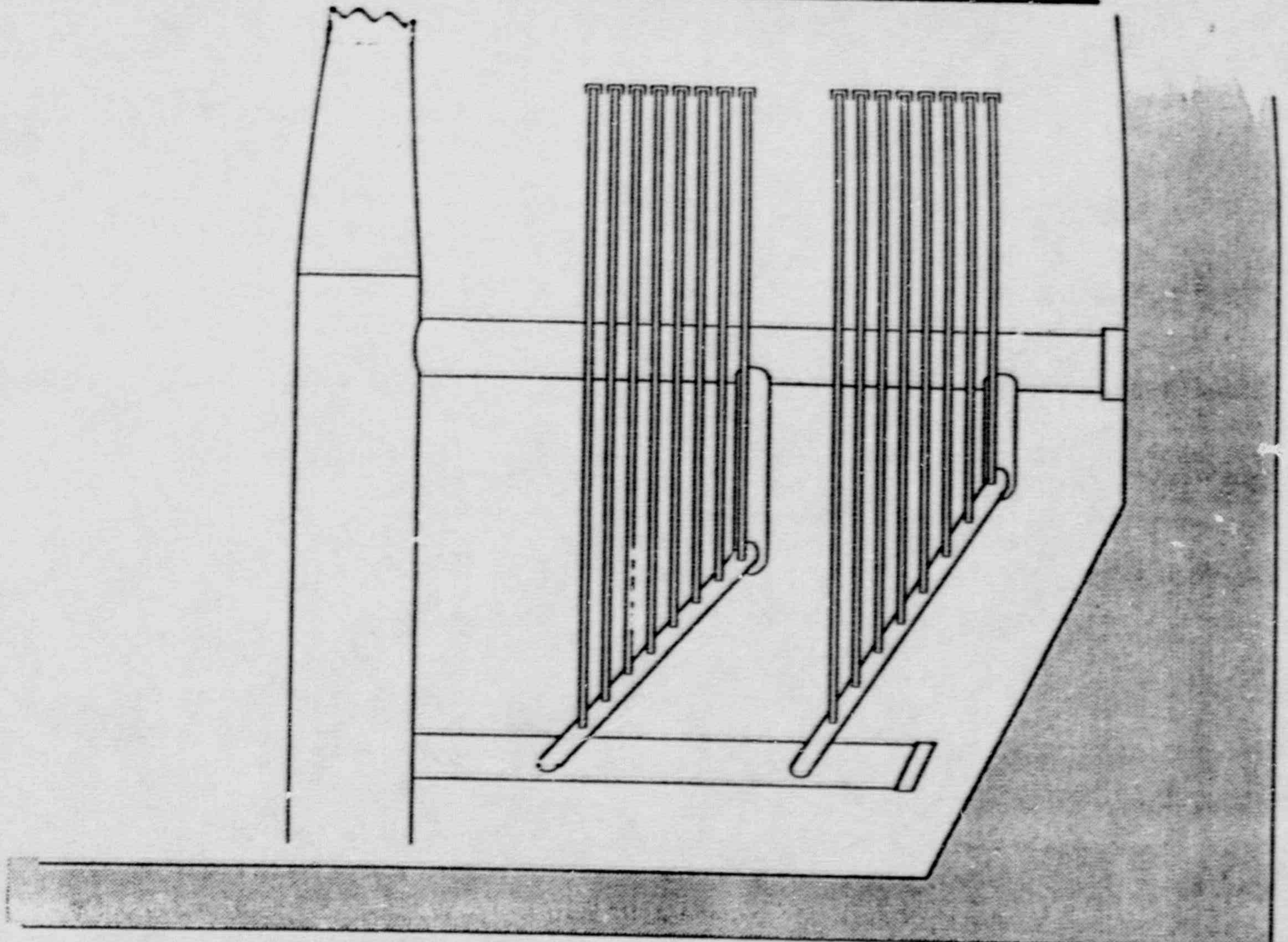

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ABB

SWEDISH FILTRA - MVSS VERIFICATION.

- CONDITIONS
- METHODS
- RESULTS

SWEDISH FILTRA
VERIFICATION.

CONDITIONS:

		PWR	BWR
• RELIEF GAS FLOW, kg/s	:	0,1/13	0,1/12
• TEMP, °C	:	150	70/150
• AEROSOL			
DISTRIBUTION	:	LOG - NORMAL	
AMMD, µm	:	3	
σ_G	:	2	
• DECON. FACTORS AEROSOLS AND IODINE			
DESIGN	:	1500	500
GUARANTEE	:	500	100

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SWEDISH FILTRA - MVSS VERIFICATION.

METHODS:

- FULL-SIZE SEGMENT.
- PROTOTYPICAL GEOMETRICS.
- PROTOTYPICAL FLOW CONDITIONS.
- PROTOTYPICAL AEROSOL.
- PROTOTYPICAL EVAPORATION.

- ANALYZE FULL-SIZE CONDITIONS (IF NOT GIVEN).
- REALIZE RELEVANT CONDITIONS IN LAB.
- MAKE LAB EXPERIMENT.

SWEDISH ...
VERIFICATION.

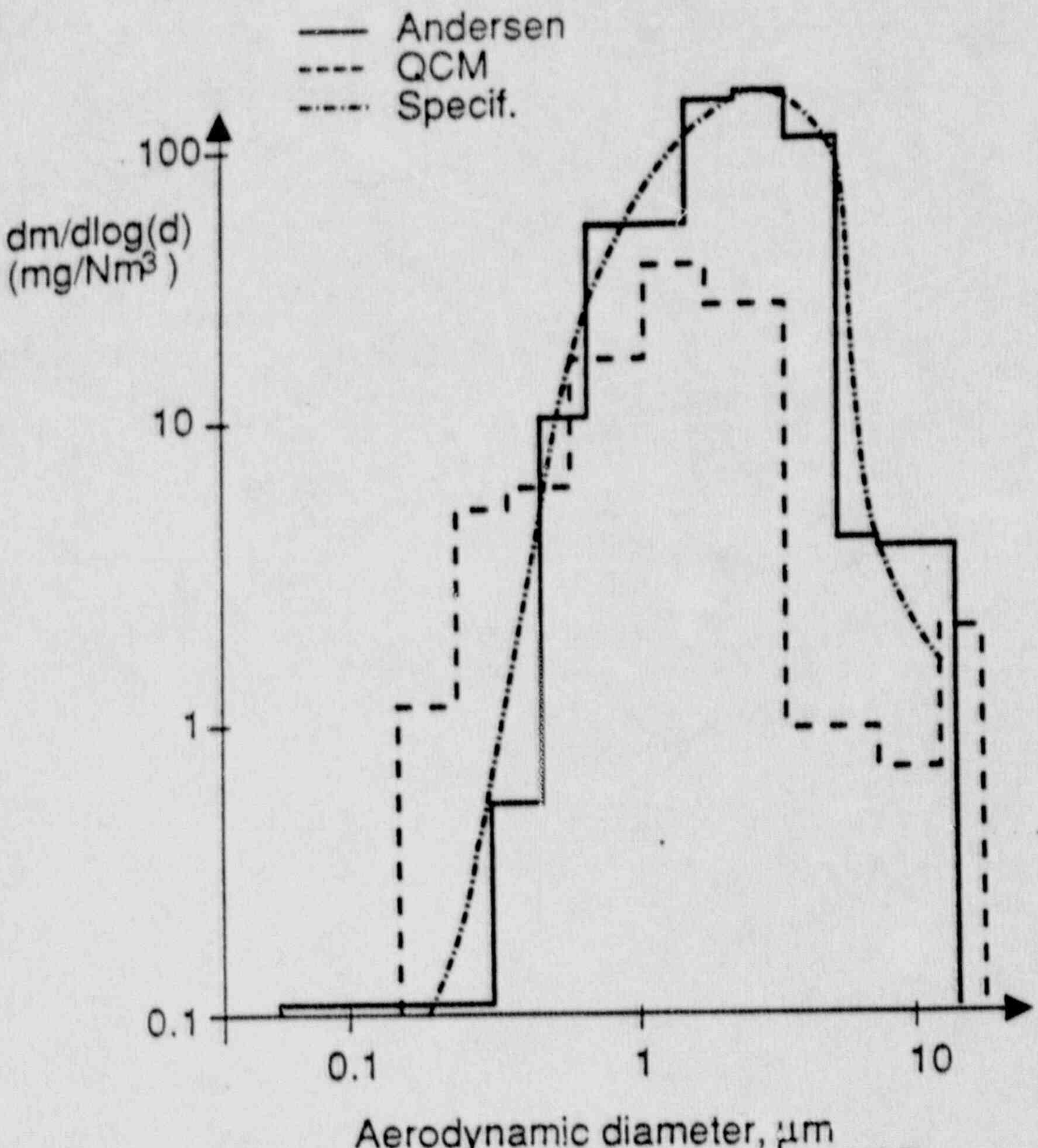
METHODS:

ITEMS

1 AEROSOL GENERATION.
2 FULL SIZE SEGMENT.
3 FLOW MODELLING.
4 AEROSOL COLLECTION EXPTS.
5 EFFECT OF EVAPORATION.
6 SCRUBBER LIQUID REENTRAINMENT.
7 IODINE COLLECTION.

SWEDISH FILTRA - MVSS
VERIFICATION

AEROSOL GENERATION



		LAB.
COMPOSITION	CORIUM	SiO_2
MMD, µm	1,5	1,8
DENSITY, kg/m^3	4 000	2650
AMMD, µm	3,0	3,0
SIGMA	2,0	2,0

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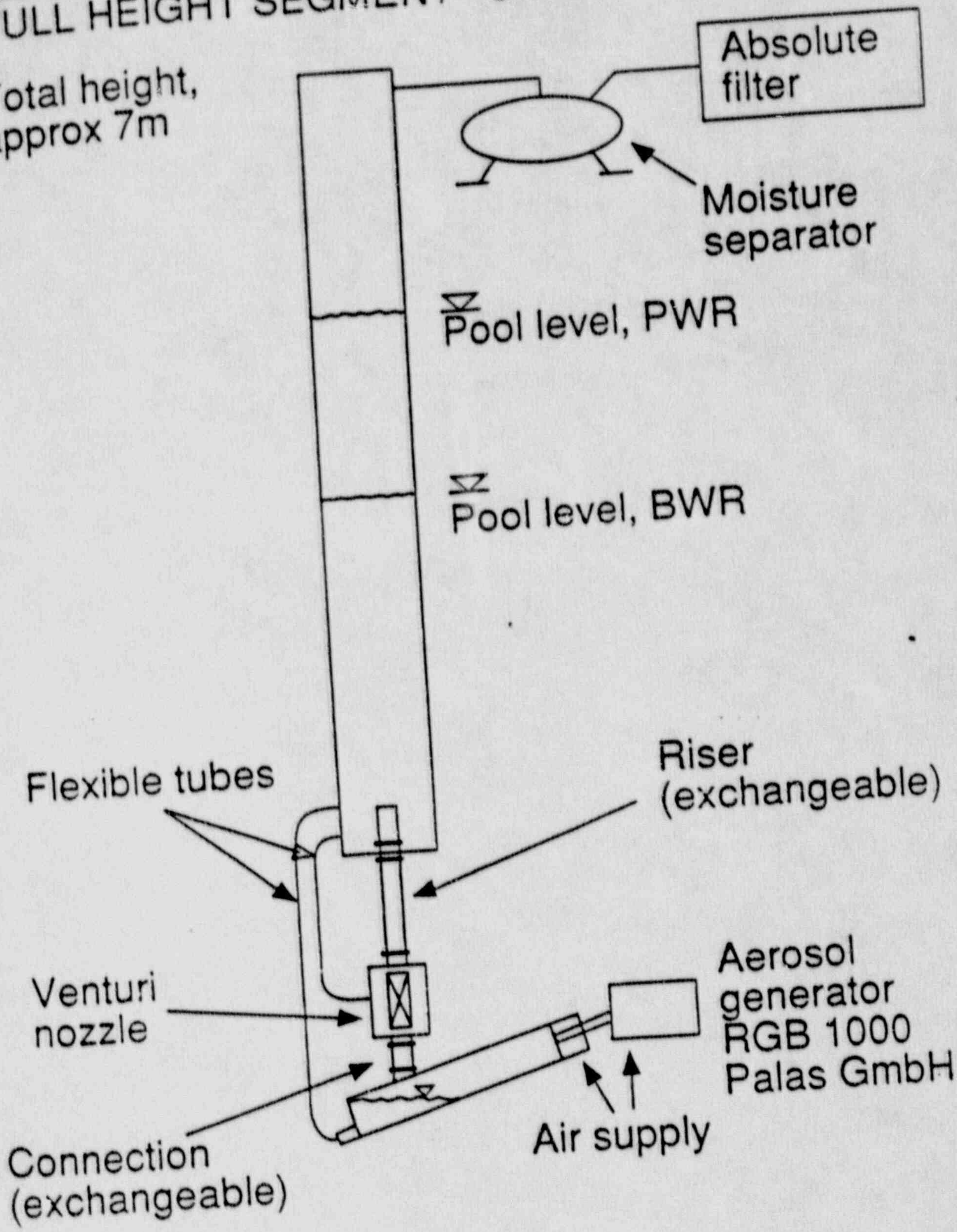
SWEDISH FILTRA - MVSS VERIFICATION

FULL HEIGHT SEGMENT - SINGLE NOZZLE RIG

Total height, approx 7m



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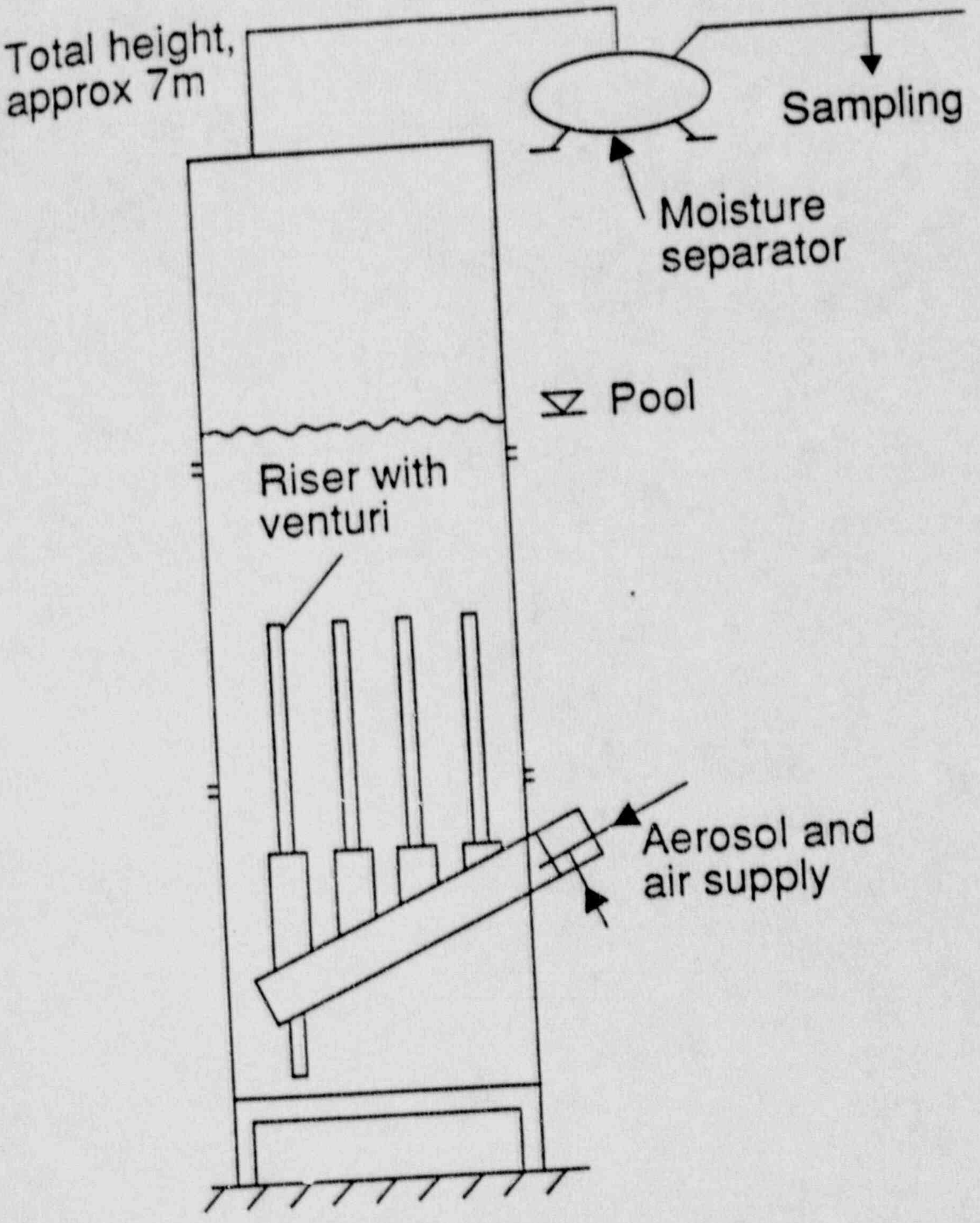
SWEDISH FILTRA - MVSS VERIFICATION

FULL HEIGHT SEGMENTS - FOUR NOZZLES



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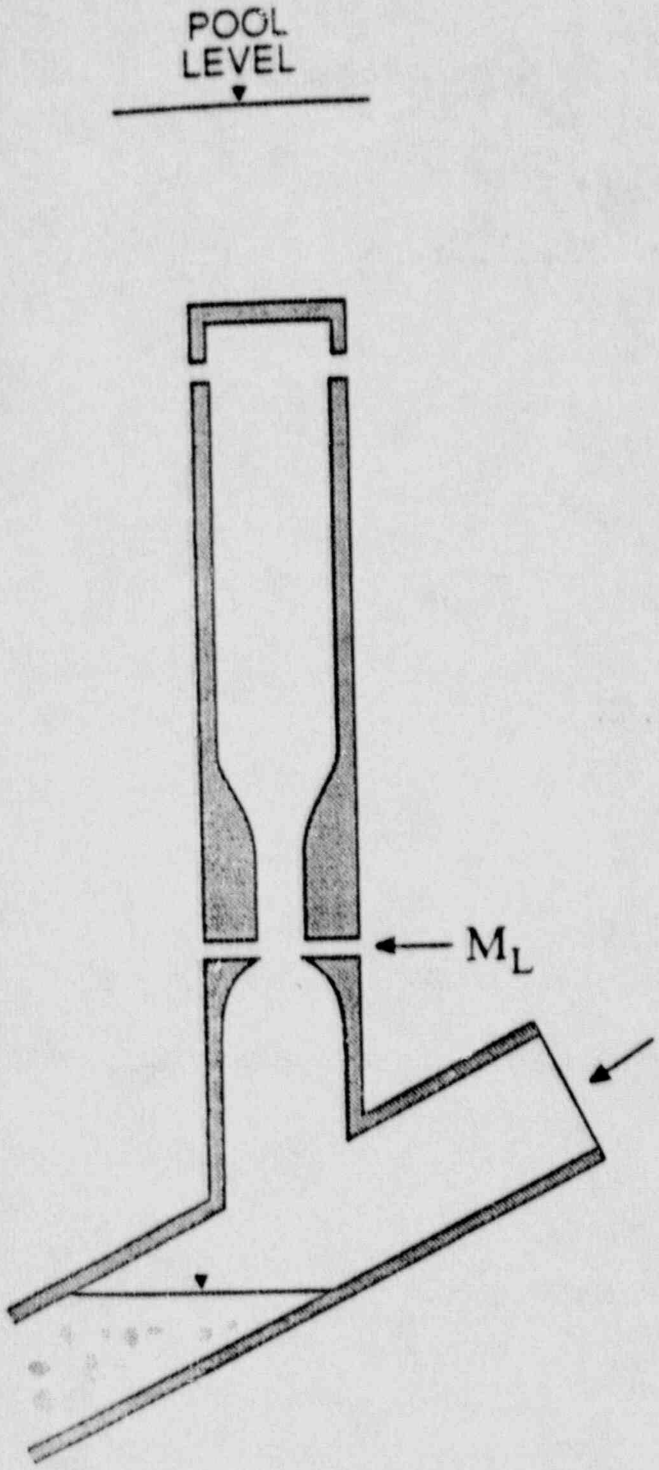
FLOW MODELING

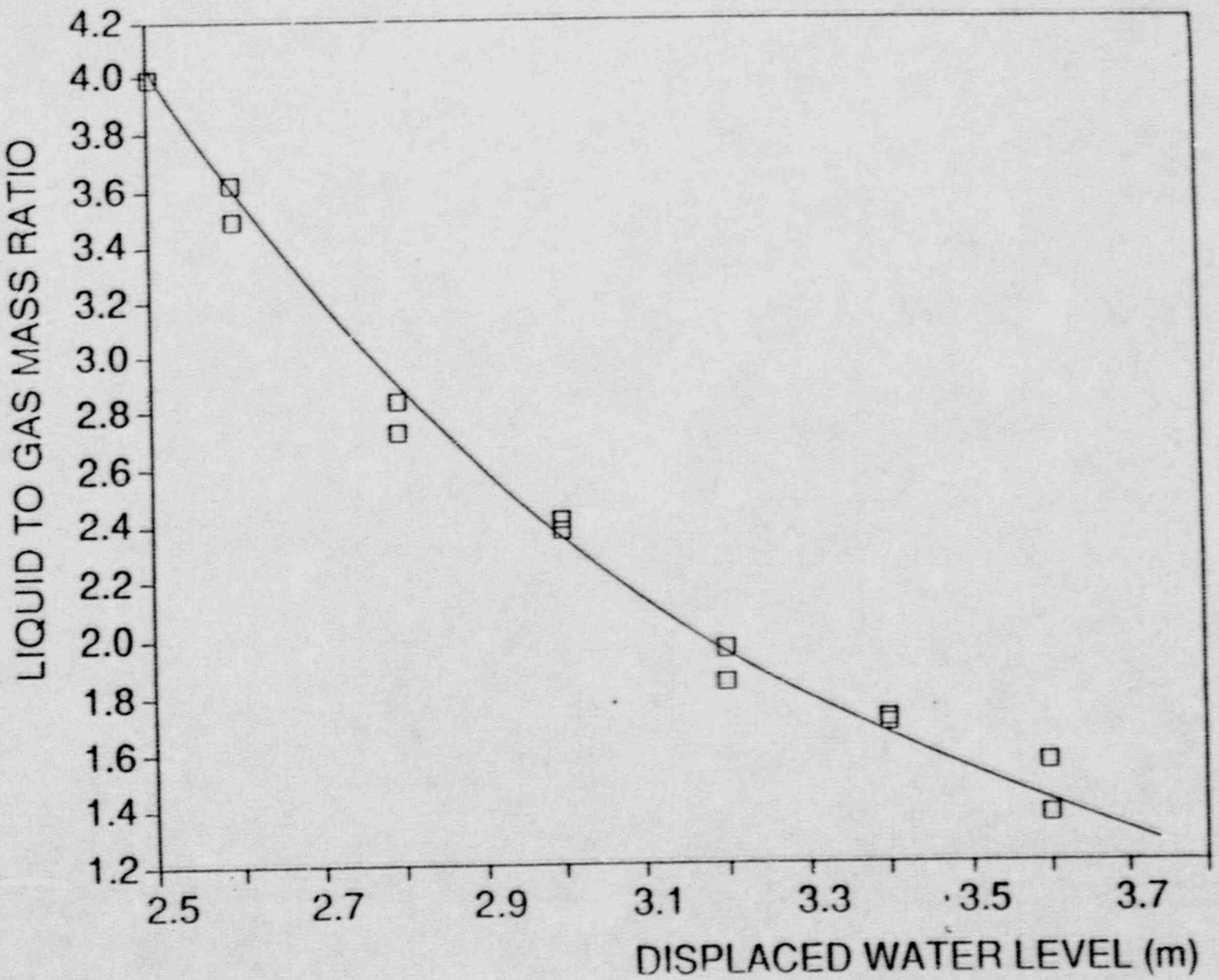


INPUT
GEOMETRY
INLET PRESSURE
GAS COMPOSITION

CALCULATIONS:
~ 6.TWO-PHASE FLOW
EQUATIONS
/ CONSTITUTIVE EQN.

OUTPUT:
VENTURI GAS AND
LIQUID FLOWS:
M_L, M_G
PRESSURES

FLOW MODELLING. RESULT OF EXPERIMENTS IN FULL-SCALE PROTOTYPICAL ARRANGEMENT.



AEROSOL COLLECTION EXPERIMENTS 2

RESULTS

- Worst case acc. to calculations.
- Lowest possible pool (1 m submergence).

Measured decontamination factor:

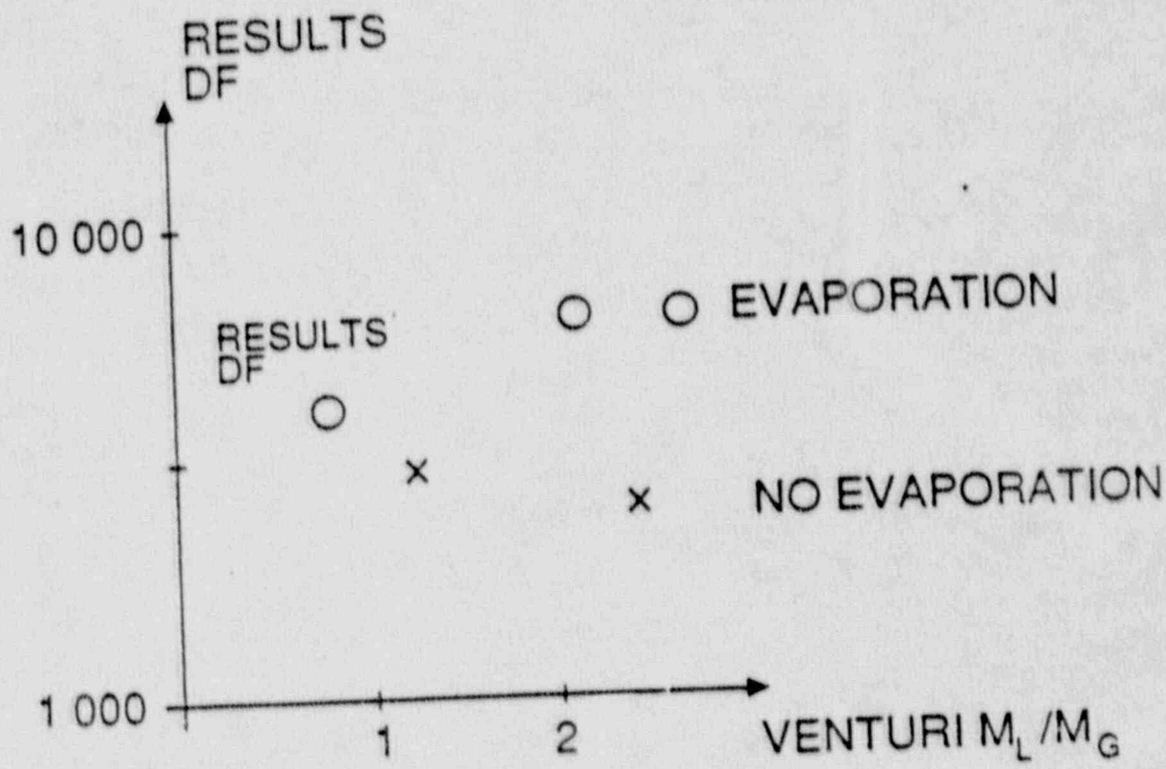
Geometry #	PWR	BWR
1	2701	889
2	1846	687
3	3194	776
4	2462	762
5	2470	835

- NO negative effects of load transients or parallel nozzle operation.

EFFECT OF SCRUBBER LIQUID EVAPORATION

CHANGE IN GAS
MOISTURE CONTENT

REAL PWR CASE : 4%
REPRODUCED IN LAB : 9%



POOL HEIGHT . 2m
ΔP TOTAL ~ 40kPa

SCRUBBER LIQUID RE-ENTRAINMENT

What is contribution due to prolonged bubbling of hot, clean gas through system?

	Lab	Long-term case
Scrubber liquid		
Solute conc., GIL	2	3
Evaporation (change in gas moisture)	2%	<2%

Measured emission of scrubber liquid solute.

$5. \times 10^{-11}$ kg/kg gas

~ 1 PPM of scrubber activity released during 10 day episode.

IODINE ABSORBTION

	Rate constant
$I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$	high
$I_2 + I^- \rightarrow I_3^-$	even higher
$I_3 + 2S_2O_3 \rightarrow S_2O_6^{2-} + 3I^-$	high

➡ System with infinite solubility.

➡ Rate of mass transfer given by physical processes.

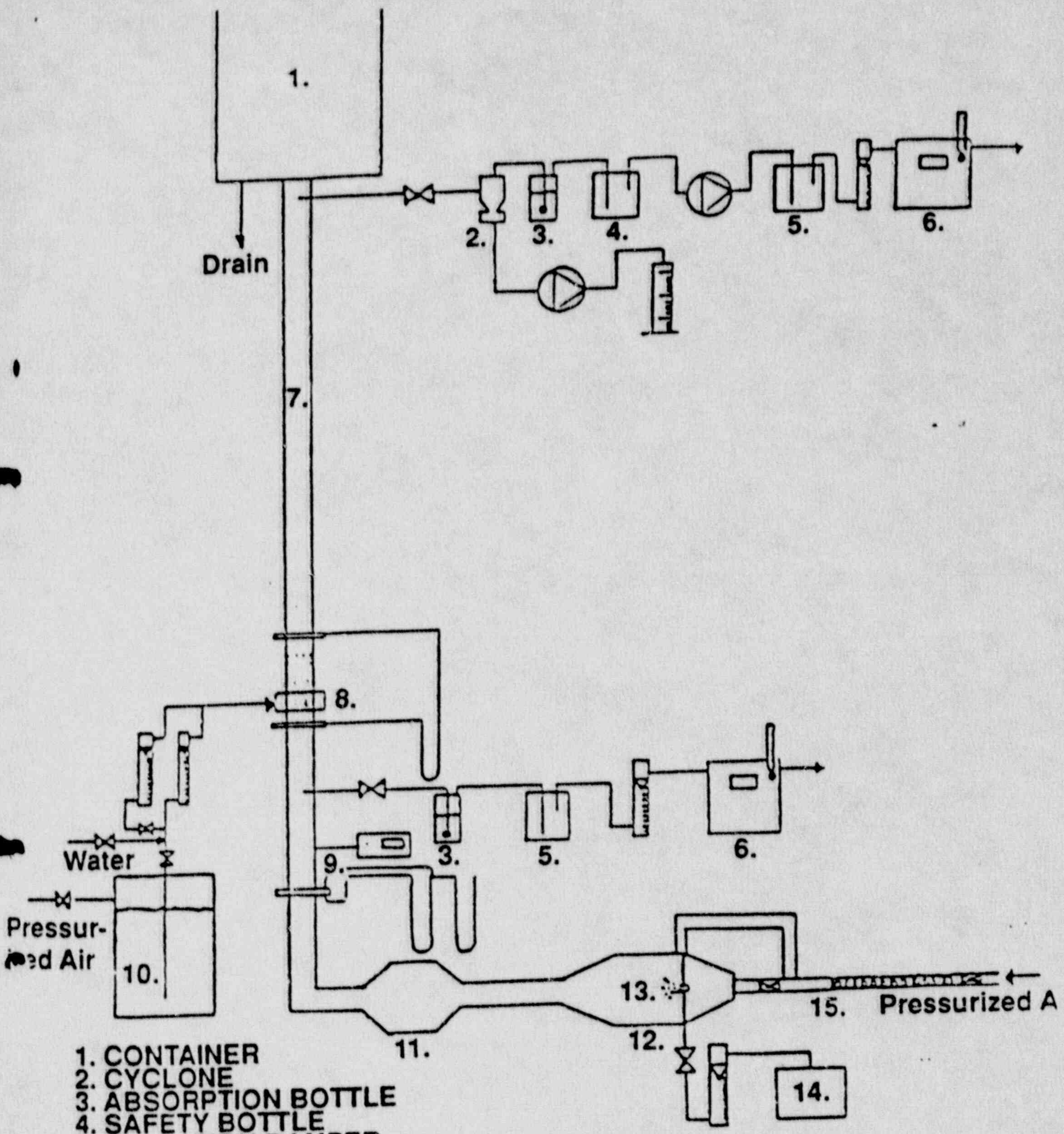
➡ Then, gas absorbtion theory givès that:

$$DF = EXP(\underline{k_G A}\ R\ T/Q_G)$$

System constant

➡ Add mass transfer in pool.

I_2 VENTURI ABSORBTION EXPERIMENT



1. CONTAINER
2. CYCLONE
3. ABSORPTION BOTTLE
4. SAFETY BOTTLE
5. PULSATION DAMPER
6. GAS METER
7. RISER
8. VENTURI
9. THERMOMETER
10. THIOSULFATE SOLUTION TANK
11. PARTICLE FILTER
12. EVAPORATION CHAMBER
13. NOZZLE
14. IODINE - ETHANOL CONTAINER
15. HEAT EXCHANGER

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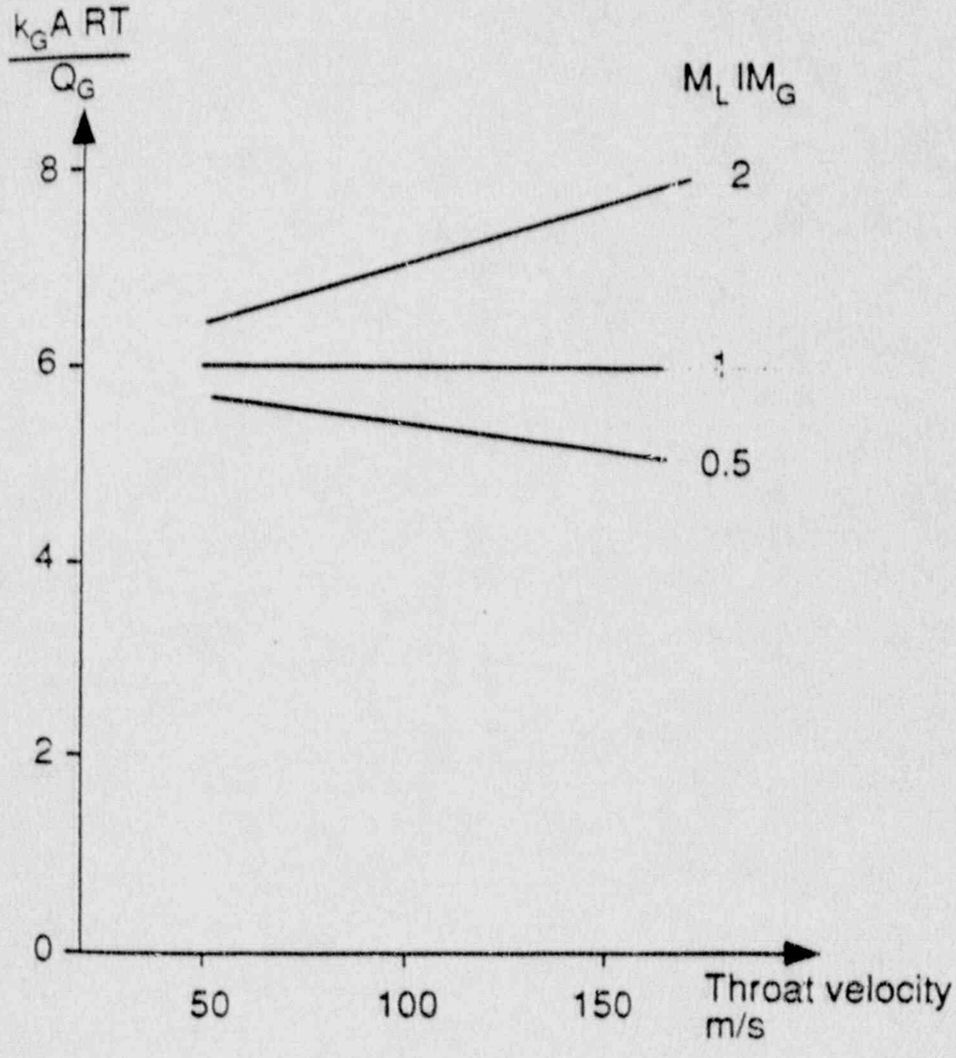
IODINE ABSORBTION. EXAMPLE OF ROOM TEMPERATURE ABSORBTION RESULTS



VERIFICATION.

IODINE ABSORBTION

DF_{tot} = DF (VENTURI)

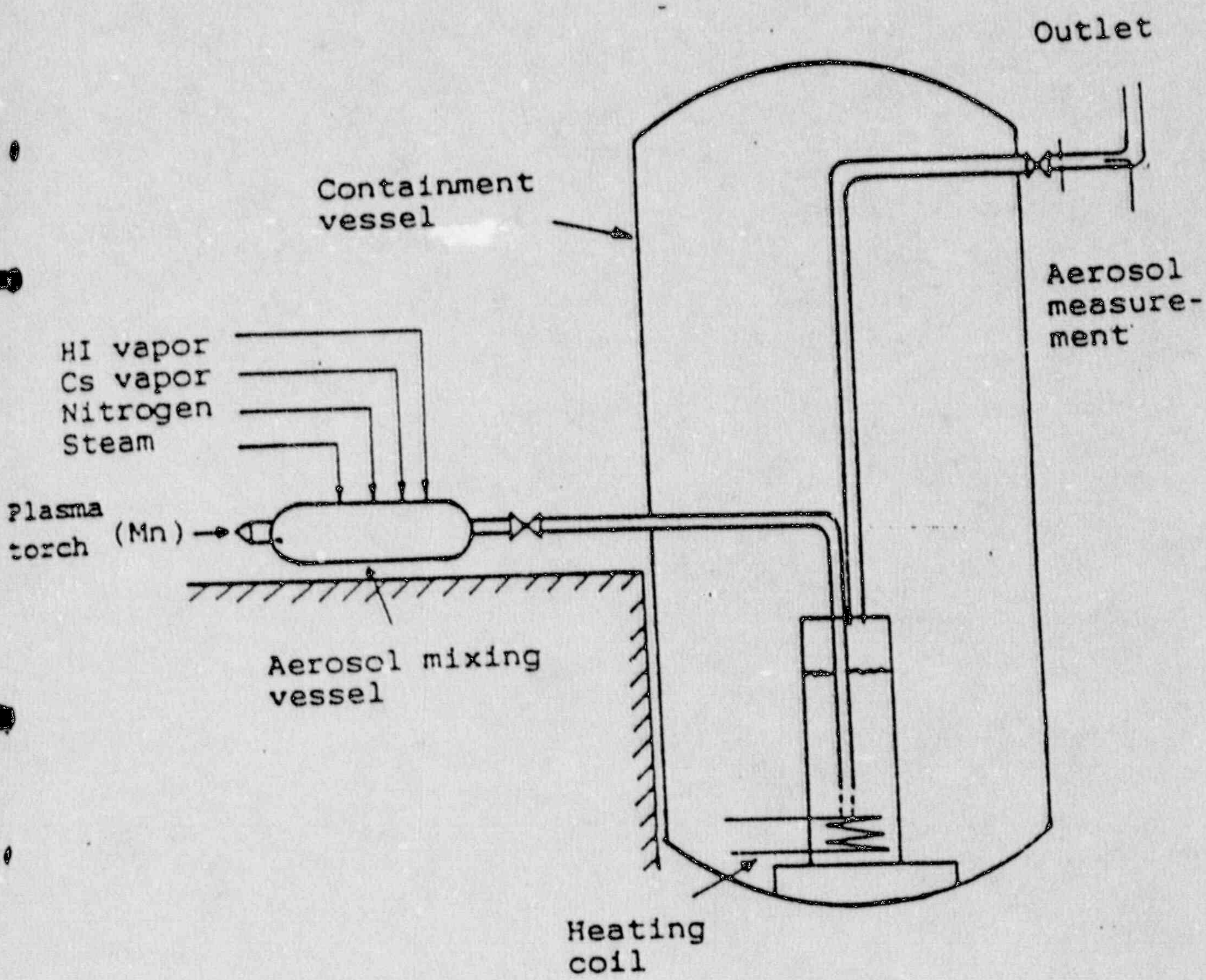
X DF (RISE PIPE)

X DF (POOL)

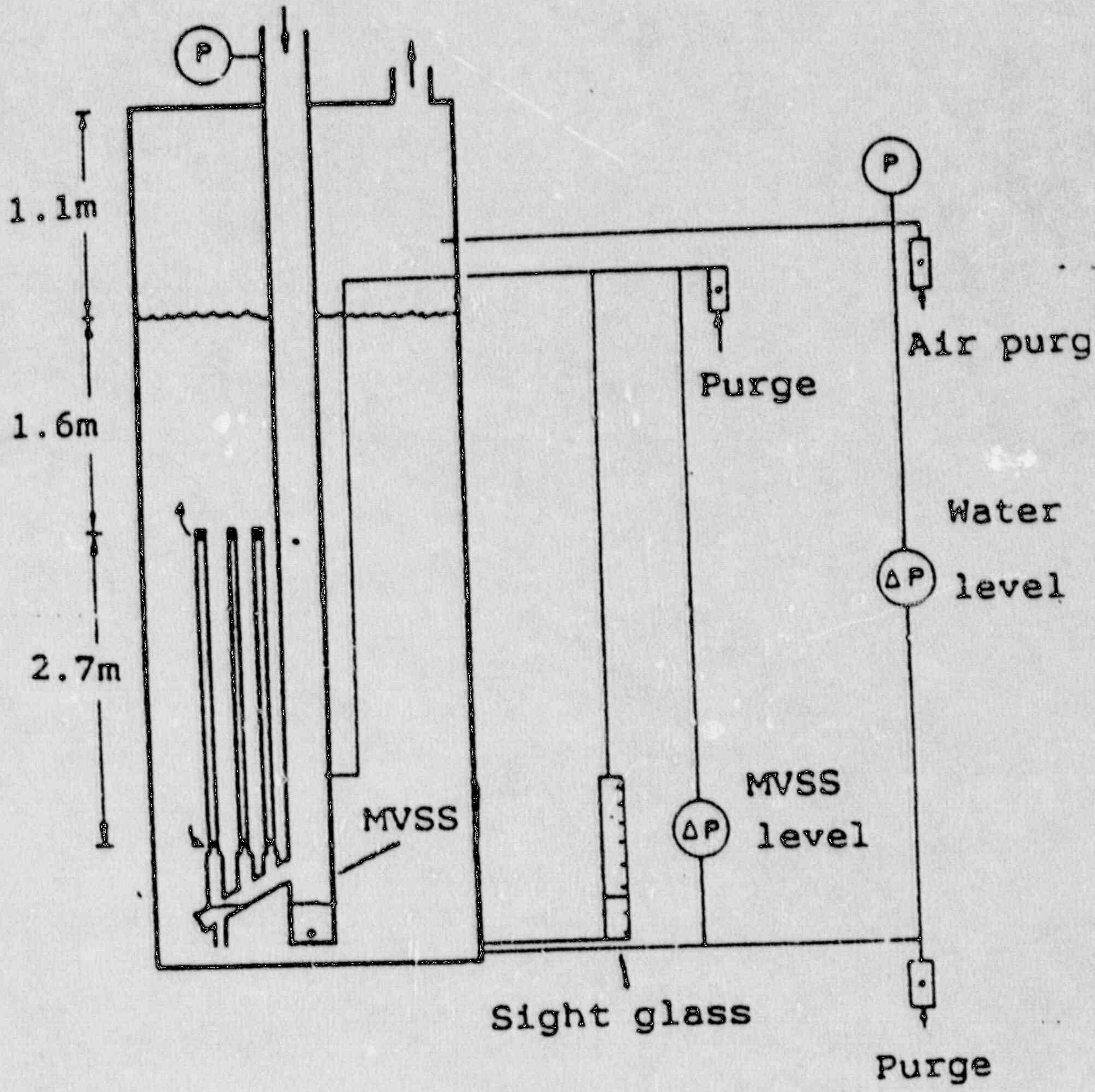
Conservative estimates of Swedish cases:

	BWR	PWR
DF_{tot} >	600	3500

ACE - Filter test series arrangement



ACE - Filter test series arrangement



AEROSOL COLLECTION EXPERIMENTS

TEST CONDITIONS

Inlet:	AA11	AA12
Gas flow rate, m^3/s	0.090	0.093
Gas temperature	113	129
Pressure, kPa	153	150
Volume steam fraction	0.012	0.407
Saturation temperature, °C	17	87

Outlet:		
Gas flow rate, m^3/s	0.096	0.061
Pool temperature, °C	23	32
Submergence of top of MVSS, m	1.67	1.77
Pressure, kPa	106	105
Volume steam fraction	0.024	0.044

DECONTAMINATION FACTORS

DF FROM AEROSOL CONC. (Impactor measurements)	AA11	AA12
Cs	25 000	31 000
Mn	1 500	3 800
I	19 000	55 000

Enclosure 8

NUREG-0800
(Formerly NUREG-75/087)

U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants

Section No. 6.5.5
Revision No. 0

Appendix No. ______
Revision No. ______

Branch Tech. Position ______
Revision No. ______

Date Issued December 1988

FILING INSTRUCTIONS

PAGES TO BE REMOVED		NEW PAGES TO BE INSERTED	
PAGE NUMBER	DATE	PAGE NUMBER	DATE
None		Section 6.5.5 (New) 6.5.5-1 Rev. 0 Thru 6.5.5-5	December 1988

The U.S. Nuclear Regulatory Commission's Standard Review Plan, NUREG-0800, prepared by the Office of Nuclear Reactor Regulation, is available for sale by the National Technical Information Service, Springfield, VA 22161.

U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

6.5.5 PRESSURE SUPPRESSION POOL AS A FISSION PRODUCT CLEANUP SYSTEM

REVIEW RESPONSIBILITIES

Primary - Chemical Engineering Branch

Secondary - Plant Systems Branch
Radiation Protection Branch

I. AREAS OF REVIEW

The pressure suppression pool is reviewed under this plan only when the applicant claims credit for fission product scrubbing and retention by the suppression pool. The pressure suppression pool and the drywell, when considered as a barrier to the release of fission products, are reviewed to assess the degree to which fission products released during postulated reactor accidents will be retained in the suppression pool. Leakage paths that allow fission products to bypass the pool are identified and reviewed, and the maximum fractional bypass leakage is obtained, for use in the evaluation of radiological dose consequences.

1. Fission Product Control Requirements

   Sections of the applicant's safety analysis report (SAR) related to accident analyses, accident dose calculations, and fission product control are reviewed to establish whether or not fission product scrubbing of the drywell or reactor compartment atmosphere is claimed or required for mitigation of radiological consequences following a postulated accident.

2. Design Bases

   The design bases for the fission product removal function of the suppression pool and the drywell or reactor compartment are reviewed to verify that they are consistent with the assumptions made in the accident evaluations of SAR Chapter 15.

The methodology used in this SRP section is not intended for containment venting evaluation. Containment venting will be considered in the evaluation of pressure suppression pools as fission product cleanup systems when the Commission approves the final guidance on containment venting.

3. System Design

The information on the design of the suppression pool is reviewed to familiarize the reviewer with the expected temperature histories, depth of fission product entry expected during postulated accidents, and potential leakage paths through drywell penetrations.

4. Testing and Technical Specifications

The details of the applicant's proposed preoperational tests and, at the operating license stage, the surveillance requirements are reviewed to ensure that the pool depth and amount of leakage bypassing the pool are maintained consistent with the assumptions used in assessing the pool's effectiveness in fission product cleanup.

II. ACCEPTANCE CRITERIA

The acceptance criteria for the fission product cleanup function of the suppression pool are based on the relevant requirements of the following regulations:

A. General Design Criterion 41 (Ref. 1) as it relates to the control of fission products following postulated accidents.

B. General Design Criterion 42 (Ref. 2) as it relates to the periodic inspections of engineered safety features.

C. General Design Criterion 43 (Ref. 3) as it relates to the periodic functional testing of engineered safety features.

Where it can be shown to be in compliance with these criteria, the suppression pool may be given appropriate credit for fission product scrubbing and retention (except for noble gases, for which no pool retention is allowed) in the staff's evaluation of the radiological consequences of design-basis accidents. Other assumptions concerning the release of radioactivity are to be taken from Regulatory Guide 1.3 (Ref. 4), except for Position C.1.f., which this SRP section replaces.

Specific criteria that must be met to receive credit include:

1. The drywell and its penetrations must be designed to ensure that, even with a single active failure, all releases from the reactor core must pass into the suppression pool, except for small bypass leakage.

2. The bypass leakage assumed for purposes of evaluating fission product retention must be no less than that accepted in the review under SRP Section 6.2.1.1.C, and must be demonstrated in periodic tests by the license technical specifications also reviewed under that section.

3. For plants that have already received a construction permit, the iodine retention calculated using this section must not be used to justify removal of the standby gas treatment or other filtered exhaust system from status as engineered safety features, and any change in plant design, proposed testing, surveillance or maintenance must be supported by considerations of lowered operator dose and other projected benefits. For such plants, the charcoal filters must be at least maintained to the minimum level of Table 2 in Regulatory Guide 1.52 (Ref. 5), Revision 2.

Acceptable methods for computing fission product retention by the suppression pool are given in subsection III, "REVIEW PROCEDURES."

While granting credit for suppression pool scrubbing in the calculations of accident doses, the acceptance criteria of containment leakage in SRP Section 6.2.1.1.C and the acceptance criteria of the engineered safety feature atmosphere cleanup systems in SRP Section 6.5.1 should still be met.

III. REVIEW PROCEDURES

The reviewer selects and emphasizes specific aspects of this SRP section as are appropriate for a particular plant. The judgment on which areas need to be given attention and emphasis in the review is based on a determination of whether the material presented is similar to that recently reviewed on other plants and whether items of special safety significance are involved.

The first step in the review is to determine whether or not the suppression pool is to be used for mitigating radiological consequences. If no credit is claimed for fission product removal in the accident analyses, no further review is required under this SRP section.

If the suppression pool is intended as an engineered safety feature for mitigation of radiological doses, then the reviewer estimates its effectiveness in removing fission products from fluids expelled from the drywell or directly from the pressure vessel through the depressurization system.

1. Pool Decontamination Factor

The decontamination factor (DF) of the pool is defined as the ratio of the amount of a contaminant entering the pool to the amount leaving. Decontamination factors for each fission product form as functions of time can be calculated by the SPARC code (Ref. 6). An applicant may use the SPARC code or other methods to calculate the retention of fission products within the pool, provided that these methods are described in the SAR adequately to permit review. If the time-integrated DF values claimed by the applicant for removal of particulates and elemental iodine are 10 or less for a Mark II or a Mark III containment, or are 5 or less for a Mark I containment, the applicant's values may be accepted without any need to perform calculations (Refs. 7 and 8). A DF value of one (no retention) should be used for noble gases and for organic iodides. The applicant should provide justification for any DF values greater than those given above.

If the SPARC code is used for the calculation of fission product decontamination, the review should be coordinated with the branch that is responsible for establishing the input parameters for the calculations.

2. Pool Bypass Fraction

The fraction of the drywell atmosphere bypassing the suppression pool by leaking through drywell penetrations is obtained as a product of the review under SRP Section 6.2.1.1.C. If B is the bypass fraction and DF is the time-integrated pool decontamination factor, then the overall decontamination, D, to be used for accident dose calculations, may be taken as:

$$D = \frac{DF}{1 + B(DF-1)}$$

The reviewer should clearly distinguish that fraction of B, which may be further treated by the standby gas treatment system, from that fraction of B which also bypasses the secondary containment building.

3. Other Containment Atmosphere Cleanup Systems

Drywell or containment spray systems for which fission product cleanup credit is claimed are reviewed under SRP Section 6.5.2, and credit for both suppression pool and spray cleanup can be given as a result of the separate reviews.

4. Technical Specifications

The technical specifications are reviewed to ensure that they require periodic inspection to confirm suppression pool depth and surveillance tests to confirm drywell leak tightness, consistent with the bypass fraction used in computing the overall decontamination.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided by the applicant and that the review and any calculations support conclusions of the following type, to be included in the staff's safety evaluation report:

The staff has reviewed the fission product scrubbing function of the pressure suppression pool and finds that the pool will reduce the fission product content of the steam-gas mixture flowing through the pool following accidents that blow down through the suppression pool. The staff estimates that the pool will decontaminate the flow by a factor of ___ for molecular iodine vapor and by a factor of ___ for particulate fission products. No significant decontamination of noble gases and organic iodides will occur in the pool. The system is largely passive in nature, and the active components are suitably redundant so that its fission product attenuation function can be accomplished assuming a single failure. The applicant's proposed program for preoperational and surveillance tests will ensure a continued state of readiness, and that bypass of the pool is unlikely to exceed the assumptions used in the dose assessments.

The staff concludes that the pressure suppression pool as a fission product cleanup system is acceptable and meets the requirements of General Design Criterion 41 with respect to the iodine removal function following a postulated loss-of-coolant accident, General Design Criterion 42 with respect to the capability for periodic inspection of the system, and General Design Criterion 43 with respect to the capability for periodic testing of the system.

V. IMPLEMENTATION

The following guidance is provided to applicants and licensees about the staff's plans for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with the specified portions of the Commission's regulations, the methods described herein are to be used by the staff in its evaluation of conformance with Commission regulations.

Implementation of the acceptance criteria of subsection II and the review procedures in subsection III is as follows:

(1) Operating plants and applicants for operating licenses pending at the date of issue of this SRP section need not comply with the provisions of this SRP section, but may do so voluntarily.

(2) Future applicants will be reviewed according to the provisions of this SRP section.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 41, "Containment Atmosphere Cleanup."

2. 10 CFR Part 50, Appendix A, General Design Criterion 42, "Inspection of Containment Atmosphere Cleanup Systems."

3. 10 CFR Part 50, Appendix A, General Design Criterion 43, "Testing of Containment Atmosphere Cleanup Systems."

4. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.3, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Boiling Water Reactors."

5. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.52, "Design, Testing, and Maintenance Criteria for Postaccident Engineered-Safety-Featured Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants."

6. P. C. Owczarski, R. I. Shreck, and A. K. Postma, "Technical Bases and Users Manual for the Prototype of a Suppression Pool Aerosol Removal Code (SPARC)," U.S. Nuclear Regulatory Commission Report, NUREG/CR-3317, 1985.

7. P. C. Owczarkski and W. K. Winegardner, "Capture of Iodine in Suppression Pools," 19th DOE/NRC Nuclear Air Cleaning Conference, Seattle, 1986.

8. R. S. Denning et al., "Radionuclide Release Calculations for Selected Severe Accident Scenarios," U.S. Nuclear Regulatory Commission Report, NUREG/CR-4624, Volume 1, July 1986.

NRC FORM 335
(2-87)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by PPMB, DPS, add Vol. No., if any)
NUREG-0800
Section 6.5.5, Rev. 0

2. TITLE AND SUBTITLE
Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, Revision 0 to SRP Section 6.5.5, "Pressure Suppression as a Fission Product Cleanup System"

3. LEAVE BLANK

4. DATE REPORT COMPLETED

MONTH	YEAR
December	1988

5. AUTHOR(S)

6. DATE REPORT ISSUED

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7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
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Washington, D.C. 20555

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Same as above

11a. TYPE OF REPORT
SRP Section (Guide)

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES
Rev. 0 to Section 6.5.5, "PRESSURE SUPPRESSION POOL AS A FISSION PRODUCT CLEANUP SYSTEM."

13. ABSTRACT (200 words or less)

This section resolved an inconsistency in NRC regulatory guidance by giving credit to pressure suppression pools as post-accident fission product cleanup systems in boiling water reactors.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS
Standard Review Plan
Pressure Suppression Pool
Fission Product Cleanup

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT
Unlimited

16. SECURITY CLASSIFICATION
(This page)
unclassified
(This report)
unclassified

17. NUMBER OF PAGES

18. PRICE

Enclosure 9

NUREG/CR-4624
BMI-2139
Vol. 1

Radionuclide Release Calculations for Selected Severe Accident Scenarios

BWR, Mark I Design

Prepared by R. S. Denning, J. A. Gieseke, P. Cybulskis, K. W. Lee,
H. Jordan, L. A. Curtis, R. F. Kelly, V. Kogan, P. M. Schumacher

Battelle's Columbus Division

Prepared for
U.S. Nuclear Regulatory
Commission

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26pp

surprising and would not have been expected a priori. The high releases appear to be due to the coincidence of high debris temperatures and high gas generation rates. The other cases involved as high or higher temperatures and comparable or higher gas release rates. In the other cases, however, the temperatures at the time of peak gas generation were lower than in the base case. Peak gas generation is always predicted immediately after zirconium burnout and is the result of carbon oxidation by carbon dioxide.

The tellurium, strontium, and barium releases are high in all the cases considered and the differences between the cases do not appear to be particularly significant. The differences in the releases of the lanthanum and cerium groups confirm the sensitivity of the releases of the refractory species to the temperature and gas sparging history of the debris. The variations among these cases are believed to be representative of the uncertainties associated with such predictions.

The present sensitivity study was limited to a single scenario and, for reasons of consistency with other parts of the analysis, did not include variations in the initial temperature and composition of the debris. The latter could have greater influences on the predicted results.

6.3 Suppression Pool Decontamination

The environmental fission product releases for a number of core meltdown accident sequences for the Peach Bottom Mark I BWR design have been assessed to serve as input to the forthcoming NRC risk reference document (NUREG-1150). A key factor in the Peach Bottom analyses is the evaluation of fission product scrubbing by the suppression pool; the latter was assessed by means of the SPARC computer code. In order to help quantify the uncertainties associated with the overall source term predictions, a limited set of sensitivity calculations has been performed with the SPARC code itself. These calculations were based on an ATWS scenario which involved core melting in an intact containment and assumed successful containment venting as the containment pressure was predicted to increase above the design level. The specific calculations performed and the results obtained are discussed below.

The accident scenario, including thermal hydraulics and fission product source terms to the containment, were based on the TC3 scenario previously considered. The variations considered in the SPARC sensitivity study were limited to changes in some of the input variables and the fixing or deactivation of some of the aerosol removal mechanisms. The specific cases considered are described below.

1. The base case scenario is identical to the reference TC3 calculation except that the soluble fission product fraction was fixed at 50 percent. This was done to maintain consistency between the several runs of the sensitivity study. In the base case, the bubble size was taken as 0.75 cm in diameter, with an aspect ratio of 3:1. The centrifugal particle removal model was activated. For the flow through the spargers (in-vessel releases) a pool submergence of 12 ft was utilized; for the flow through the downcomers (ex-vessel releases) a submergence of 4 ft was assumed. Since SPARC does not permit the redefinition of the effective bubble size, the above bubble size was utilized for the entire sequence.
2. For the case intended to represent minimum pool scrubbing, the bubble size was taken to be 1.5 cm in diameter, with an aspect ratio of 1:1. (While the foregoing combination will indeed tend to reduce the calculated particle removal from the bubble, it may not be totally self-consistent insofar as the larger bubble would tend to be less spherical than the base case.) The soluble fraction was assumed to be zero, and the centrifugal circulation removal model was turned off for this case.

2a. Since the above case aimed at minimizing the pool decontamination factor was not totally self consistent, it was repeated with an aspect ratio of 3:1.

3. In the case intended to maximize particle removal by the suppression pool, the bubble size was taken to be 0.375 cm in diameter, with an aspect ratio of 6:1. The solubility factor was set at 100 percent, and centrifugal removal was activated.

The foregoing base case bubble size and assumed variation of a factor of two about the nominal value are believed to be representative of flows through the spargers. They may not be representative of the bubble sizes for flows through the Mark I downcomers. In order to assess the influence on predicted aerosol scrubbing of possibly much larger bubbles which could be encountered in downcomer flows, several additional cases were evaluated.

4. The case of very large bubbles was represented by a bubble diameter of 10 cm and an aspect ratio of 1:1. The solubility factor was again fixed at 50 percent, and the centrifugal removal mechanism was activated.

4A. A repeat of the above large bubble case except for the use of a more realistic aspect ratio of 6:1 for the large bubble size being considered.

5. As a further variation on the effect of bubble size, a case with a 1.5 cm bubble diameter, an aspect ratio of 3:1, zero particle solubility, and nominal centrifugal particle removal was evaluated.

5A. The above intermediate bubble size case was repeated assuming 50 percent solubility of the particles.

The time dependent aerosol mass flow into the suppression pool considered is illustrated in Figure 6.1; (average particle size as a function of time is given in Figure 6.2.). The mass flow at about 100 minutes comes from in-vessel and enters the pool through the spargers. The flow occurring after about 200 minutes is associated with the ex-vessel release of fission products and enters the pool through the downcomers. The later releases have been found to dominate the predicted consequences for the Peach Bottom design.

The predicted decontamination factors for the base case are illustrated in Figure 6.3. The overall decontamination factor for this case, defined as the mass of aerosol entering the pool divided by the mass of aerosol leaving the pool over the entire accident period, was calculated to be approximately 284. It is clear from the figure that the predicted decontamination factors for the flow through the spargers are much higher than those for the downcomer flows. The decontamination factors for the flow through the downcomers are considerably lower, but are still high enough in this case to provide substantial reduction in environmental source terms. The results for the minimum pool scrubbing case (Case 2) are illustrated in Figure 6.4. The overall decontamination factor for this case was approximately 3.4. This value is much lower than typically assessed and may

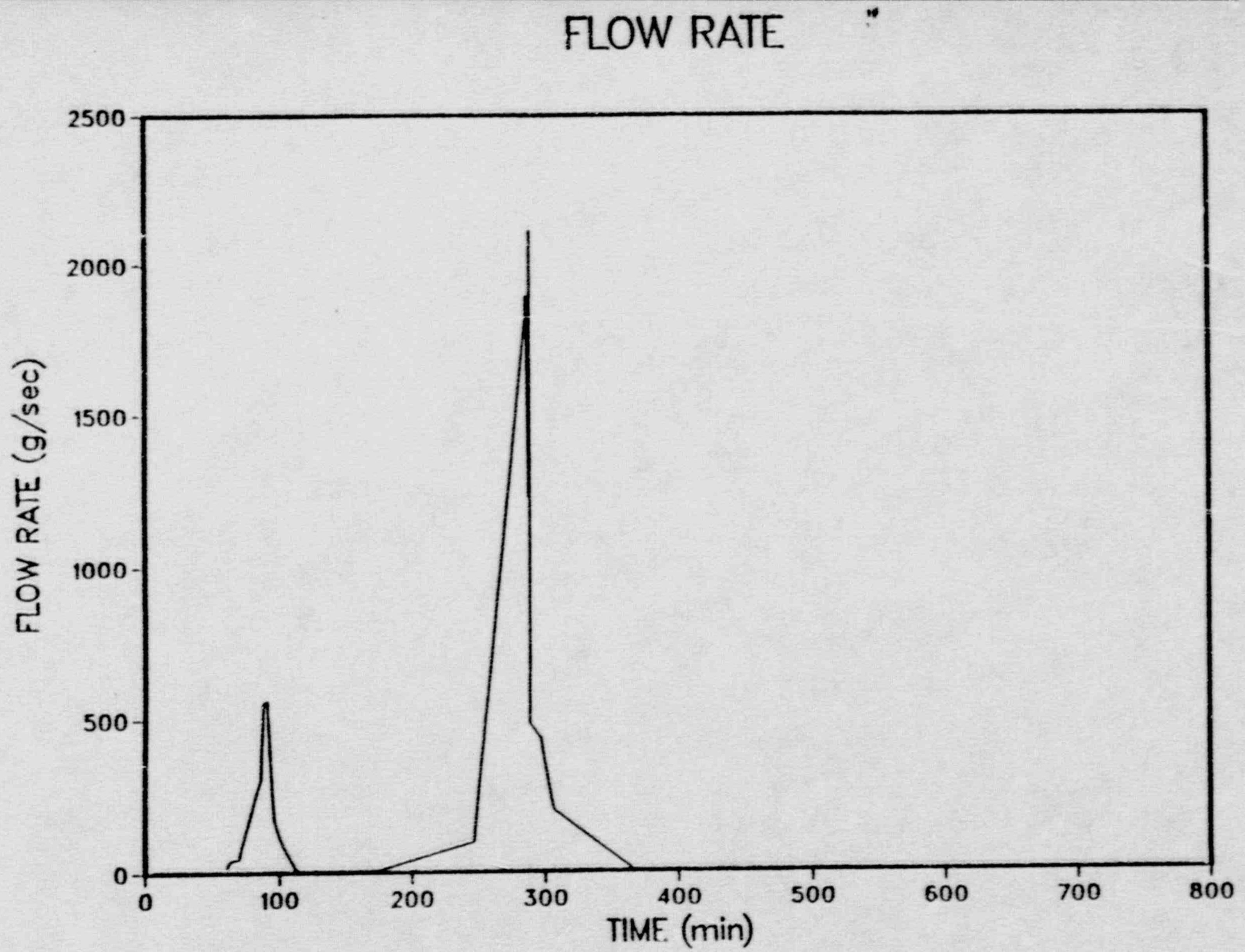

FIGURE 6.1. MASS FLOW INTO SUPPRESSION POOL

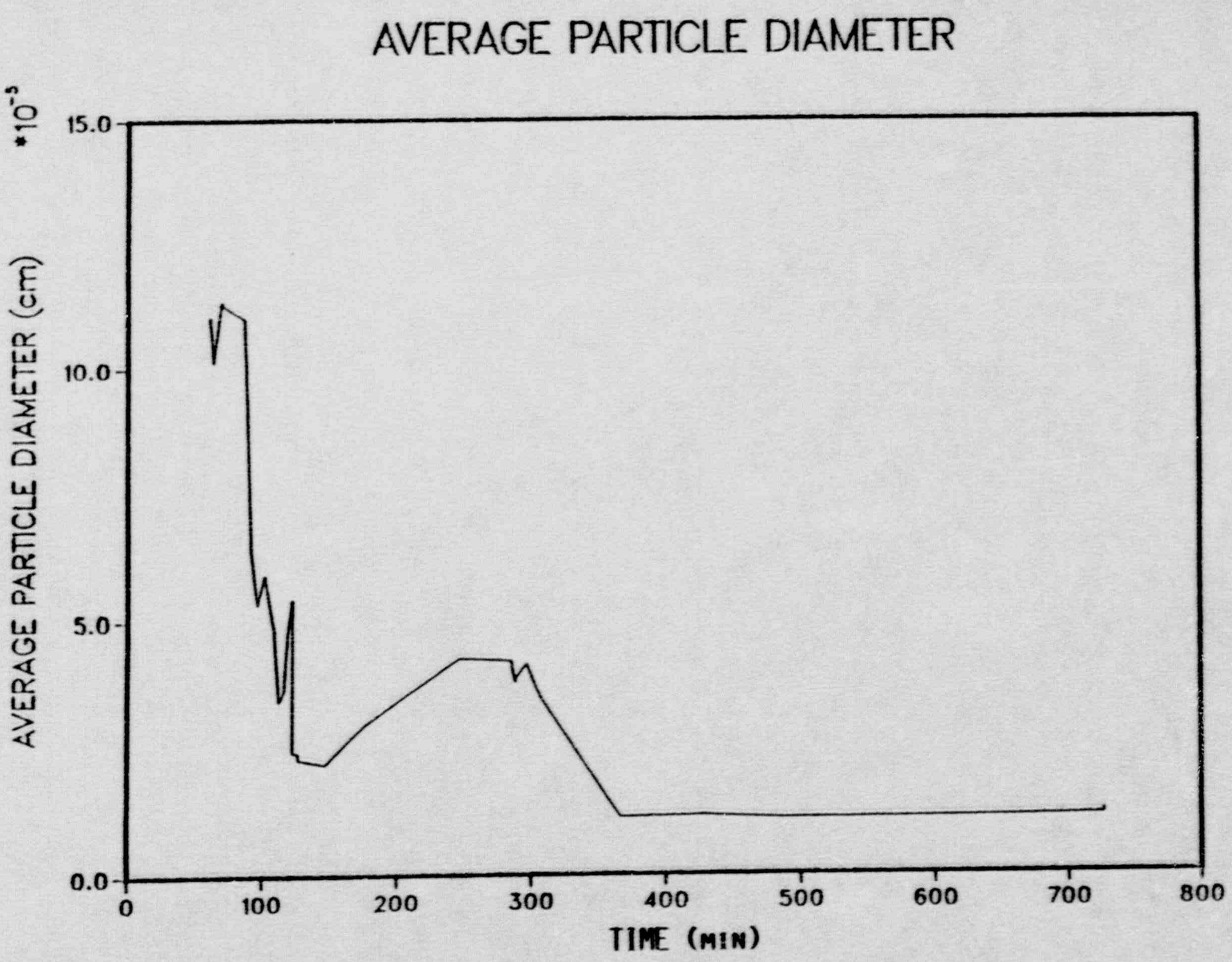

FIGURE 6.2. AVERAGE PARTICLE SIZE

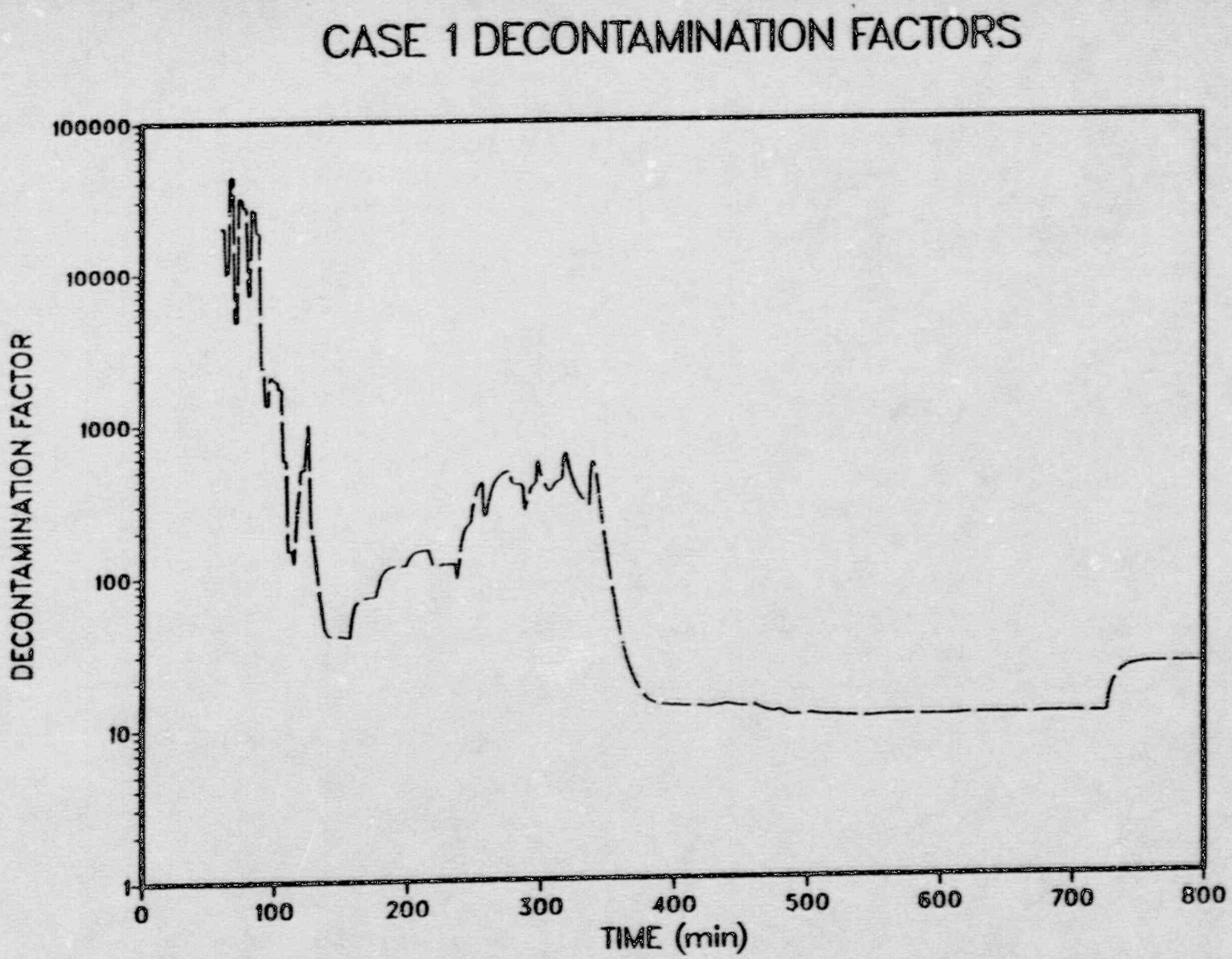

FIGURE 6.3. BASE CASE DECONTAMINATION FACTORS

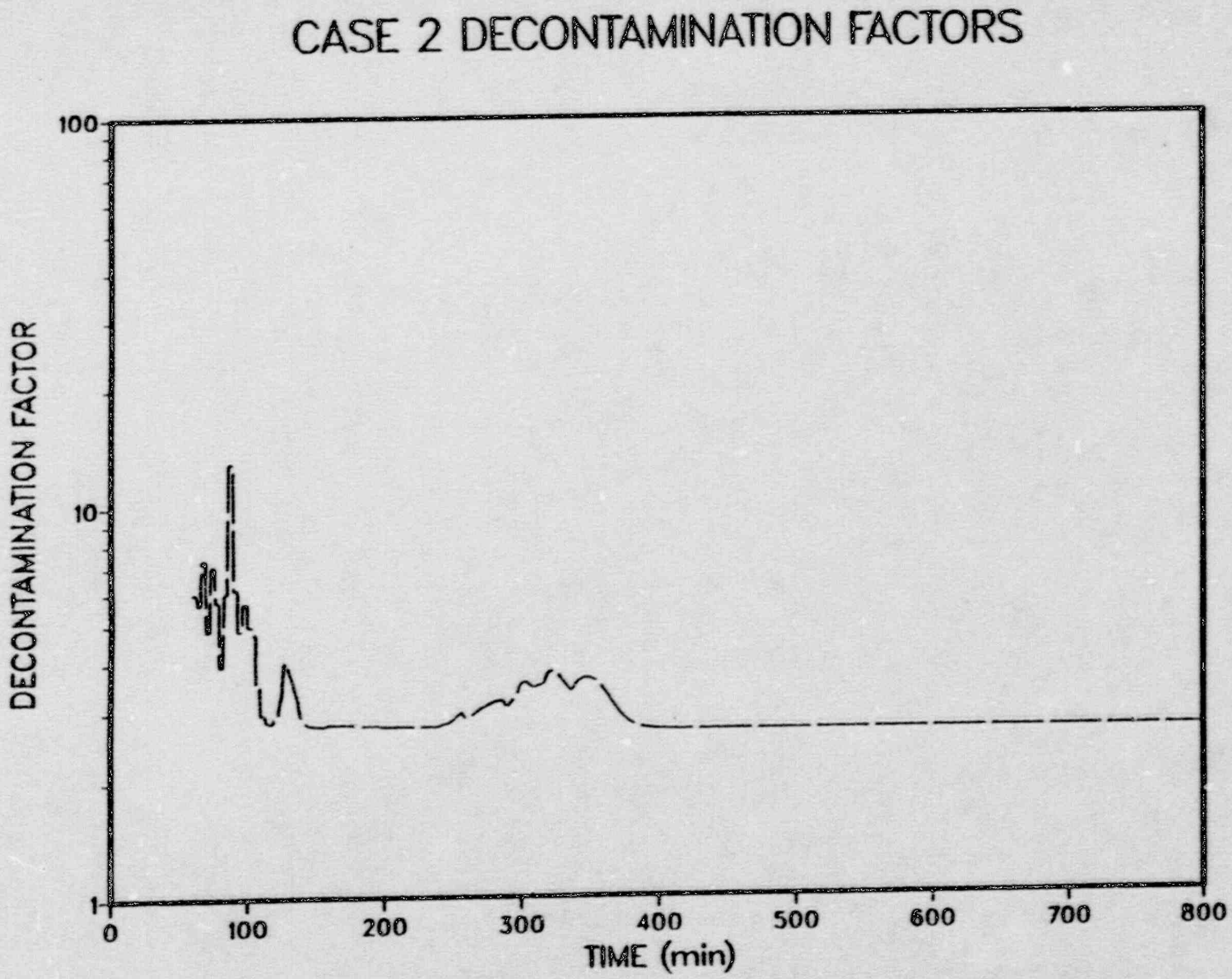

FIGURE 6.4. DECONTAMINATION FACTORS FOR MINIMUM SCRUBBING

indeed represent an extreme case. Changing the aspect ratio from 1:1 to 3:1 with the other parameters the same (Case 2A) had a perceptible but negligible effect on the overall decontamination factor, as illustrated in Figure 6.5.

The high pool scrubbing case (Case 3) is illustrated in Figure 6.6; the overall decontamination factor for this case was about 61,300. For the conditions assumed here the pool is extremely effective for both the in-vessel as well as ex-vessel releases. The decontamination factor for both flow paths is seen to be limited at times to the hard-wired maximum of 100,000.

The calculated results for the very large bubble case (Case 4) are illustrated in Figure 6.7; the overall decontamination factor for this case is about 3.8. The dependence on bubble size is quite substantial. A repeat of this case except for a change to a more realistic aspect ratio of 6:1 for large bubbles (Case 4A, Figure 6.8) produced an overall decontamination factor of 43.

Figure 6.9 illustrates the predicted results for an intermediate (1.5 cm) bubble size, aspect ratio of 3:1, zero solubility, but including the centrifugal particle removal mechanism (Case 5). The overall decontamination factor for this case was predicted to be about 15. The predicted decontamination factors for the sparger flow are once again seen to be quite high, but are considerably lower for the downcomer flow. An additional case (Case 5A, Figure 6.10) with the solubility factor at 50 percent produced an overall decontamination factor of 71.

Table 6-4 summarizes the overall decontamination factors found in this study. The range of overall decontamination factor predicted in this study is perhaps greater than might have been expected. This is particularly true if one considers the fact that the aerosol particle size was not varied. The lowest decontamination factors observed are associated with flow through the Mark I downcomers. Comparison of the results for Cases 2A, 5, and 5A illustrate the effects of particle solubility and the centrifugal particle removal mechanisms. While Cases 2 and 2A indicate little effect of bubble aspect ratio under pessimistic scrubbing conditions, the results for Cases 4 and 4A indicate a significant effect of the aspect ratio for very large bubble sizes.

The results of the present sensitivity study, based on fixed source terms and accident thermal hydraulics, but considering possible uncertainties

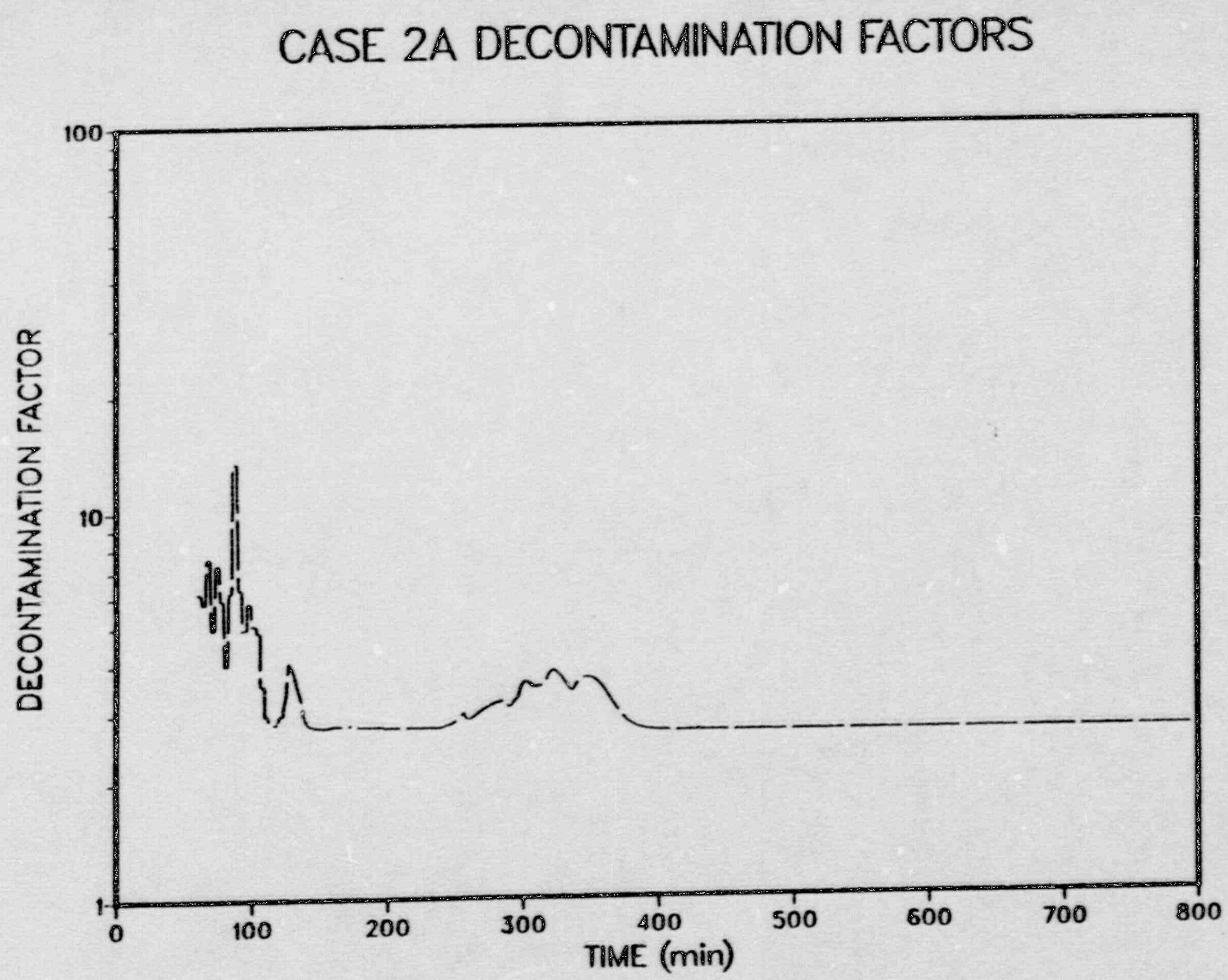

FIGURE 6.5. DECONTAMINATION FACTORS FOR MINIMUM SCRUBBING WITH ELLIPTICAL BUBBLES

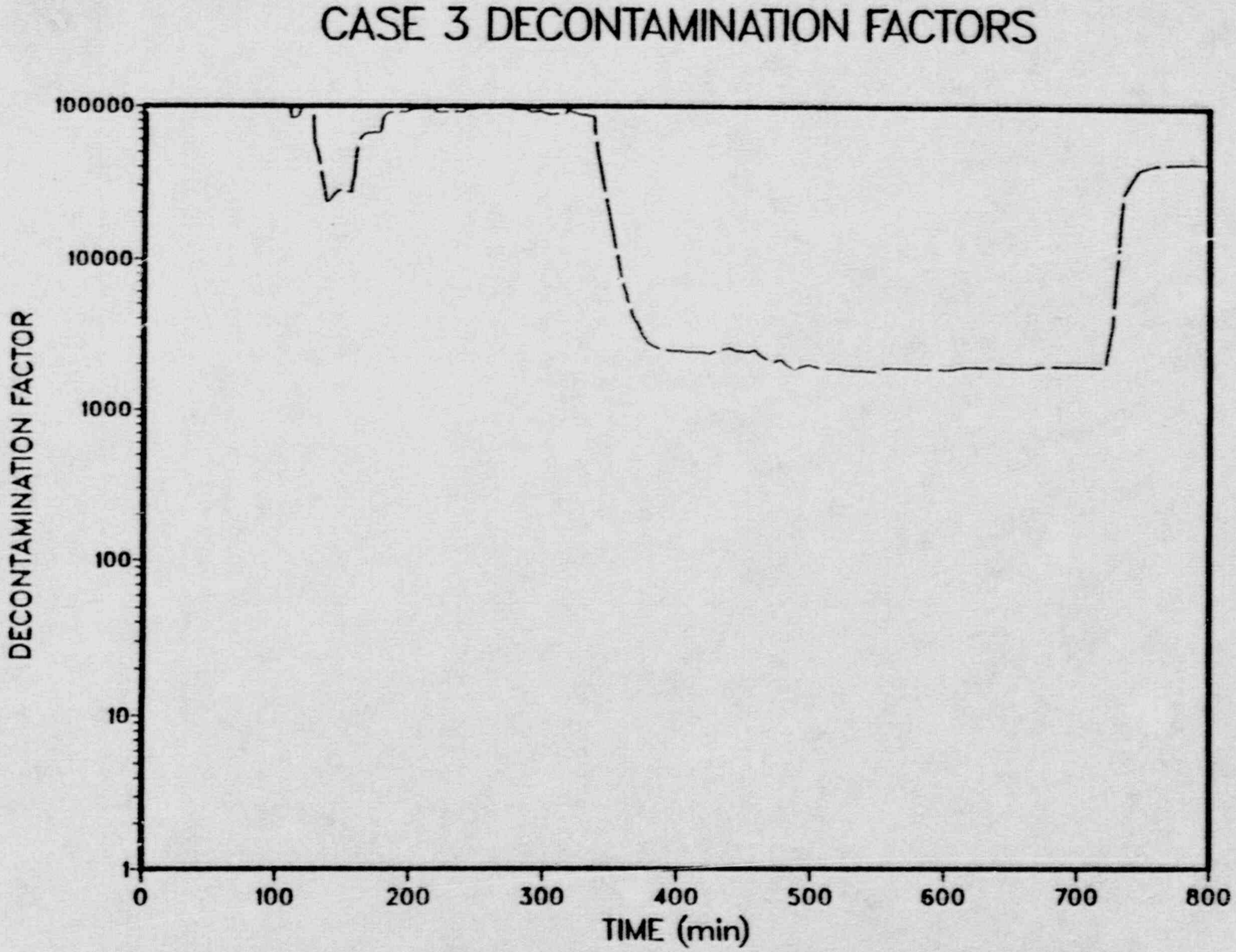

FIGURE 6.6. DECONTAMINATION FACTORS FOR MAXIMUM SCRUBBING

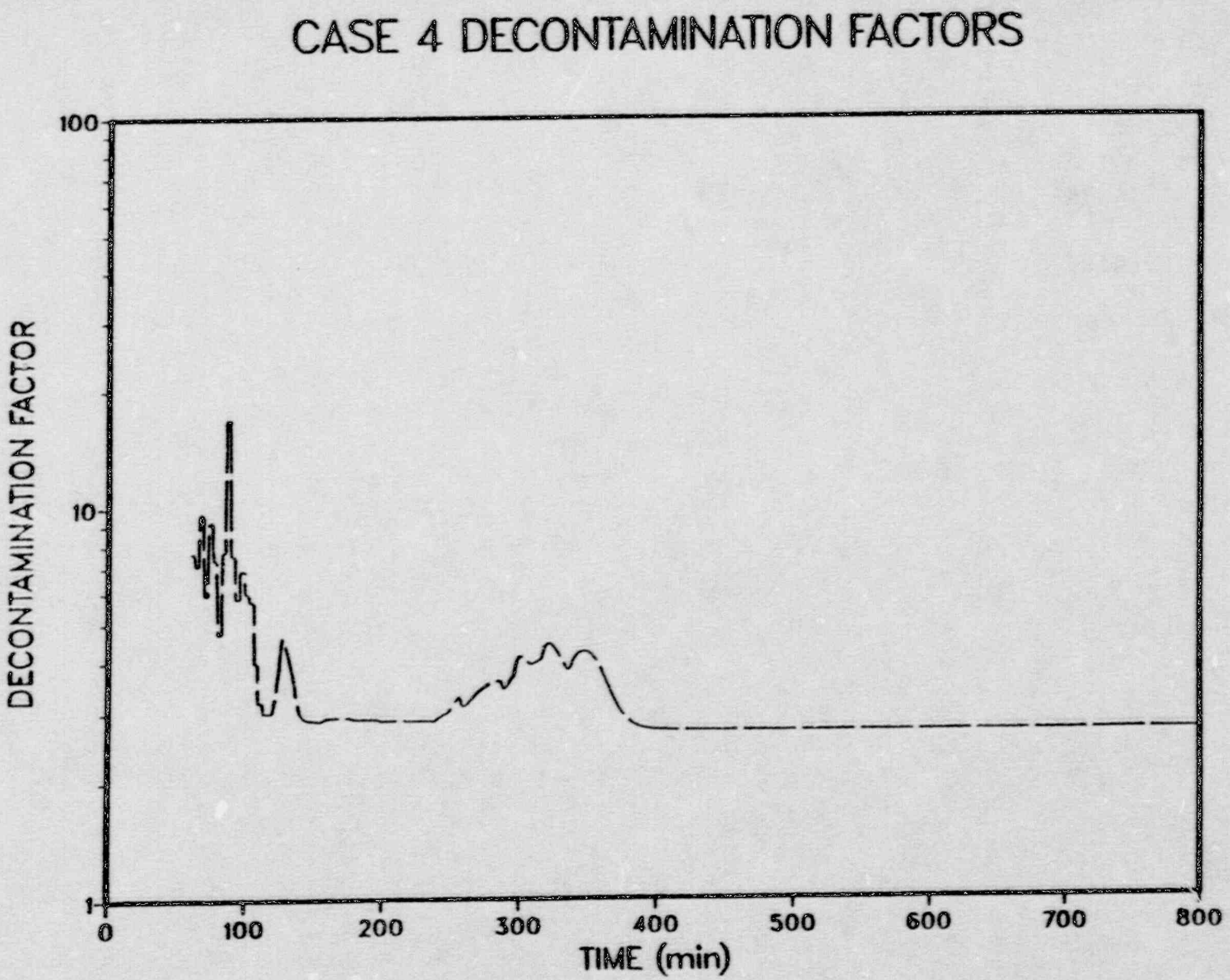

FIGURE 6.7. DECONTAMINATION FACTORS FOR LARGE SPHERICAL BUBBLES

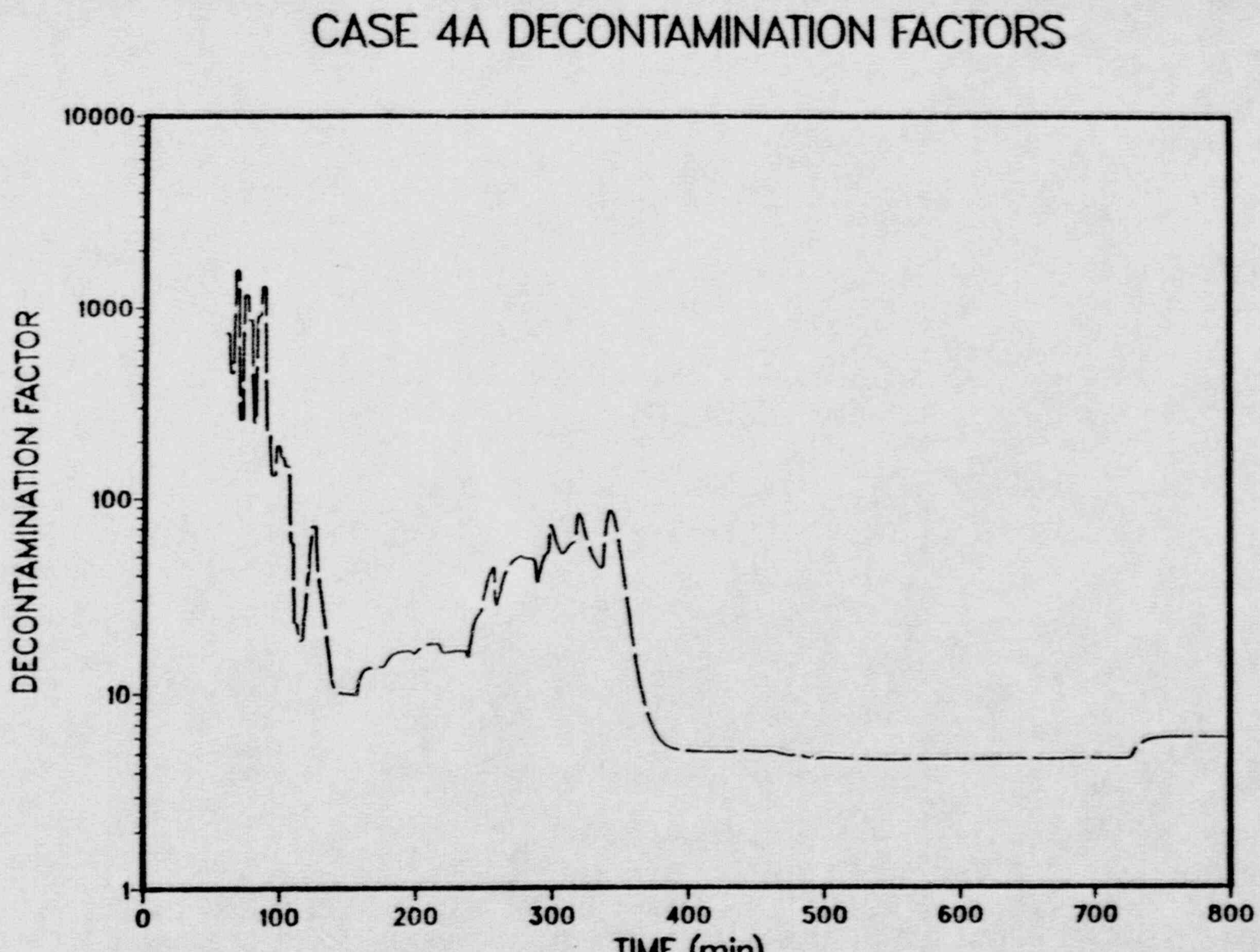

FIGURE 6.8. DECONTAMINATION FACTORS FOR LARGE ELLIPTICAL BUBBLES

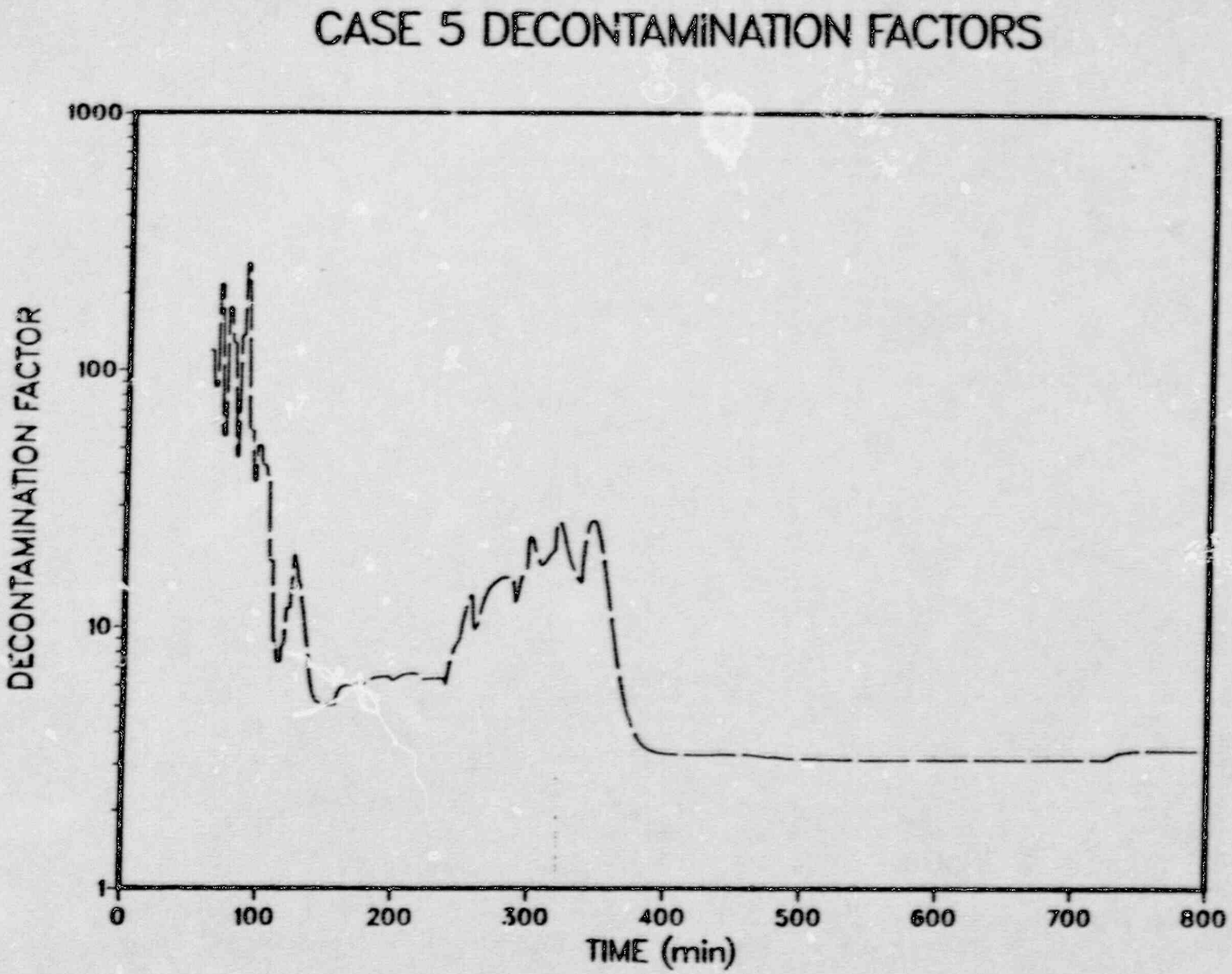

FIGURE 6.9. DECONTAMINATION FACTORS FOR INTERMEDIATE ELLIPTICAL BUBBLES WITH PARTICLE CIRCULATION

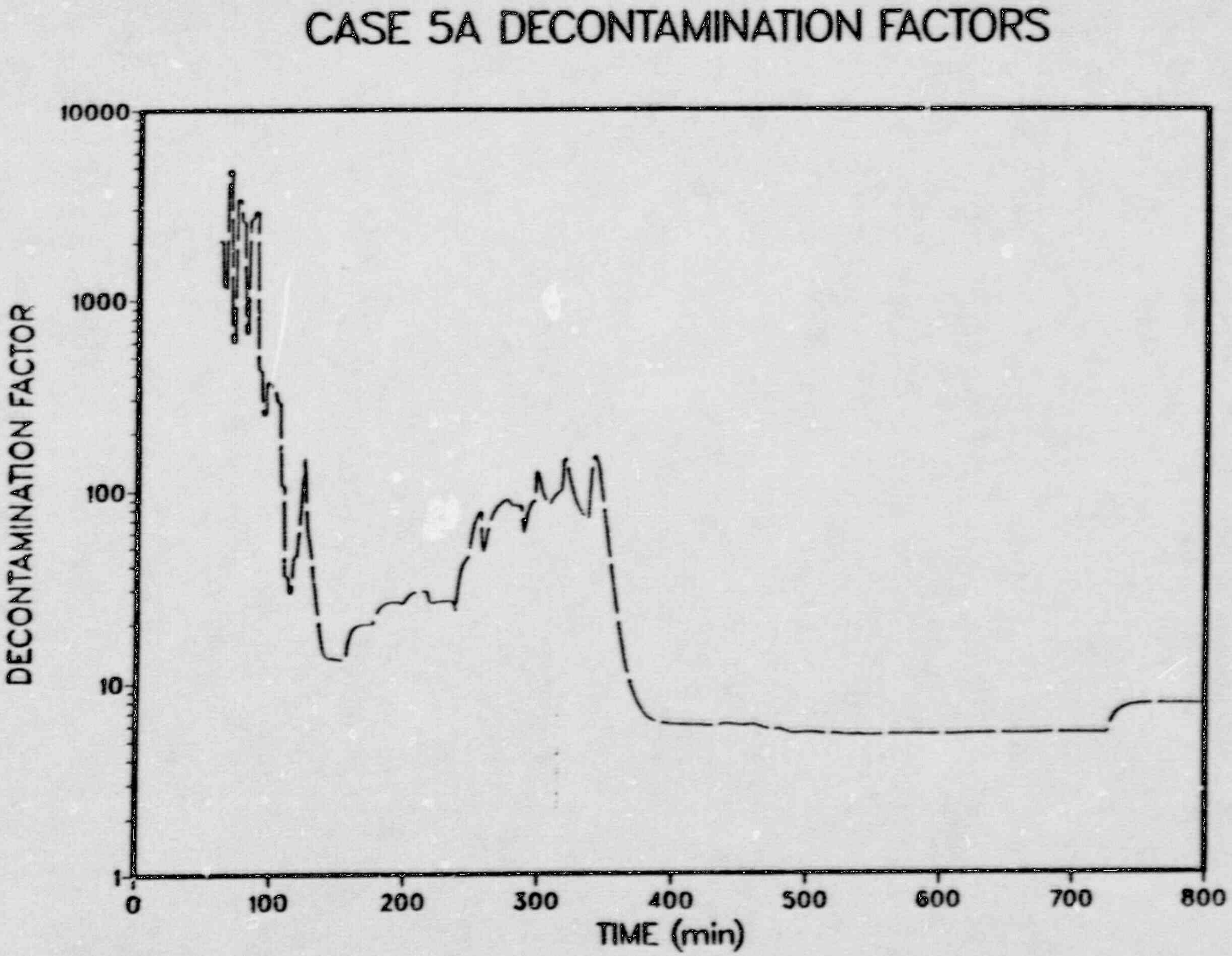

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FIGURE 6.10. DECONTAMINATION FACTORS FOR INTERMEDIATE ELLIPTICAL BUBBLES INCLUDING CIRCULATION AND SOLUBLE PARTICLES

TABLE 6.4. SUMMARY OF OVERALL DECONTAMINATION FACTORS

Case	Bubble Size (cm)	Aspect Ratio	Solubility (%)	Circulation (on/off)	Decontamination Factor
1	0.75	3:1	50	On	284
2	1.5	1:1	0	Off	3.4
2A	1.5	3:1	0	Off	3.4
3	0.375	6:1	100	On	61,300
4	10.0	1:1	50	On	3.8
4A	10.0	6:1	50	On	43
5	1.5	3:1	0	On	15
5A	1.5	3:1	50	On	71

in the SPARC input and modeling parameters indicate a high degree of sensitivity. This sensitivity is particularly noticeable for the ex-vessel releases which reach the suppression pool through the Mark I downcomers. While the base case decontamination factors are quite substantial, those for some of the bounding cases are quite low.