UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAY 17 1976

Thomas M. Novak, Chief, Reactor Systems Branch, DSS
THRU: W. Minners, Section Leader, RSB, DSS AT

SUMMARY OF MEETING WITH GENERAL ELECTRIC COMPANY

A meeting was held with General Electric in Bethesda on March 23, 1976, to discuss core spray distribution tests and proposed changes to the GE-ECCS Evaluation Model..

GE personnel presented a progress report on the core spray distribution tests and their implications for operating reactors. GE also discussed potential improvements applicable to their inventory and core heatup models.

The enclosure provides more detail concerning the items discussed.

Ronald K. Frahm
Reactor Systems Branch
Division of Systems Safety

Enclosures:
1. Meeting Minutes
2. List of Attendees
3. Slide Presentations

cc: S. Hanauer
V. Stello
D. Ross
T. Novak
Z. Rosztoczy
R. Baer
R. Woods
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ACRS (21)
NRC PDR
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MEETING MINUTES

I. Core Spray Distribution Tests

General Electric (GE) presented the results of tests with single nozzles in a steam environment, Nozzles of the high velocity type with a fine spray showed some effect of cone contractions. Nozzles of the low velocity types with coarse spray were little affected by steam. The VNC type nozzles, although they produce a coarse spray have a deflector and showed abrupt cone contractions under certain pressure/temperature conditions. For BWR/2, 3 reactors the fine, high velocity type nozzles are used to cover the peripheral fuel while the coarse low velocity type cover the remainder of the core. Therefore it is concluded that core spray distribution will be little changed by a steam environment in BWR/2, 3 type reactor configurations. BWR/4 reactors use VNC nozzles to cover the peripheral and center region assemblies with the fine, high velocity type covering the intermediate region. However, the VNC nozzle cone contraction that affects spray distribution maybe compensated for by the superposition and interaction of the two spray spargers.

GE also presented material to quantify the observed contraction for different reactor types. BWR/2, 3 and Vermont Yankee have two nozzle types; an atomizing nozzle (covers periphery) and an open elbow nozzle (covers remainder of the core). Because the atomizer nozzles cover the periphery, the sensitivity of the angle of elevation on cone narrowing was investigated. The results showed that even with a severe position change no peripheral fuel bundles will starve, even though some of the edge channels are below the design minimum flow rate. The sensitivity of the BWR/2, 3 open elbow nozzles (coarse spray) to steam showed that patterns in air and steam are nearly identical at one atmosphere; showed a concentration in the center of the cone as pressure is raised with a maximum occurring at three atmospheres and remaining constant at high pressures. The tests showed that BWR/2, 3 type nozzles are less sensitive to a steam environment than the VNC nozzle used in the tests, therefore no further spray distribution tests are planned for BWR/2, 3 reactors.

The VNC nozzle used on BWR/4, 5 reactors showed an abrupt cone contraction in steam. The VNC nozzle, without a deflector in air, gave the same spray pattern as an open elbow nozzle in steam. The VNC contracted pattern in steam is twice as broad as an open elbow nozzle in steam and a VNC without deflectors in air. The simulated VNC cone contraction in air showed a significant change in spray distribution with VNC deflectors removed. For the single sparger

VNC (w/o deflector) tests, there was full coverage of the core; with a minimum channel flow of 2.09 GPM (with updraft). Between 18 to 26% of the channels had less than the 3.25 gpm minimum design requirement. The tests showed that air updraft also improved flow coverage in the low flow regions. The double sparger tests, with no air updraft, resulted in full distribution with no channels below the minimum design flow of 3.25 gpm. Again there was a significant change in spray distribution with the VNC nozzle deflectors removed. The simulation of the VNC cone contraction in air showed that the superposition of flows from many nozzles contributed to uniformity of spray distribution and BWR core spray distribution can tolerate cone angle changes without degradation of distribution.

With regard to the ECCS capability of a BWR/4, the two sparger tests showed that the 3.25 gpm minimum flow requirement is exceeded. For a design basis LOCA, assuming a single failure of the LPCI injection valve (2 core spray systems available), the reflood time is 240 seconds and the peak cladding temperature (PCT) is 2200°F with full core spray heat transfer. For an assumed diesel-generator single failure (2 LPCI + 1 core spray failed) leaving only one core spray sparger available, and with the test results showing that only 75% of the channels received the minimum 3.25 gpm; the calculated PCT was 1950°F (at a reflood time of 110 sec) assuming half core spray heat transfer. GE felt that these results show that the LPCI failure is still the worst single failure and that the current MAPLHGR limits still apply.

Future experimental programs to be undertaken by GE include: distribution tests of all GE nozzles in the single nozzle ASEA facility; single steam nozzle tests to quantify nozzle performance; and full scale tests with modified nozzles to simulate horizontal steam test results. GE wants to simulate the cone angle change more precisely in air tests (because the effect of cone angle may be overpredicted by the air test).

Future analytical work includes: single-droplet model development single-nozzle model development, and developing a multiple-nozzle interaction model. A core spray distribution model will be developed to investigate the sensitivity of BWR/4, 5, and to facilitate the design of BWR/6.

II. Evaluation Model Improvements

1. Reflood Model Experimental Programs

GE plans a study of steam-water interaction effects in a BWR system during a LOCA. Separate effects studies include single and parallel bundle studies with thermal-hydraulics in the upper plenum. The system features incorporated in the test apparatus include representation of two bundle flow paths, one bypass region flow path and one jet pump flow path. Adiabatic tests are being run with steam injected into bundle flow paths to simulate vaporization, and the two-phase characteristics are being evaluated with attention to counter-flow of liquid and steam at the flow path entrances and exits. Heated tests in which bundle flow path steam is internally generated are also being run. This test program is being run to quantify parallel channel hydraulic stability and CCFL breakdown.

GE is considering a one-sixth scale reactor simulation for investigating thermal-hydraulic phenomena in the upper plenum region. Adiabatic air/water tests and steam/water tests will investigate multiple-channel CCFL effects, including effects on core spray distribution and temperature distribution across the top of the core as the liquid is heated by the steam upflow.

The effect of system feedback on CCFL performance characteristics is being investigated in the single bundle/ECC System test apparatus. In this test CCFL performance is evaluated under transient conditions representative of the LOCA, including feedback from the system hydraulic characteristics.

Modifications to the two-loop test apparatus (TLTA) are also planned. Interaction effects of ECC injection on the bypass and bundle exit CCFL characteristics in the upper plenum will be evaluated. Later testing will examine BWR reflooding characteristics.

Proposals for a large scale integral ECCS facility will be made to EPRI and NRC in late 1976. This facility will use full scale reactor components including 32 full size bundles incorporating actual tie plates, spacers, channel boxes, control rods, guide tubes, and steam separators.

Early results of these experimental programs show conservatism in the treatment of CCFL in the reflood calculation; further experiments will be used to develop more realistic correlations to predict reflood times.

2. Core Heatup Model Potential Improvements

A radiation model coupled to the fuel clad swelling model using individually calculated radii; and grey body factors recalculated each time a perforation occurs, will be incorporated into CHASTE.

A modified Bromley-Ellion correlation will be used in the post nucleate boiling; post lower-plenum flashing; fuel channel heat transfer (when covered by bypass inventory); and post re-flooding regimes.

The conduction model will be improved by using 11 nodes vs 4 nodes, constant Δ volume vs constant Δ radius, full implicit integration, and better time step and noding sensitivity.

3. SAFE Code Potential Improvements

The improved model will use discrete physical regions (instead of large thermodynamic nodes), hydraulic modelling will consider void distribution within nodes, inventory redistribution will be considered in all nodes, CCFL will be considered at restrictions. A homogeneous critical flow model with choked conditions at two regions, to be incorporated into LAMB and SAFE, is now in progress.

GE plans to show the overall conservatism in the evaluation model and provide a basis for reducing operating restrictions.

ATTENDEES - CORE SPRAY MEETING

NRC	GE
R. Frahm	P. W. Marriott
W. Minners	A. J. Levine
R. Woods	R. E. Schaffstall (Bethesda GE)
W. Hodges	
J. Guibert	
J. Thomas	
Y. Y. Hsu (RSR)	
N. Zuber (RSR)	
P. Boehnert (ACRS)	

EFFECT ON STEAM ENVIRONMENT ON CORE SPRAY NOZZLE ANGLES

- INTRODUCTION AND BACKGROUND
- DESCRIPTION OF PHENOMENA
- QUANTIFICATION OF CONTRACTION
- EFFECT ON BWR/2,3, VERMONT YANKEE
- EFFECT ON BWR/4,5
  - VNC NOZZLE PERFORMANCE IN STEAM
  - SIMULATION OF VNC CONTRACTION IN AIR
  - CONCLUSIONS
- EFFECTS OF COUNTER-CURRENT FLOW LIMITING
- PROGRAMS TO INVESTIGATE PHENOMENA
- SUMMARY OF STATUS

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INTRODUCTION & BACKGROUND

MAY 74 – ASEA – ATOM TESTS SHOW NARROWING IN STEAM

JUNE 74 – ASEA TESTS (SINGLE NOZZLE, HIGH PRESSURE, VISUAL ONLY)

- CONFIRMATION OF PREVIOUS RESULTS

JULY 74 – GE TESTS (SINGLE NOZZLE, LOW PRESSURE, VISUAL ONLY)

- ELBOWS: NO EFFECT
- VNC: BIG EFFECT
- OTHERS: INTERMEDIATE EFFECT

AUGUST 74 – NRC BRIEFING MEETING

SEPTEMBER 74 – 218 BWR/4 AIR TESTS WITH CONTRACTED VNC

- TOTAL CORE COVERAGE
- SOME CHANNELS LESS THAN DESIGN REQUIREMENT WITH SINGLE SPARGER
- LIKELY TO BE OK WITH BOTH SPARGERS

– BWR/2,3 AIR TEST

- ATOMIZER AIMING ANGLES VARIED TO DETERMINE SENSITIVITY
- SMALL EFFECT ONLY AT PERIPHERY

NOVEMBER 74 – BEGIN TESTS TO DETERMINE FEASIBILITY OF ALL-ELBOW SPARGERS FOR BWR/4,5

– BEGIN ANALYTICAL MODELLING AND SUPPORTING TESTS

MAY 75 - NRC PROGRESS MEETING - REPORT ON PROGRAMS UNDERWAY

JUNE 75 - ASEA TESTS (SINGLE NOZZLE, HIGH PRESSURE, DETAILED MEASUREMENT)

- VNC CONTRACTION "THRESHOLD" QUANTIFIED
- OPEN ELBOW PATTERN CONCENTRATION

SPETEMBER 75 - 218 BWR/4 DOUBLE-HEADER TEST WITH SIMULATED CONTRACTION

- ADEQUATE DISTRIBUTION

SEPTEMBER-
DECEMBER 75 - ASEA TESTS (SINGLE NOZZLE, HIGH PRESSURE, DETAILED MEASUREMENT)

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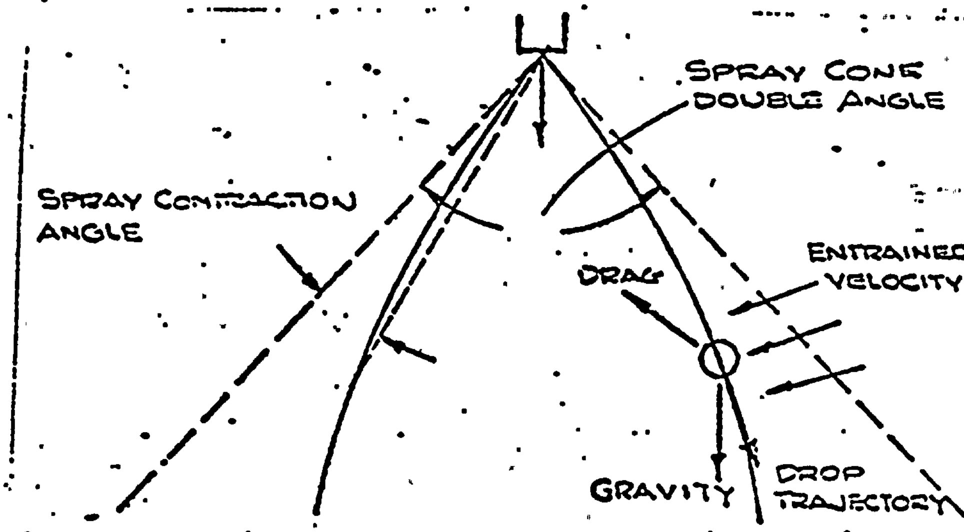
NOZZLE PATTERN EFFECTS



- SPRAY CONE CONTRACTED DUE TO "PUMPING:" AFFECTED BY
  - DROPLET VELOCITY
  - TOTAL FLOW RATE
  - DROPLET SIZE
  - VAPOR DENSITY AND VISCOSITY
- SPRAY CONE CONTRACTED DUE TO CONDENSATION: AFFECTED BY
  - ALL OF THE ABOVE
  - DROPLET SUBCOOLING

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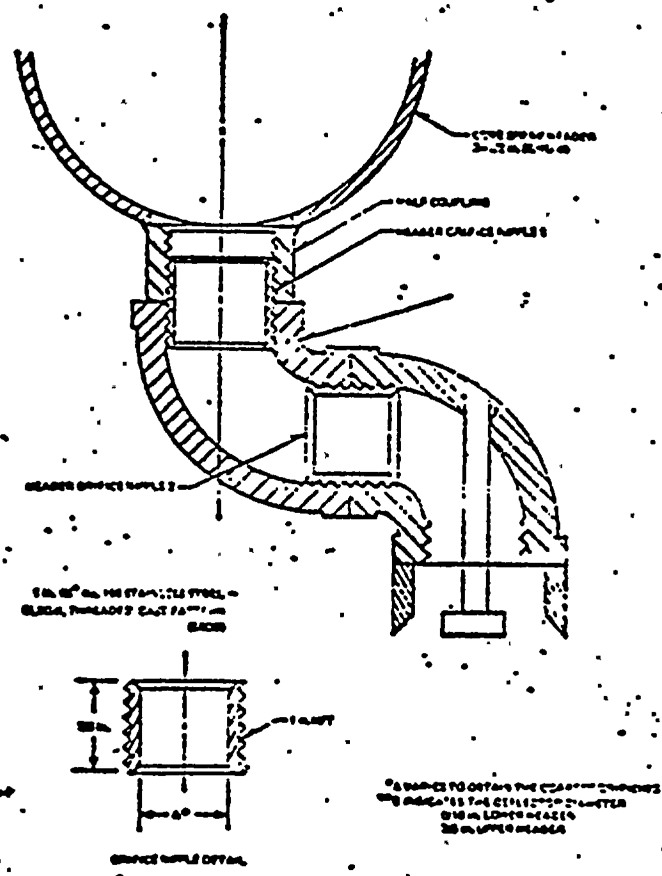
DESCRIPTION OF VNC NOZZLE

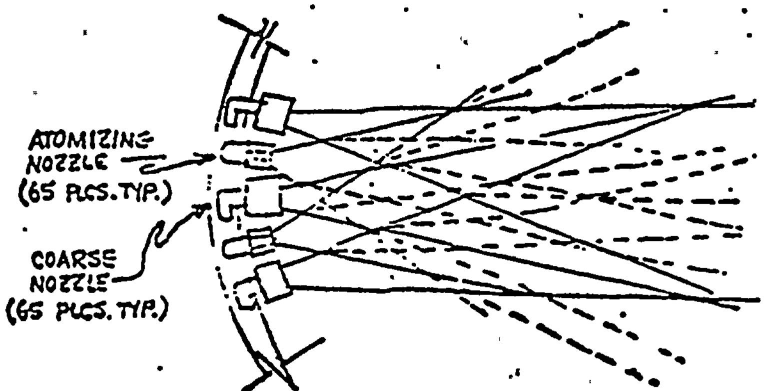


Typical One-inch Shielded VNC Nozzle

- PIPE ELBOW – DEFLECTOR – SHIELD
- HOLLOW CONE (≈ 70° VERTEX)
- COARSE, LOW-VELOCITY DROPS

EFFECT ON BWR CORE SPRAY DISTRIBUTION

- GE BWR CORE SPRAY SYSTEMS DESCRIPTION (TYPICAL)



- SUPERPOSITION, INTERACTION BETWEEN NOZZLES AND BETWEEN SYSTEMS CONTRIBUTES TO UNIFORMITY OF DISTRIBUTION

- TWO INDEPENDENT FULL-CAPACITY SYSTEMS

EFFECT ON BWR CORE SPRAY DISTRIBUTION

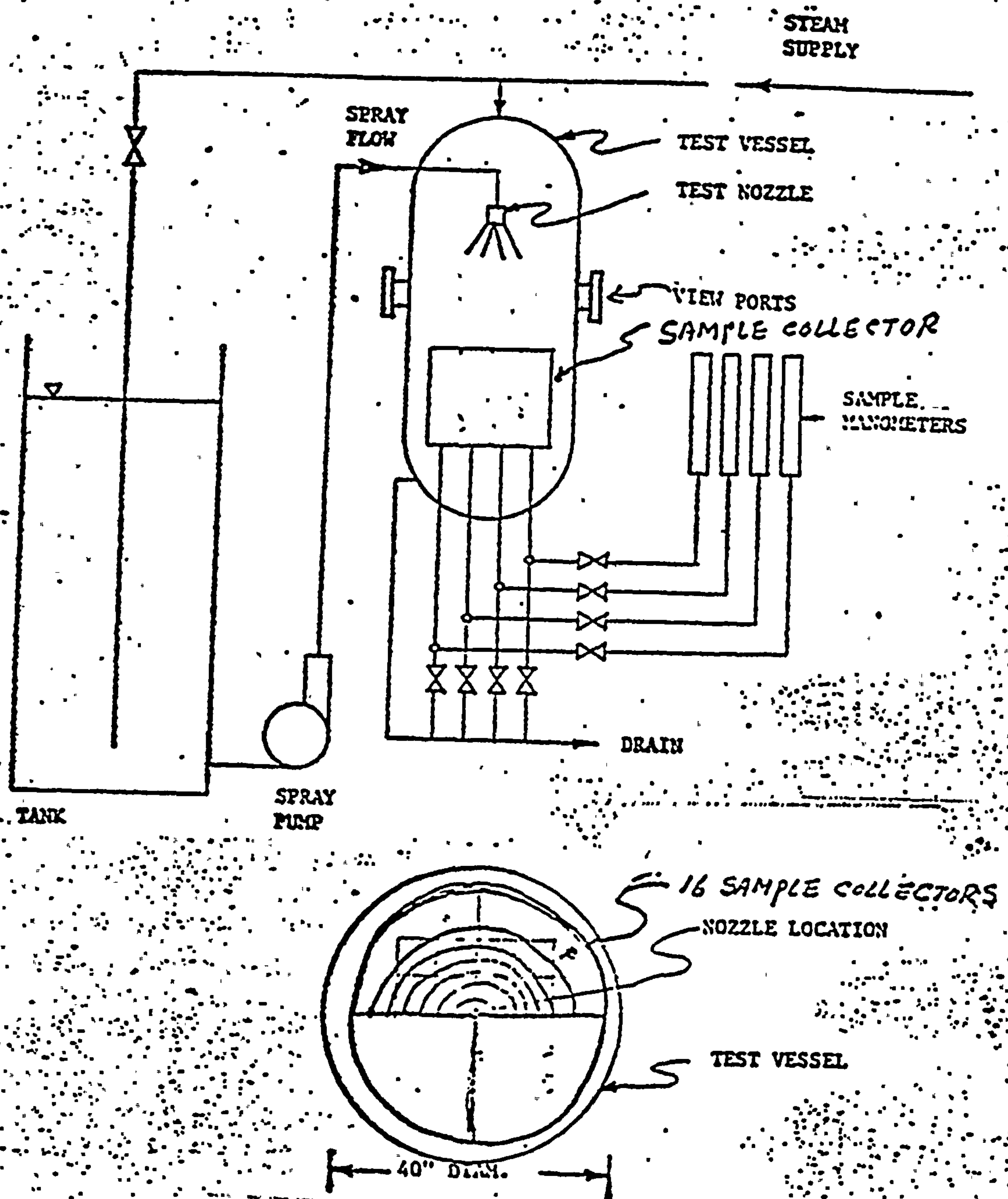
- SUMMARY OF FINDINGS - SINGLE NOZZLE TESTS
  - FINE, HIGH VELOCITY TYPES: RESULTS SIMILAR TO ASEA TESTS - SOME EFFECT
  - COARSE, LOW VELOCITY TYPES: LITTLE EFFECT
  - VNC NOZZLE: ABRUPT CONE CONTRACTION UNDER CERTAIN PRESSURE/TEMPERATURE CONDITIONS

- CONFIGURATION OF BWR/2,3 REACTORS (TYPICAL)
  - FINE, HIGH VELOCITY TYPES COVER PERIPHERAL FUEL ASSEMBLIES
  - COARSE, LOW VELOCITY TYPES COVER REMAINDER OF CORE
  - CONCLUSION: LITTLE EFFECT

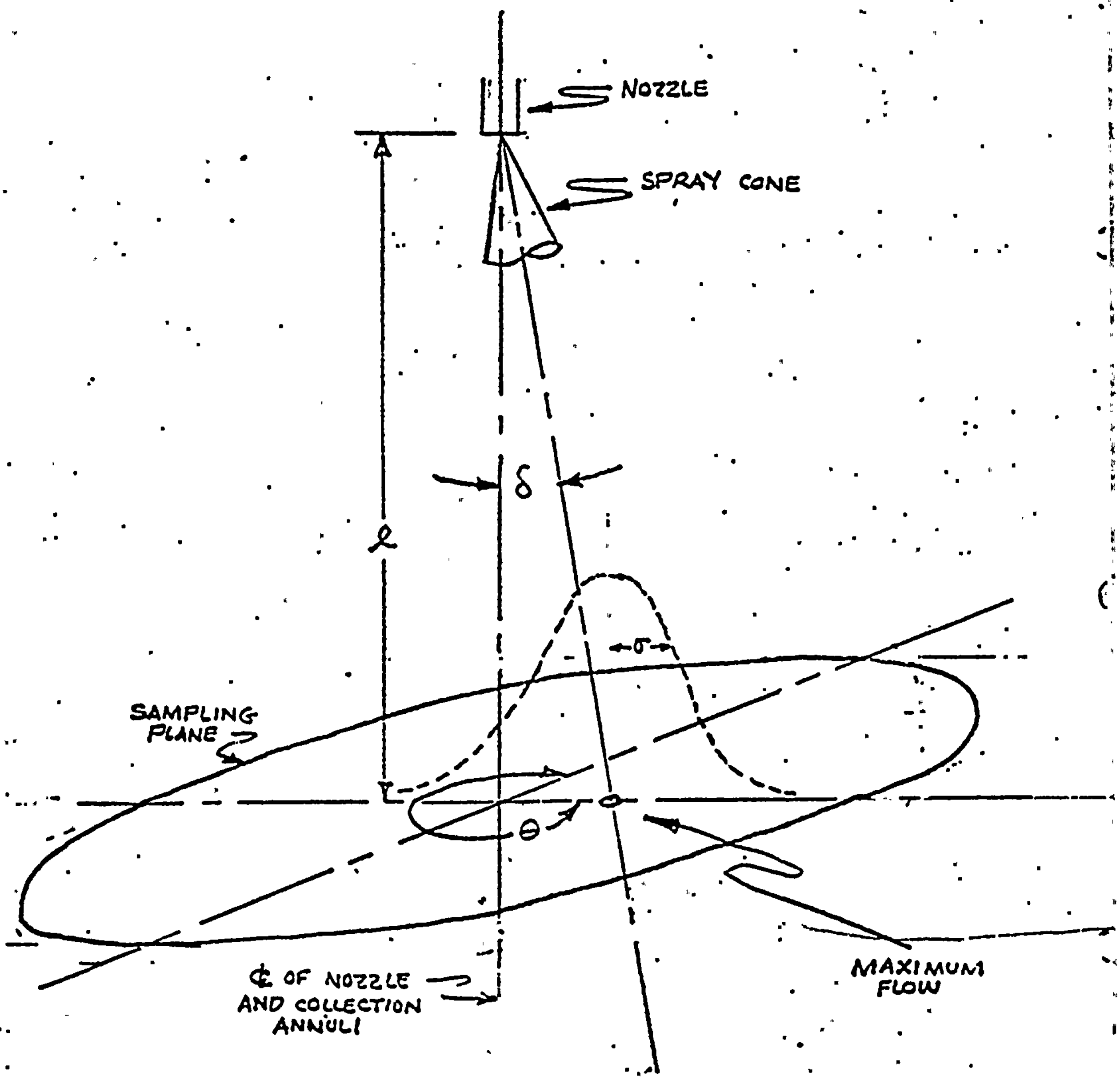
- CONFIGURATION OF BWR/4 REACTORS (TYPICAL)
  - VNC NOZZLES COVER PERIPHERAL ASSEMBLIES AND CENTER REGION
  - FINE, HIGH VELOCITY (BUT RELATIVELY INSENSITIVE) TYPE COVERS INTERMEDIATE REGION
  - VNC CONTRACTION COMPENSATED BY SUPERPOSITION AND INTERACTION

QUANTIFICATION OF CONTRACTION

- TEST FACILITY
- DEFINITION OF CHARACTERISTIC PARAMETERS
- EXPERIMENTAL RESULTS



TEST FACILITY



DEFINITION OF CHARACTERISTIC PARAMETERS

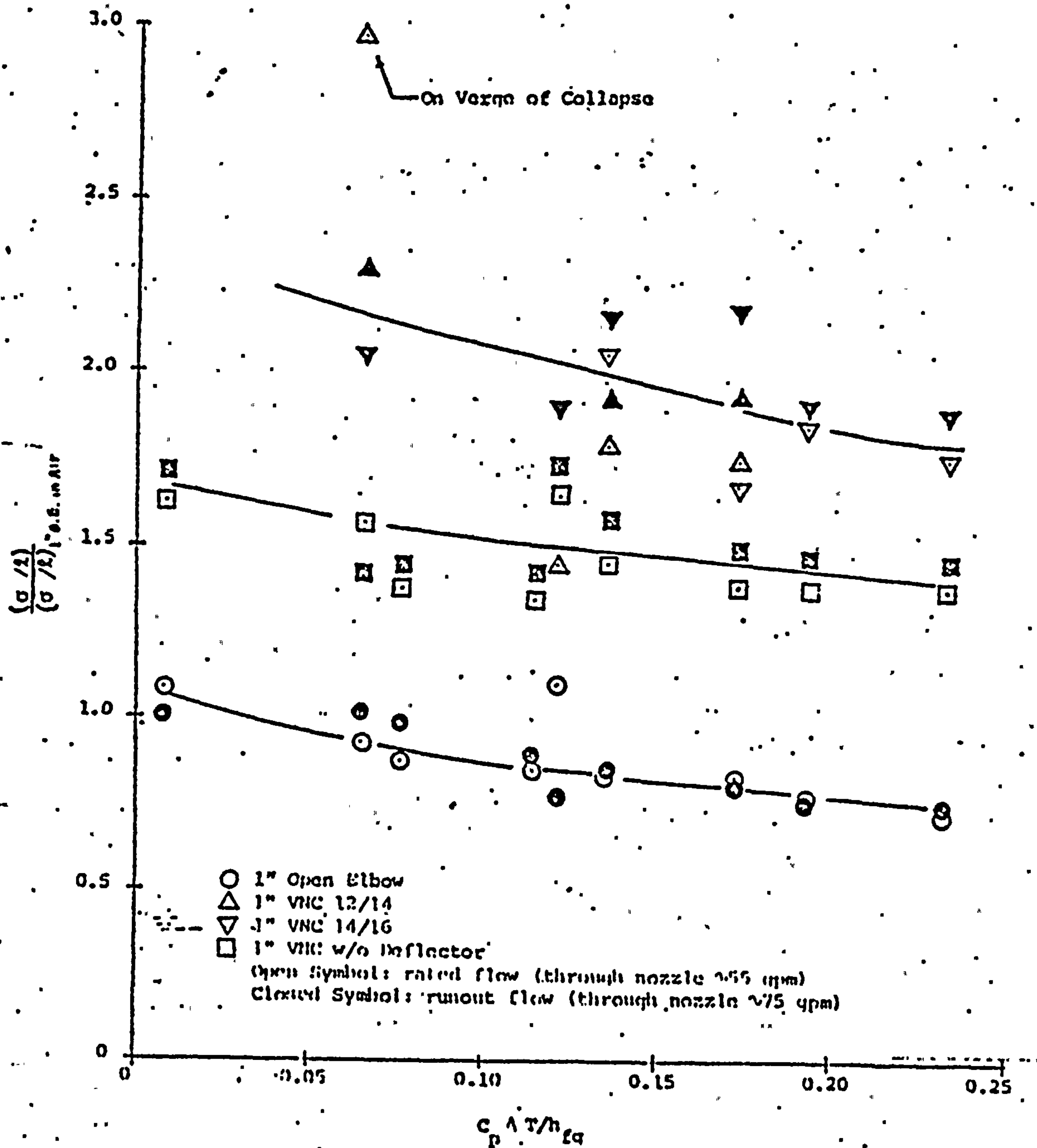


Figure 5. SPRAY WIDTH VS. SUBCOOLING

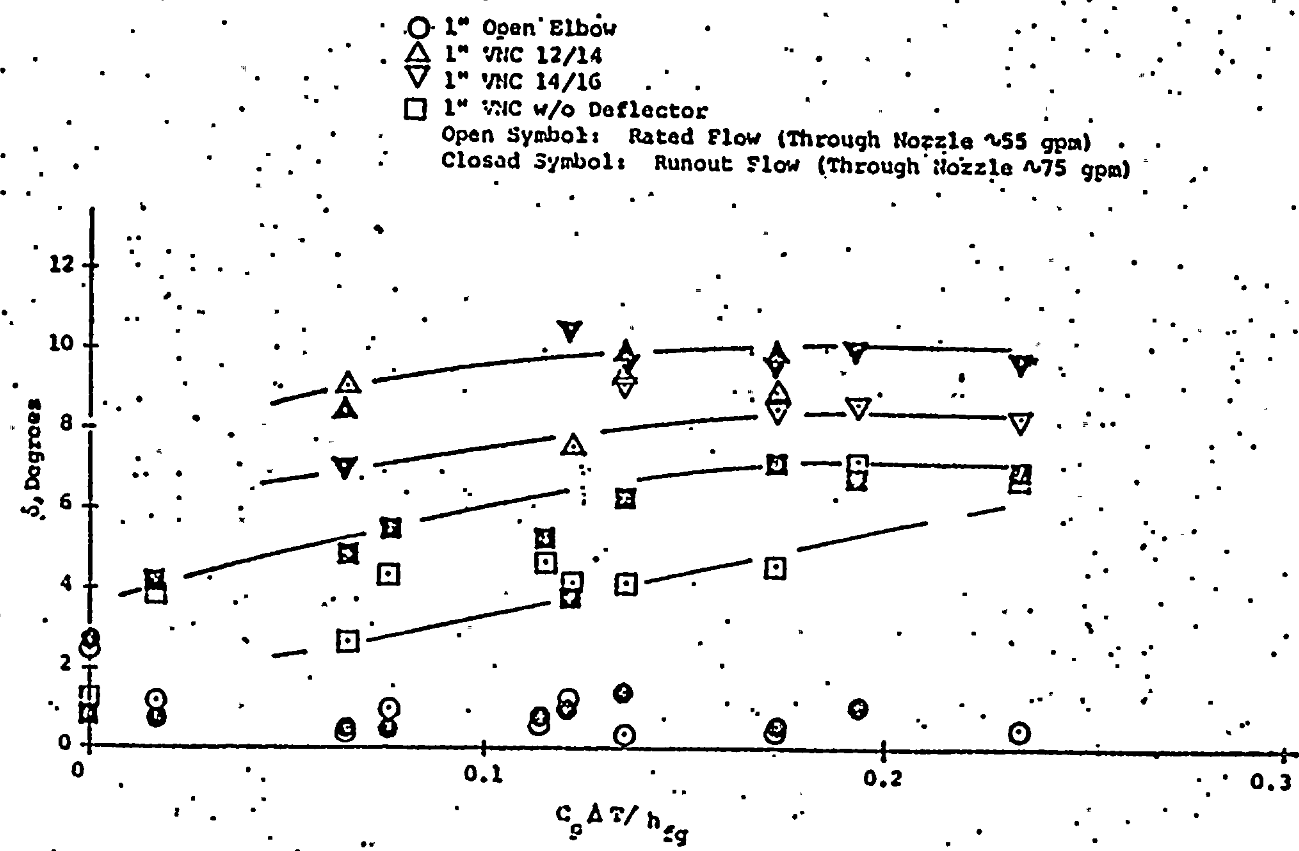


Figure 6. SKEWING ANGLE VS. SUBCOOLING

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CLASS III
February, 1976

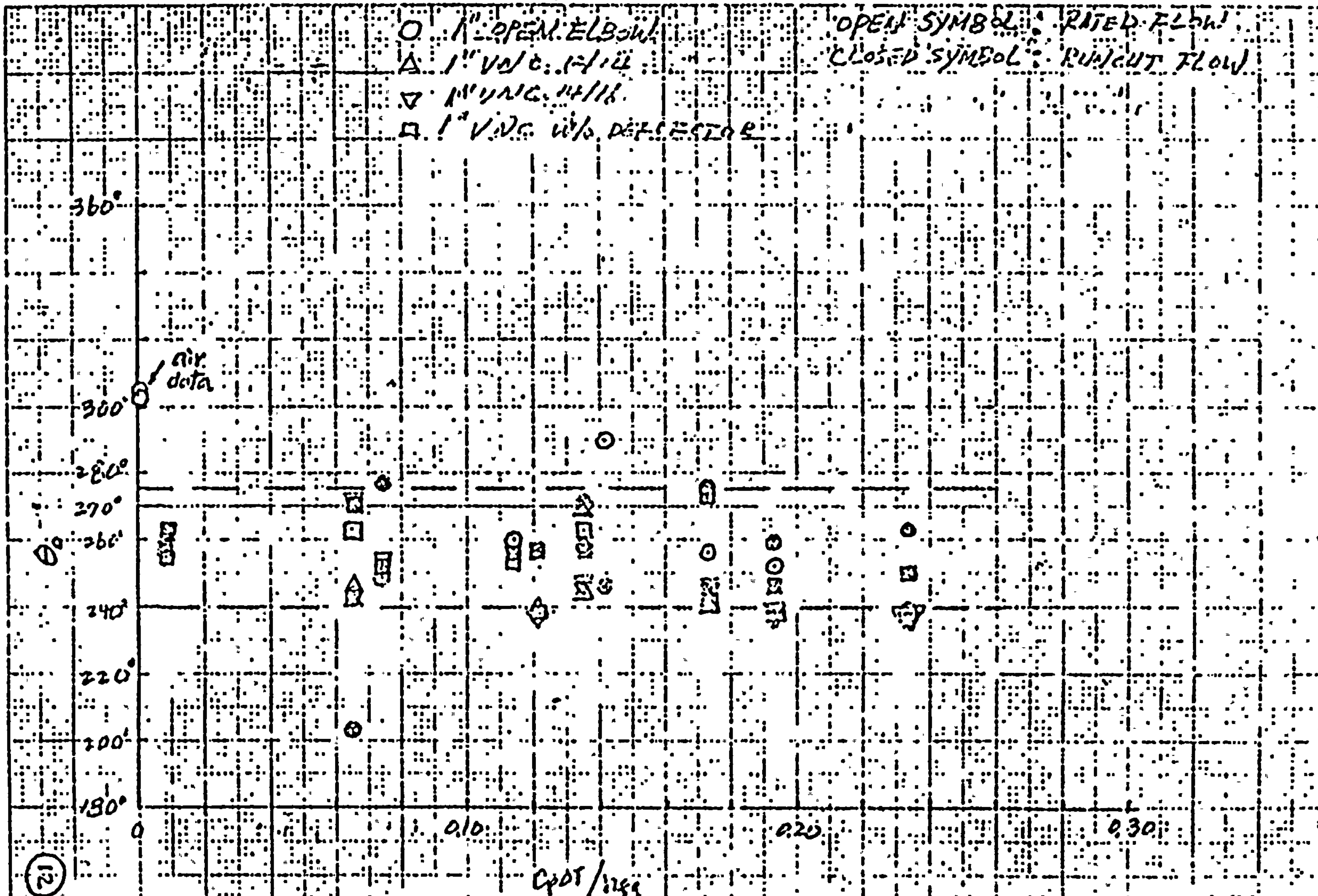
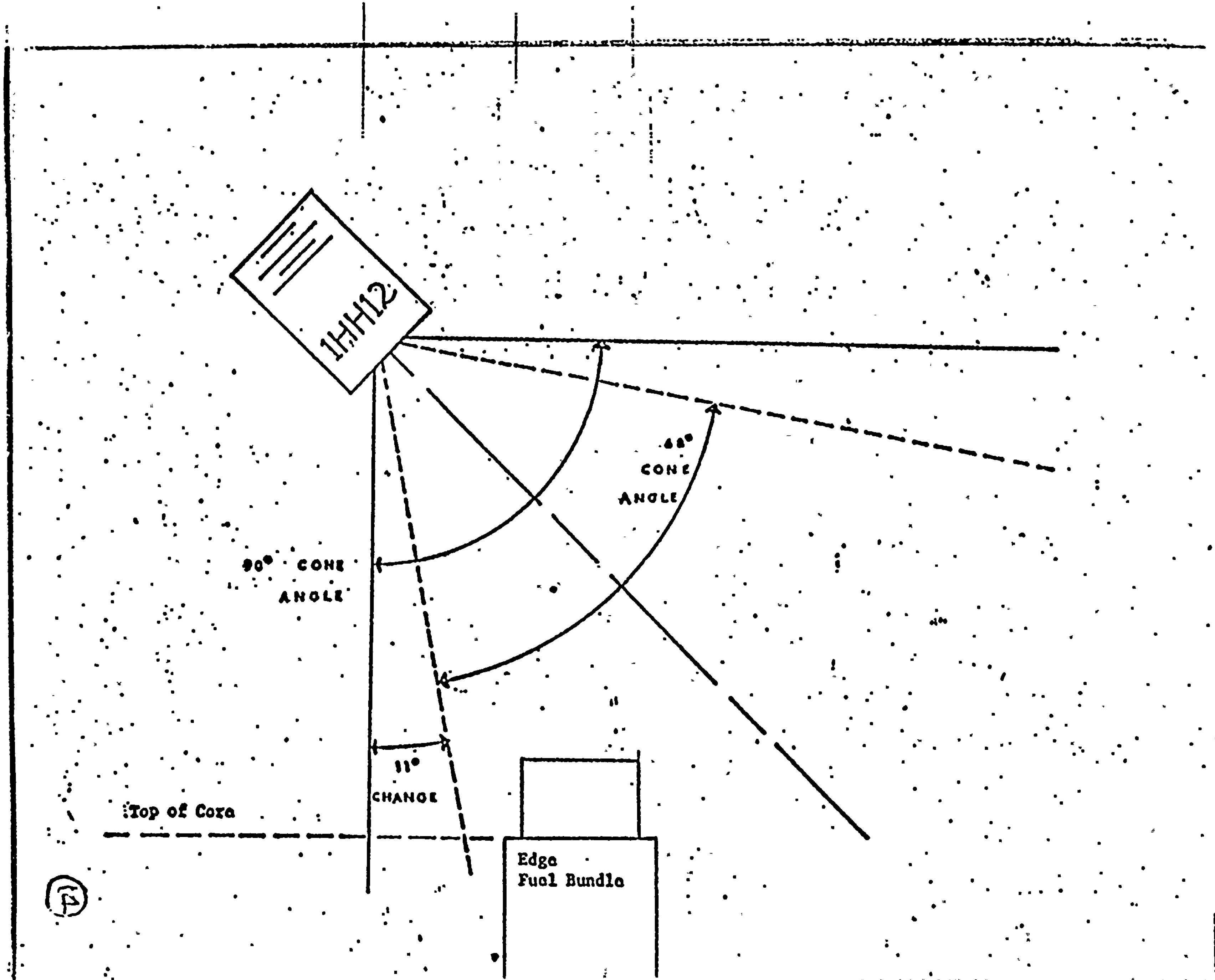


Fig 7 Skewing Direction vs Subcooling

(12)

EFFECT ON BWR/2,3, VERMONT YANKEE

- TWO NOZZLE TYPES - TWO EFFECTS
- ATOMIZING NOZZLE (COVERS PERIPHERY)
- OPEN ELBOW NOZZLE (COVERS REMAINDER OF CORE)


1HH12
CONE
ANGLE
CONE
ANGLE
CHANGE
Top of Core
Edge
Fuel Bundle

EFFECT ON BWR/2,3
ATOMIZER AIMING TESTS

- BECAUSE ATOMIZERS COVER PERIPHERY, INVESTIGATE SENSITIVITY TO CONE NARROWING BY ADJUSTING ELEVATION UPWARD

NOZZLE INCLINATION CHANGE	"CONE ANGLE CHANGE"	# OF EDGE CHANNELS BELOW 2.45 GPM	LOWEST GPM
0	0	0	2.6
11	22	0	2.8
16	32	1	2.4
21	42	1	2.3
26	52	3	2.1

- CONCLUSIONS
  - MINIMAL IMPACT ON PERIPHERAL BUNDLE FLOW FROM 11° UPWARD AIMING
  - PRACTICALLY NO EFFECT ON DISTRIBUTION OVER MOST OF CORE

EFFECT ON BWR/2,3
OPEN ELBOW NOZZLE SENSITIVITY TO STEAM

- PATTERNS IN AIR AND STEAM PRACTICALLY IDENTICAL AT 1 ATMOSPHERE
- CONCENTRATION IN CENTER OF CONE AS PRESSURE IS RAISED
- MAXIMUM CONCENTRATION AT 3 ATM, CONSTANT AT HIGHER PRESSURE

EFFECT ON BWR/2,3

CONCLUSIONS

- RESULTS OF BWR/4 "CONE CONTRACTION" TESTS SHOW VERY LARGE CONE ANGLE CHANGES CAN BE TOLERATED WITHOUT GROSS DEGRADATION OF DISTRIBUTION
- BWR/2,3 NOZZLES MUCH LESS SENSITIVE TO STEAM ENVIRONMENT THAN VNC NOZZLE USED IN TESTS
- NO ADDITIONAL BWR/2,3 DISTRIBUTION TESTS PLANNED

EFFECT ON BWR/4,5

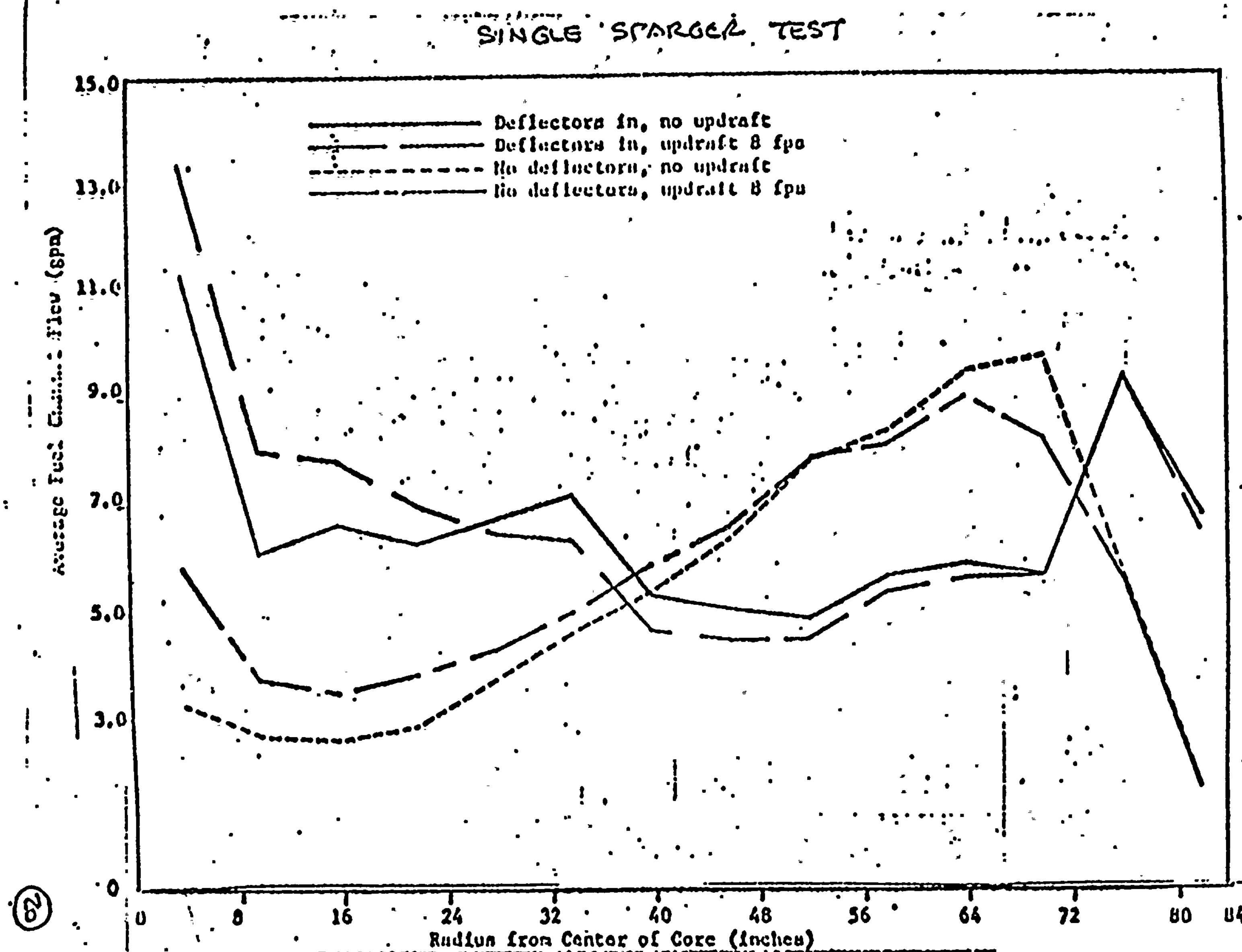
- VNC NOZZLE CONE ABRUPT CONTRACTION IN STEAM
- 7-10° SHIFT OF PATTERN CENTERLINE

SIMULATION OF VNC CONE CONTRACTION IN AIR

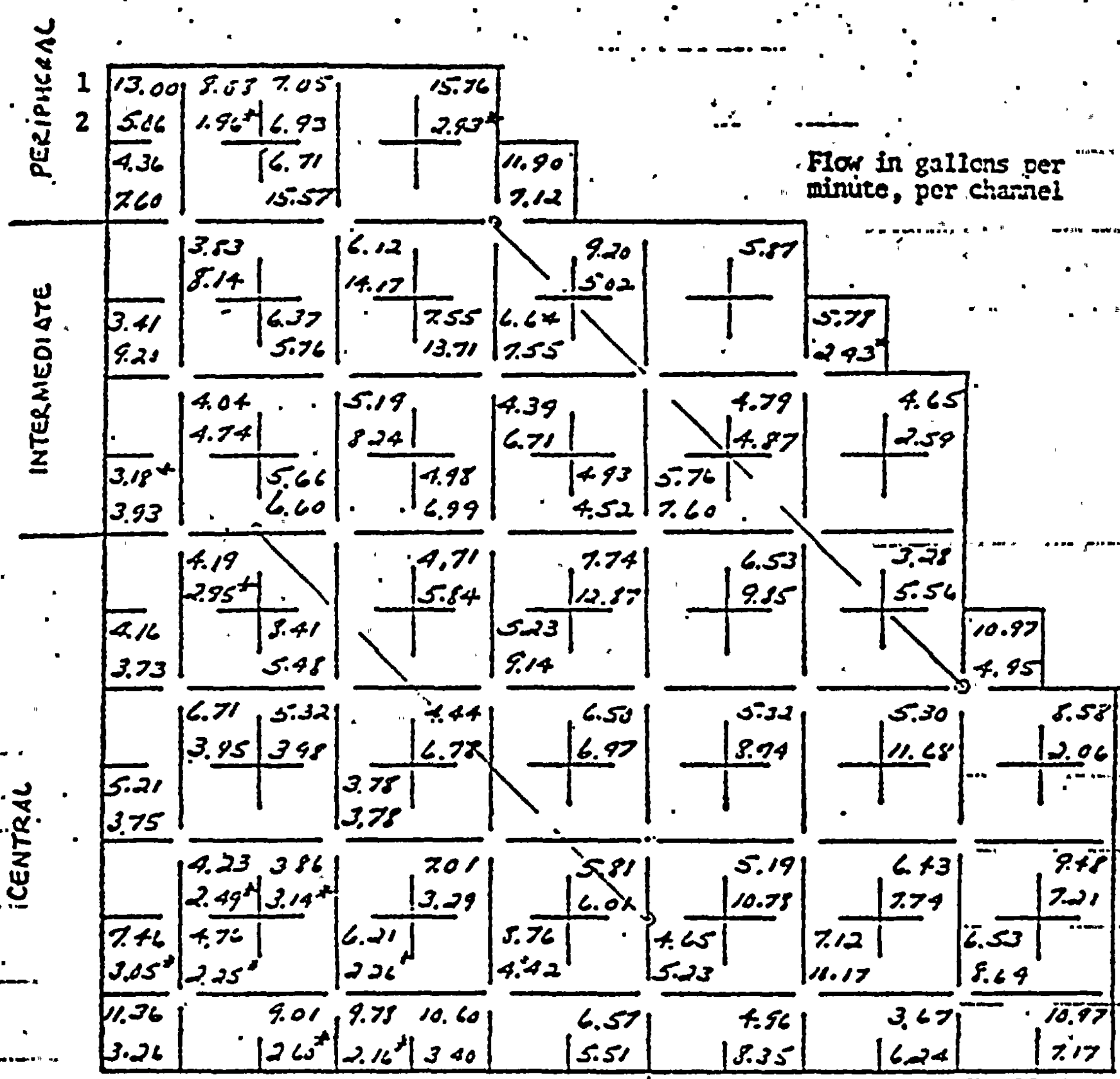
- SINGLE-NOZZLE TESTS SHOW THAT:
  - VNC IN STEAM
  - VNC W/O DEFLECTOR IN AIR

  PRODUCE ROUGHLY COMPARABLE SPRAY PATTERNS:
  - VNC CONTRACTED PATTERN BROADER THAN VNC W/O DEFLECTOR
  - VNC CONTRACTED PATTERN AXIS 7-10° OFF CENTERLINE

- VALLECITOS FULL-SPARGER SENSITIVITY TESTS
  - VNC WITH DEFLECTORS REMOVED "SIMULATE" VNC PERFORMANCE IN STEAM
  - SINGLE AND DOUBLE SPARGER TESTS


SINGLE SPARGER TEST
Deflectors in, no updraft
Deflectors in, updraft 8 fps
No deflectors, no updraft
No deflectors, updraft 8 fps
15.0
13.0
11.0
9.0
7.0
5.0
3.0
0
Average Fuel Channel Flow (gpm)
0
8
16
24
32
40
48
56
64
72
80
84
Radius from Center of Core (inches)
62

218 Standard Plant



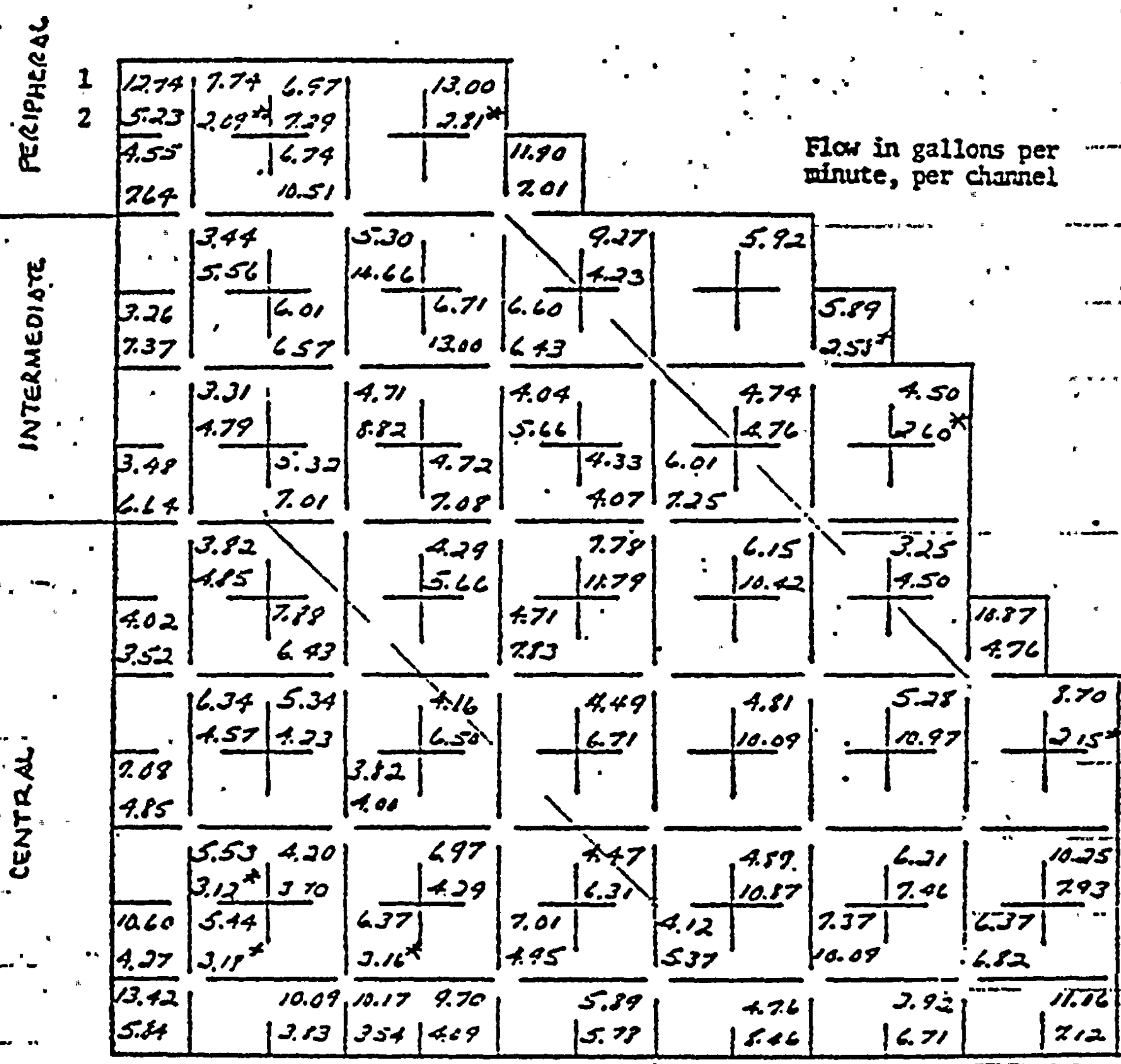
1. Deflectors in Test 3127
2. No deflectors Test 3129

* Channels below 3.25 gpm

EFFECT OF DEFLECTORS ON VNC WITH NO UPDRAFT
UPPER HEADER ONLY

218 Standard Plant

Flow in gallons per minute, per channel



1. Deflectors in Test 3128
2. No deflectors Test 3130

* Channels below 3.25 gpm

EFFECT OF DEFLECTORS ON VNC WITH UPDRAFT 8 fps
UPPER HEADER ONLY

SIMULATION OF VIC CORE CONTRACTION IN AIR

SINGLE SPARGER TEST-UPPER SPARGER

- SIGNIFICANT CHANGE IN DISTRIBUTION WITH VIC DEFLECTORS REMOVED
- FULL COVERAGE OF CORE
  - NO "STARVED" CHANNELS, MINIMUM FLOW 2.09 GPM WITH UPDRAFT
  - 18 TO 26% OF SAMPLED CHANNELS LESS THAN 3.25 GPM REQUIREMENT
- AIR UPDRAFT IMPROVES COVERAGE IN LOW-FLOW REGIONS

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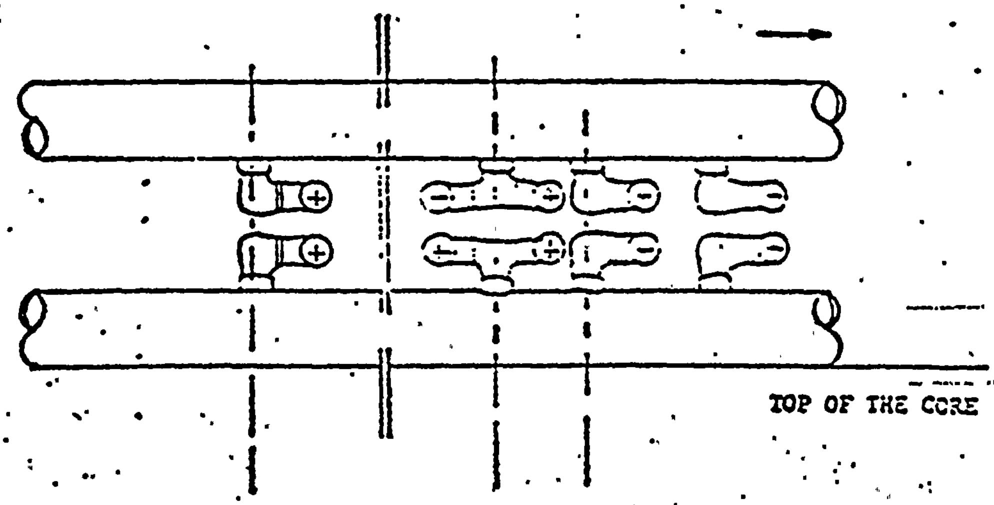
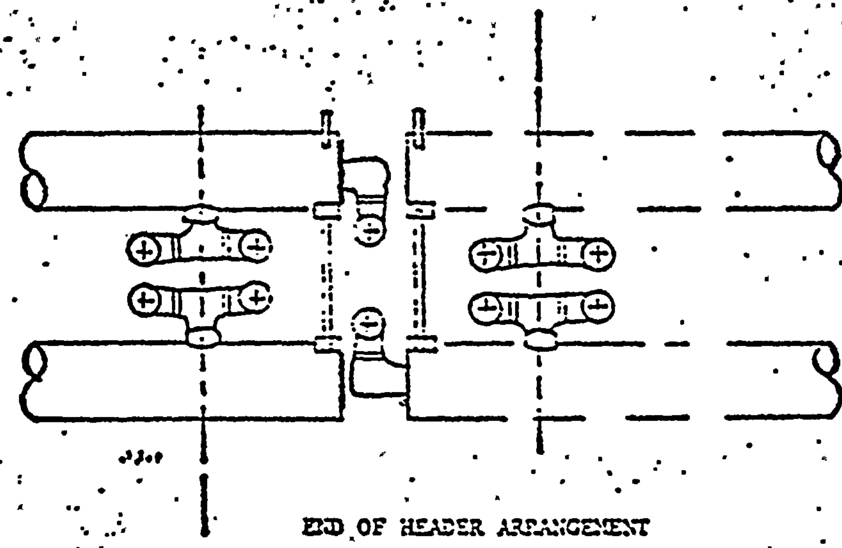
DOUBLE SPARGER TEST



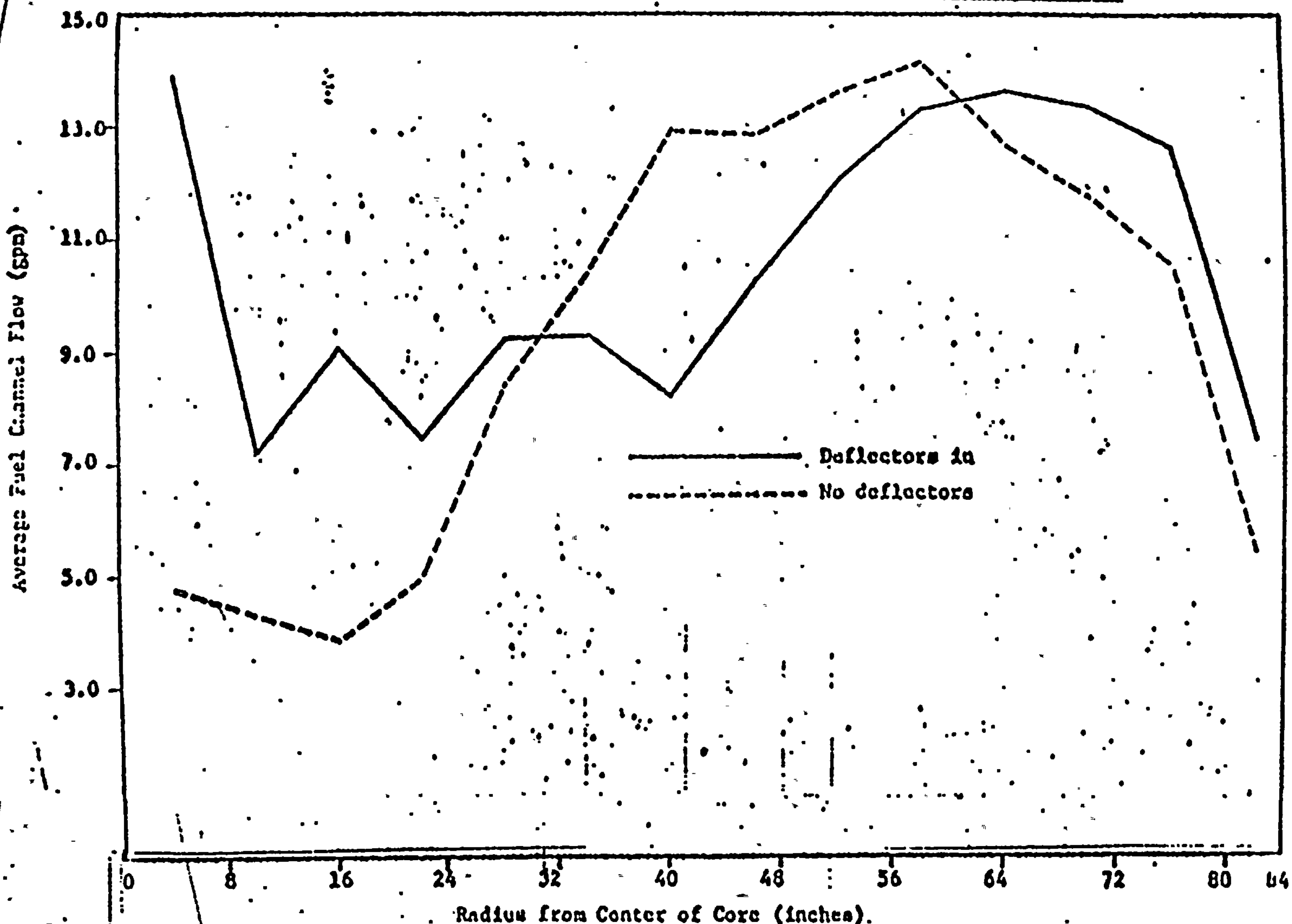
MIDDLE OF HEADER ARRANGEMENT



END OF HEADER ARRANGEMENT

THE ARRANGEMENT OF NOZZLES ON THE HEADERS

DOUBLE-SPARGER TEST



AVERAGE CHANNEL FLOW FOR BOTH HEADERS OPERATING

Figure [illegible]

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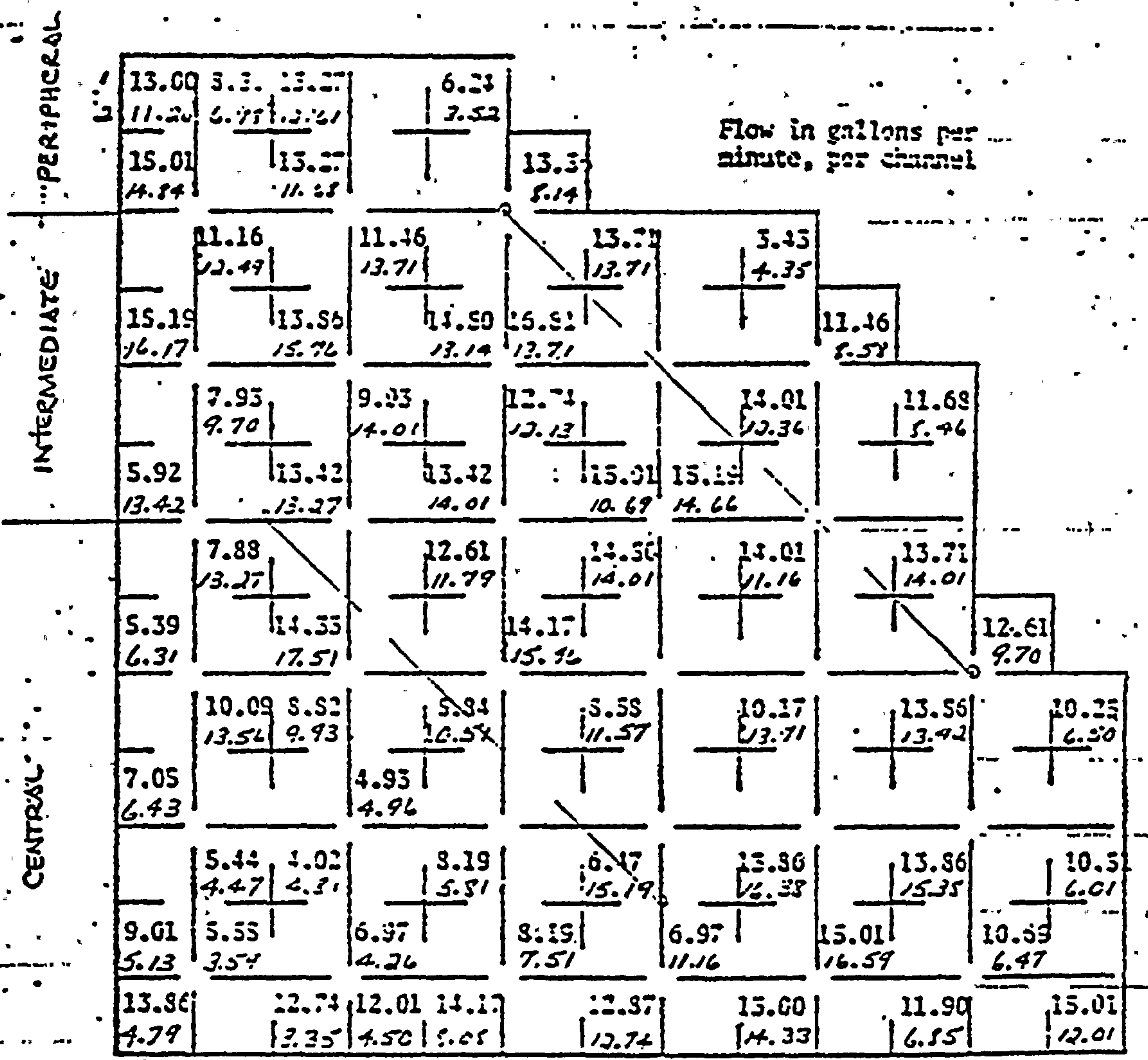
218 Standard Plant



1. Deflectors in Test 3121
2. No deflectors Test 3133

EFFECT OF DEFLECTORS ON VNC
BOTH HEADERS OPERATING

SIMULATION OF V:C CORE CONTRACTION IN AIR

DOUBLE SPARGER TEST

- SIGNIFICANT CHANGE IN DISTRIBUTION WITH V:C DEFLECTORS REMOVED
- FULL COVERAGE OF CORE, ADEQUATE DISTRIBUTION
  - MINIMUM CHANNEL FLOWS (GPM)

	PERIPHERY	INTERMEDIATE	CENTER
DEFLECTORS IN	3.43	5.92	4.02
DEFLECTORS OUT	3.52	6.85	3.35

  - DEFLECTORS IN: MORE UNIFORM PATTERN BUT SIMILAR MINIMA
- UPDRAFT COULD NOT BE TESTED (HIGH FLOW "SWAMPING" OF NON-INSTRUMENTED CHANNELS) - PROBABLY WOULD IMPROVE RESULTS SLIGHTLY

SIMULATION OF VMC CONE CONTRACTION IN AIR

DISCUSSION OF SIMULATION

- AXIS SHIFT NOT SIMULATED (NOT QUANTIFIED AT TIME OF TEST)
  - SHIFT DIRECTION PRIMARILY HORIZONTAL
  - TYPICAL SPARGER CONSTRUCTION: HALF SHIFT CCW, HALF SHIFT CW
- CONTRACTED VMC PATTERN IS TWICE AS WIDE AS MODIFIED VMC USED IN SIMULATION
  - AIR TEST HAS MORE SEVERE PATTERN CHANGE THAN REACTOR CASE
  - EFFECT OF CONE ANGLE CHANGE MAY BE OVERPREDICTED BY THE AIR TEST
- 1976 TESTS WILL:
  - QUANTIFY NOZZLE PERFORMANCE HORIZONTALLY IN STEAM
  - SIMULATE THE EFFECT MORE PRECISELY IN AIR TESTS

SIMULATION OF VNC CONE CONTRACTION IN AIR

SUMMARY AND CONCLUSIONS

- SINGLE-SPARGER TEST WITH CONTRACTION SIMULATED
  - LESS UNIFORM THAN ORIGINAL OPTIMIZED DESIGN
  - 18-26% OF SAMPLE CHANNELS LESS THAN DESIGN REQUIREMENT
  - GOOD COVERAGE OF ENTIRE CORE - MINIMUM FLOW 1.92 GPM FROM LOWER SPARGER, 2.09 GPM FROM UPPER SPARGER (UPDRAFT CASES)

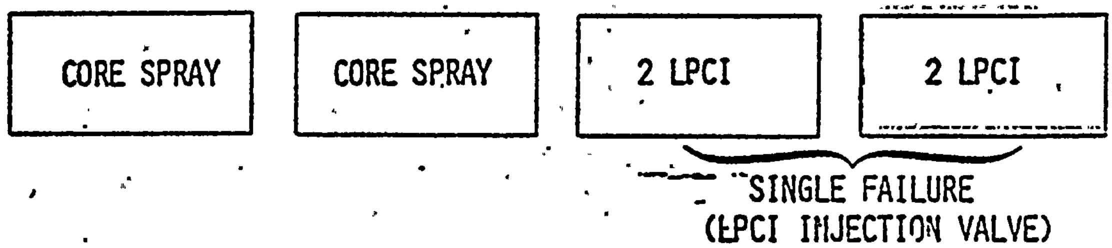
- DOUBLE-SPARGER TEST WITH CONTRACTION SIMULATED
  - BETTER DISTRIBUTION THAN SINGLE SPARGER
  - LESS UNIFORM THAN DOUBLE-SPARGER TEST WITH NO CONTRACTION (MINIMUM FLOWS SIMILAR)
  - NO CHANNELS LESS THAN DESIGN REQUIREMENT: MINIMUM FLOW 3.35 GPM

- QUALITATIVE CONCLUSIONS FROM AIR TESTS
  - SUPERPOSITION OF FLOWS FROM MANY NOZZLES CONTRIBUTES TO UNIFORMITY OF DISTRIBUTION
  - BWR CORE SPRAY DISTRIBUTION CAN TOLERATE VERY GREAT CONE ANGLE CHANGES WITHOUT CORRESPONDING DEGRADATION OF DISTRIBUTION

EFFECT ON BWR/4

CONCLUSIONS

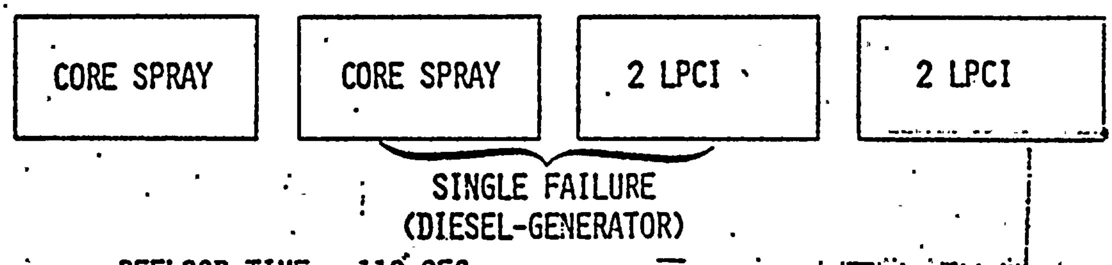
- TWO-SPARGER TEST EXCEEDS 3.25 GPM DESIGN REQUIREMENT



REFLOOD TIME: 240 SEC

PEAK CLAD TEMPERATURE (FULL SPRAY HEAT TRANSFER): 2200F (BY DEFINITION)

- SINGLE-SPARGER TESTS PRODUCE MORE THAN HALF OF 3.25 GPM DESIGN REQUIREMENT



REFLOOD TIME: 110 SEC

PEAK CLAD TEMPERATURE (HALF SPRAY HEAT TRANSFER): 1950F

- CONCLUSIONS
  - LPCI INJECTION VALVE IS STILL WORST SINGLE FAILURE
  - CURRENT MAPLHGR LIMITS APPROPRIATE
  - LPCI-MODIFIED PLANTS RESULTS SIMILAR

PROGRAMS TO INVESTIGATE PHENOMENA

- EXPERIMENTAL
- ANALYTICAL

PROGRAMS TO INVESTIGATE PHENOMENA

EXPERIMENTAL

- ASEA SINGLE-NOZZLE TESTS
  - DETAILED DISTRIBUTION TESTS OF ALL GE NOZZLES
- HORIZONTAL SINGLE NOZZLE TESTS IN STEAM
- FULL SCALE TESTS WITH NOZZLES MODIFIED TO SIMULATE HORIZONTAL STEAM TEST RESULTS
- 1/6 SCALE STEAM ENVIRONMENT TEST
  - CONFLICTING SCALING REQUIREMENTS
  - FEASIBILITY STUDIES CONTINUING

PROGRAMS TO INVESTIGATE PHENOMENA

ANALYTICAL

- SINGLE-DROPLET MODEL
- SINGLE-NOZZLE MODEL
  - MECHANISMS FOR STEAM SENSITIVITY
  - TRAJECTORY
- MULTIPLE-NOZZLE INTERACTION MODEL
- "GLOBAL" CORE SPRAY DISTRIBUTION MODEL
  - TO INVESTIGATE SENSITIVITY OF BWR/4,5
  - TO FACILITATE DESIGN OF BWR/6

CORE SPRAY DISTRIBUTION PROGRAM

SUMMARY OF STATUS

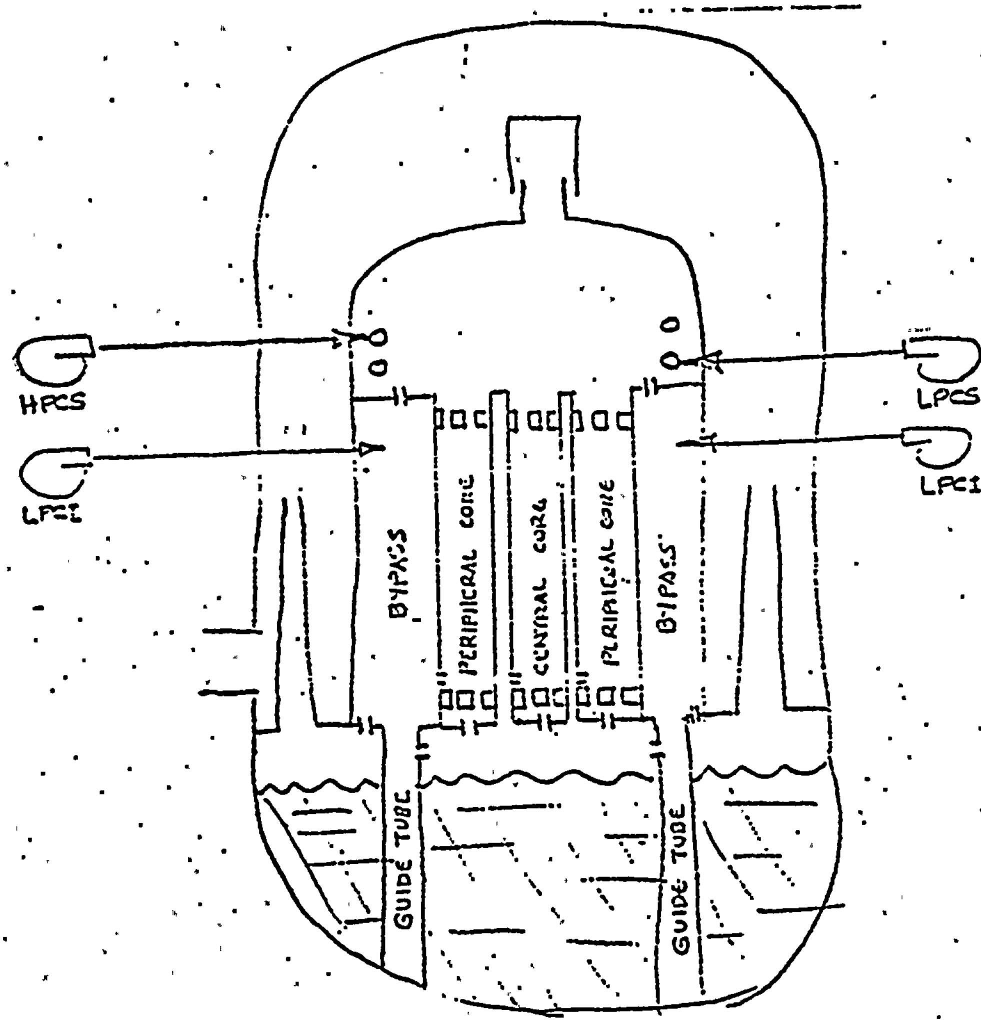
- CONCERN: SPRAY NOZZLE CONE ANGLES ALTERED IN PRESSURIZED STEAM ATMOSPHERE
  - SMALL EFFECT ON MOST BWR NOZZLES
  - "VNC" NOZZLE (USED IN BWR/4,5) EXPERIENCES ABRUPT CONTRACTION 7-10° AXIS SHIFT
  - BWR/4 DISTRIBUTION TESTS WITH SIMULATED CONTRACTION OF VNC NOZZLES
    - DISTRIBUTION OVER ENTIRE CORE WITH EITHER SPARGER INDIVIDUALLY
    - DISTRIBUTION WITH BOTH SPARGERS OPERATING: LESS UNIFORM THAN "NOMINAL" CASE, BUT SATISFIES DESIGN REQUIREMENT FOR MINIMUM BUNDLE FLOW
    - CALCULATED PEAK CLADDING TEMPERATURE CONSERVATIVE IN REACTOR EVALUATIONS
  - EXPERIMENTAL PROGRAM UNDERWAY TO FURTHER CHARACTERIZE AND QUANTIFY EFFECTS

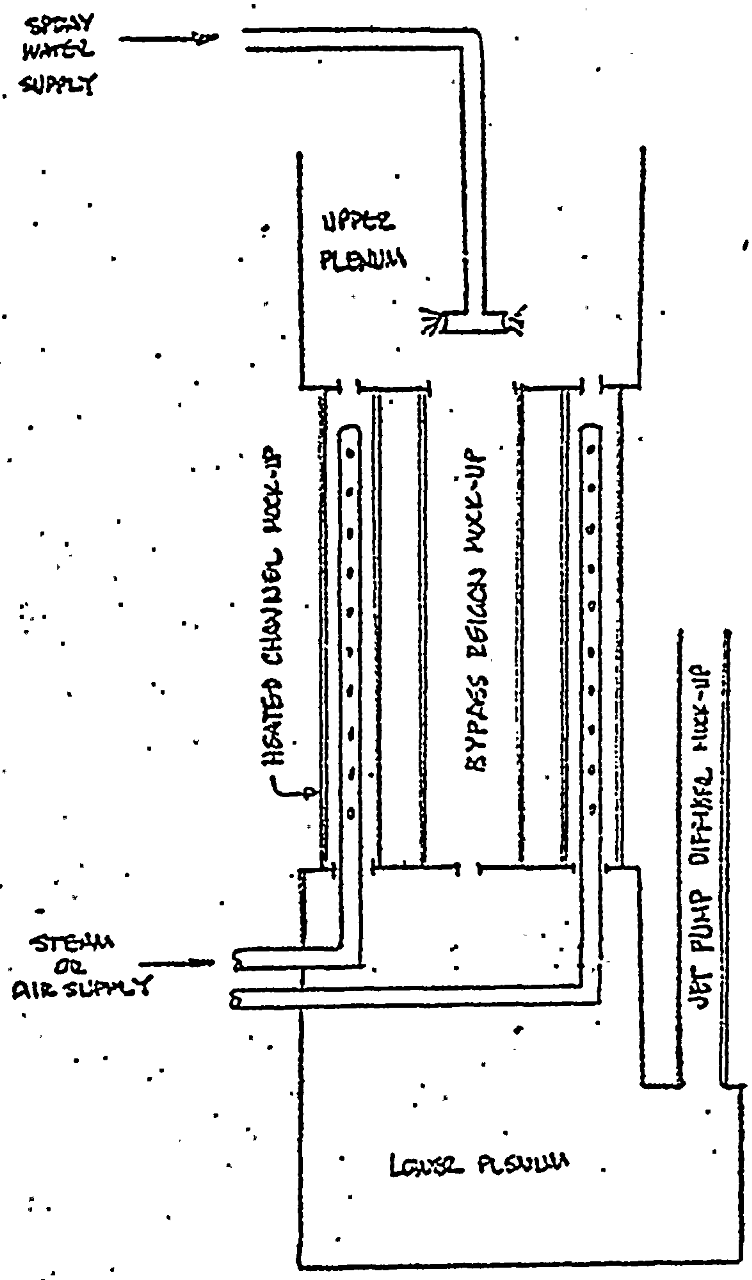
- CONCLUSIONS
  - NOZZLE-TO-NOZZLE, SPARGER-TO-SPARGER SUPERPOSITION COMPENSATES FOR SEVERE SPRAY CONE ANGLE CHANGES
  - CCFL EFFECTS ON DISTRIBUTION ARE PROBABLY OF NET BENEFIT
  - CURRENT MAPLHGR LIMITS ARE APPROPRIATE WHILE EXPERIMENTAL PROGRAMS ARE UNDERWAY

BWR REFLOOD MODELING

- BLOWDOWN DISTRIBUTES INVENTORY
  - SHROUD HEAD
  - CORE
  - BYPASS / GUIDE TUBES
  - LOWER PLENUM
- CORE SPRAY INJECTS WATER OVER CORE
  - TO LOWER PLENUM THRU FUEL
  - TO BYPASS REGION
    - FILLS GUIDE TUBES
    - TO LOWER PLENUM THRU LEAKAGE PATHS
- SUBCOOLING INTRODUCED TO PERIPHERAL ASSEMBLIES "BREAKS DOWN" CCFL
  - MAY OCCUR SHORTLY AFTER SPRAY INITIATION
  - WILL CERTAINLY OCCUR IF CORE SPRAY-SPARGERS COVER
- SUBSTANTIAL LIQUID ACCUMULATION ABOVE CORE CANNOT OCCUR
  - WILL NOT DEVELOP STATIC HEAD SUFFICIENT TO REVERSE FLOW IN JET PUMPS
  - WILL NOT DELAY REFLOODING AS CALCULATED BY CURRENT MODEL

DESCRIPTION OF REFLOOD PROCESS





REFLOOD HYDRAULICS TEST APPARATUS

- ADIABATIC TEST SECTION WITH STEAM INJECTION
- SCALED RESTRICTIONS AT CHANNEL INLET/OUTLET
- VARIABLE SPRAY WATER TEMPERATURE
- DEMONSTRATES REFLOOD HYDRAULICS AND SUBCOOLED CCFL "BREAKDOWN"

REFLOOD HYDRAULICS TEST RESULTS

- CORE SPRAY - HIGH SUBCOOLING

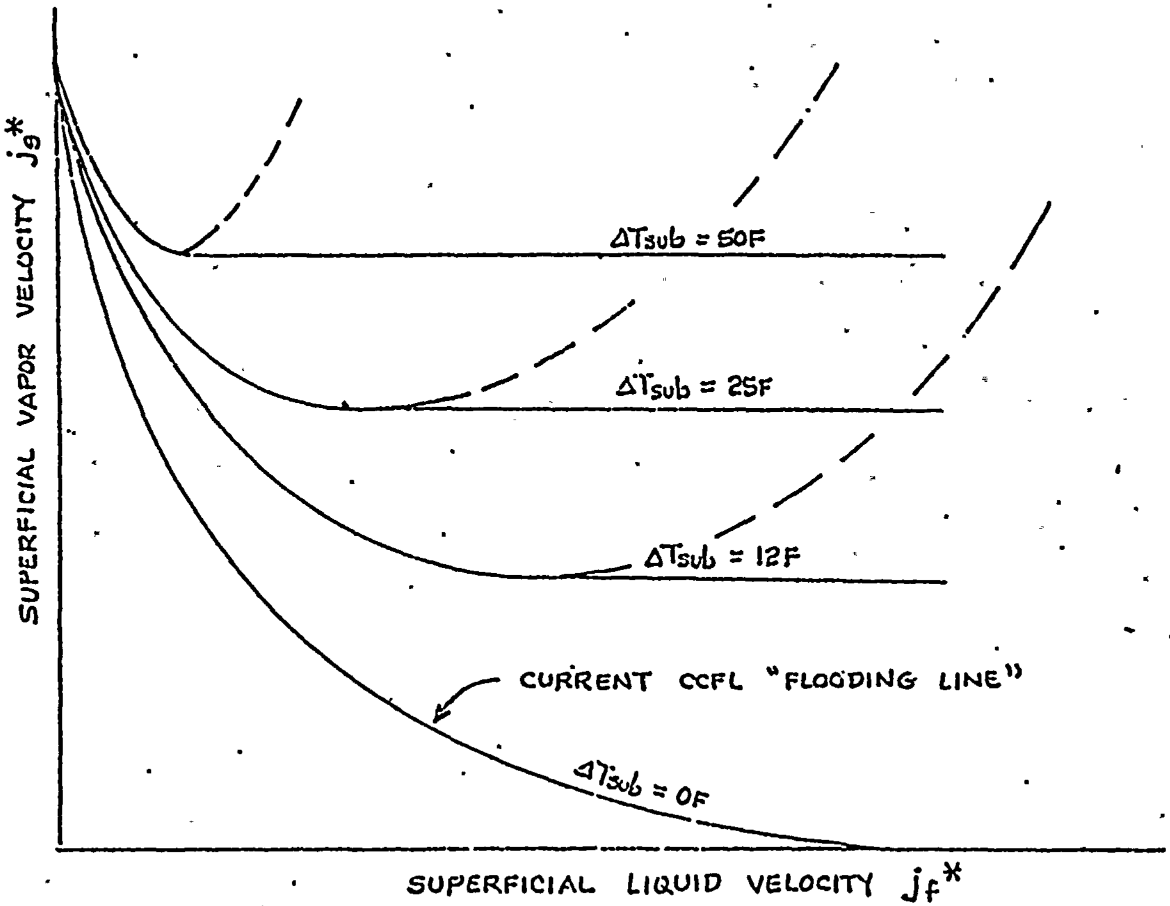
  - No CCFL limit, no upper plenum inventory build-up.

- CORE SPRAY - INTERMEDIATE SUBCOOLING

  - CCFL at inlet to channels while guide/tube bypass fills.
  - Once upper plenum begins to fill, CCFL breakdown and rapid lower plenum refill and core reflood.

- CORE SPRAY - NO SUBCOOLING

  - CCFL at inlet to channels
  - Upper plenum inventory accumulation
  - Liquid inventory loss though jet pump diffusers.



EFFECT OF SUBCOOLING ON CCFL PERFORMANCE

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BWR REFLOOD PROGRAMS

- **PARALLEL HEATED TUBE TEST** - Begin in April
  - Small scale, parallel heated tube experiment.
  - Model effects of CCFL in inlet and exit.
  - Study parallel channel flow splits in low and counter-curren flows.
- **SINGLE BUNDLE SEPARATE EFFECTS TESTS** - Begin in September
  - Full scale BWR bundle with bypass, lower plenum, jet pump, a: upper plenum simulation.
  - Look at CCFL, subcooling, vaporization.
- **1/6 SCALE TEST** - Planned late '76, final decision not made
  - Conflicting scaling laws
  - Feasibility studies continue
- **BD/ECC INTEGRAL TEST PROGRAM**
  - Investigate ECC System performance in TLTA.
  - System simulation to scale reactor conditions.
- **32 BUNDLE INTEGRAL ECCS FACILITY**
  - Large scale reactor system mock-up with actual reactor hardwa
  - Actual system effects simulation.
  - Proposals will be made to NRC and EPRI

GENERAL ELECTRIC
LOCA EVALUATION MODEL

- CORE HEATUP MODEL (CHASTE CODE)
  - RADIATION MODEL
  - LOW FLOW FILM BOILING MODEL
  - CONDUCTION MODEL
- LONG-TERM THERMAL HYDRAULIC MODEL (SAFE CODE)
- WORK IN PROGRESS
- CONCLUSIONS

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CHASTE CODE

RADIATION MODEL COUPLING, TO
FUEL CLAD SWELLING/RUPTURE MODEL

- CURRENT MODEL
  - INDIVIDUALLY CALCULATED RADII USED IN
    - GAP CONDUCTANCE MODEL
    - CONVECTION MODEL
    - METAL-WATER REACTION MODEL
  - RADIATION MODEL SIMPLIFIED
    - ALL RADII IDENTICAL
    - NOMINAL BEFORE PERFORATIONS
    - 1.23 × NOMINAL AFTER FIRST PERFORATIO[N]

- IMPROVED MODEL
  - INDIVIDUALLY CALCULATED RADII USED IN RADIATION MODEL
  - GRAY BODY FACTORS RECALCULATED EACH TIME A PERFORATION OCCURS
  - MODIFIED APPLICATION OF EXISTING MODEL

CHASTE CODE

LOW FLOW FILM BOILING MODEL

- CURRENT MODEL
  - POST-NUCLEATE BOILING: $h = 30\ B/hr\,ft^2 F$ (BOUNDS ELLION CORRELATION)
  - POST-LOWER PLENUM FLASHING: ELLION CORRELATION
  - FUEL CHANNEL HEAT TRANSFER WHEN COVERED BY BYPASS INVENTORY: NO CREDIT (SPRAY HT ONLY)
  - POST-REFLOODING: $h = 25\ B/hr\,ft^2 F$ (BOUNDS ELLION CORRELATION)

- IMPROVED MODEL
  - MODIFIED BROMLEY-ELLION CORRELATION IN ALL FOUR REGIMES
  - GOOD FIT FOR LOW-FLOW CONDITIONS (CHANNEL COOLING, POST-REFLOOD)
  - LOWER BOUND FOR CONDITIONS WHERE FLOW NOT QUANTIFIED (POST-BT, POST-LOWER PLENUM FLASHING)

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RECOMMENDED CORRELATION

$$Q'' = h_{fB}(T_W - T_{SAT}) + h_R(T_W - T_{SAT})$$

WHERE:

$$h_R = \epsilon_W \sigma \frac{(T_W^4 - T_{SAT}^4)}{(T_W - T_{SAT})}$$

$$h_{fB} = C\left[\frac{K_g^3\, g\, \rho_g\, (\rho_f - \rho_g)\, h_{fg}}{\mu_g\, (T_W - T_{SAT})\, L}\right]^{1/4}$$

$$L = 2\pi\sqrt{\frac{\sigma}{g(\rho_f - \rho_g)}}$$ (TAYLOR WAVELENGTH)

ASSOCIATED CONSTANTS:

BROMLEY: C = 0.62

ELLION: C = 0.714

BERENSON (HORIZ): C = 0.673

RECOMMENDED FOR BWR DESIGN

C = 0.62

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EXPERIMENTAL VERIFICATION

- G.E. SINGLE ROD
  - POOL QUENCH
- G.E. - BDHT
  - 49-ROD BLOWDOWN
- HITACHI
  - CHANNEL QUENCH
- PWR - FLECHT
  - 49-ROD REFLOOD
- KWU
  - 340-ROD REFLOOD

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CHASTE CODE

CONDUCTION MODEL,

- CURRENT MODEL
  - 4 RADIAL NODES
  - CONSTANT Δ (RADIUS)
  - EXPLICIT INTEGRATION

- IMPROVED MODEL
  - 11 RADIAL NODES
  - CONSTANT Δ (VOLUME)
  - FULL IMPLICIT INTEGRATION
  - BETTER COMPARISON WITH ANALYTICAL SOLUTIONS
  - BETTER TIME STEP AND NODING SENSITIVITY

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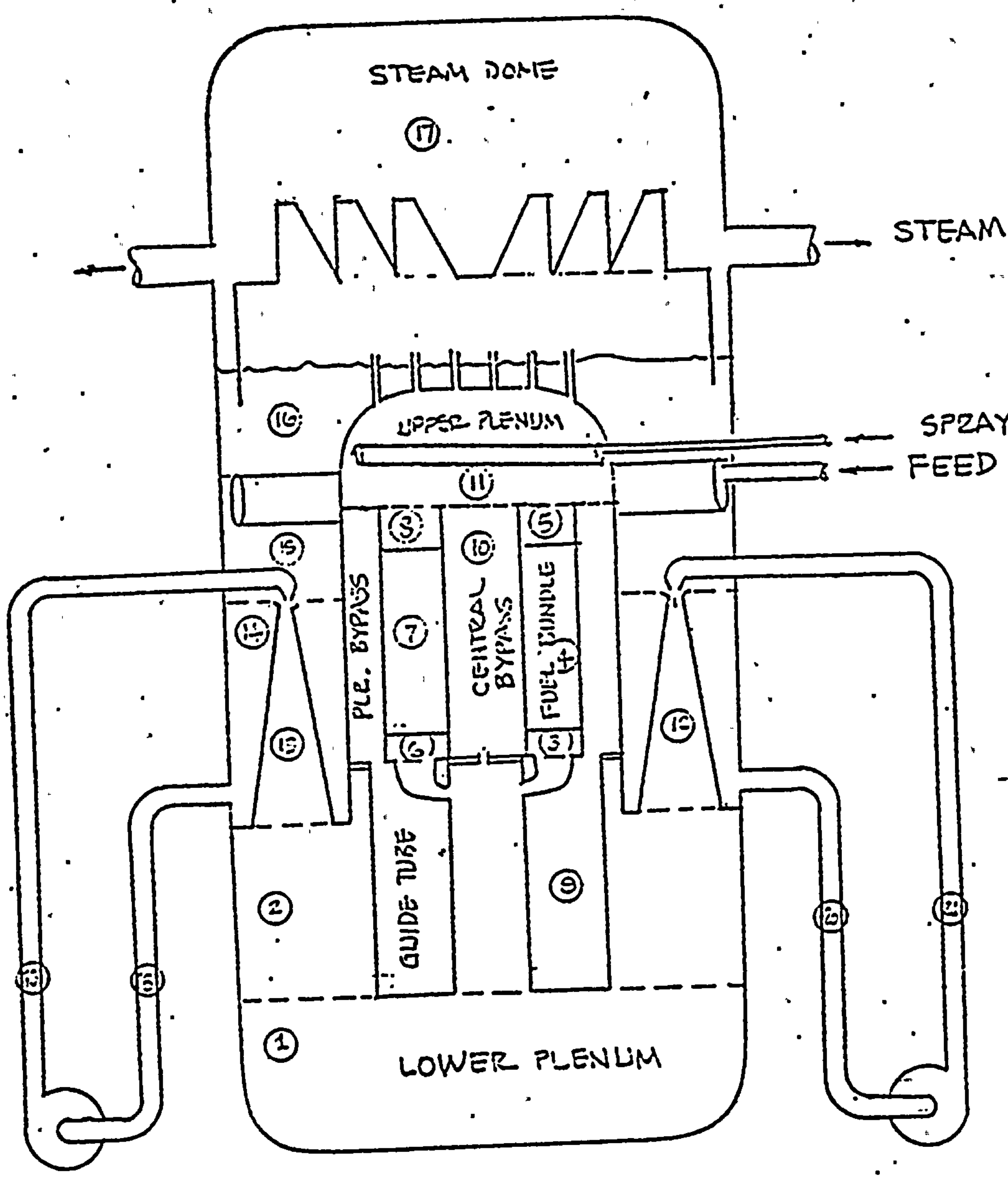
SAFE CODE

- CURRENT MODEL
  - LARGE THERMODYNAMIC NODES
  - BUBBLE RISE - HOMOGENEOUS VOIDS
  - INVENTORY REDISTRIBUTION TO TWO REGIONS (INSIDE AND OUTSIDE SHROUD)

- IMPROVED MODEL
  - DISCRETE PHYSICAL REGIONS (SIMILAR TO REFLOOD)
  - HYDRAULIC MODELING CONSIDERS VOID DISTRIBUTION WITHIN NODES
  - INVENTORY REDISTRIBUTION IN ALL NODES.
  - CCFL CONSIDERED AT RESTRICTIONS
  - VERIFICATION BY BDHT DATA PREDICTION

- APPLICATION IDENTICAL TO CURRENT MODEL
  - SPECIFIED INITIAL FLOW TRANSIENT
  - DRIVES REFLOOD (PRESSURE, ECCS FLOWS)

SAFE2 NODING



JET PUMP - BWR

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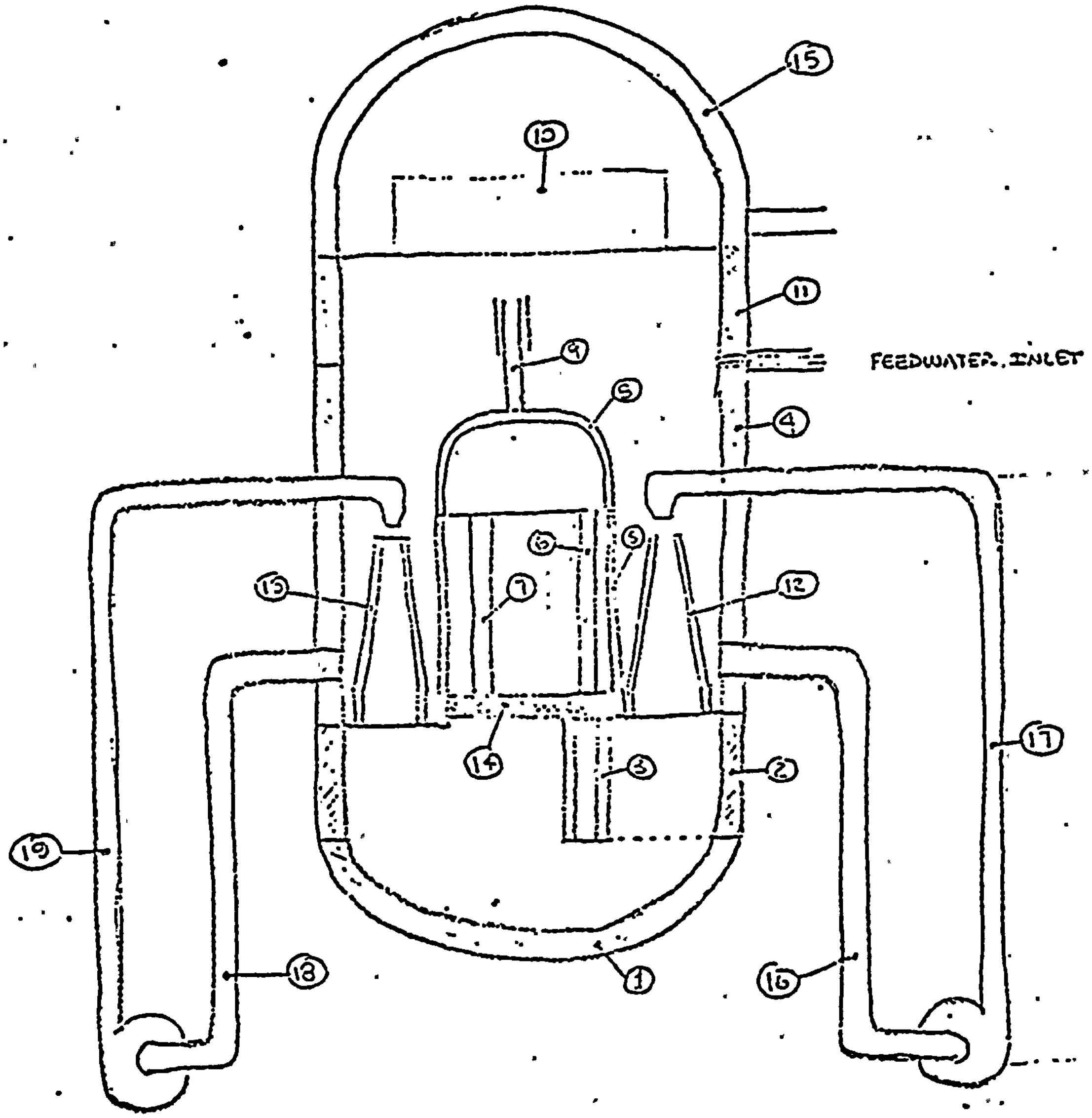
HEAT SLABS



*NOTE - EACH HEAT SLAB CAN BE ONE OF 6 DIFFERENT INPUT MATERIALS

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VOID CORRELATION PARAMETERS

EQUATIONS SOLVED -

$$\frac{\partial}{\partial z}(jA) = A f_1(\dot{Q}, \alpha, \frac{\partial p}{\partial t}, \text{prop.})$$

$$\frac{\partial}{\partial t}(\alpha A) + (C_o j + V_{gj})\frac{\partial}{\partial z}(\alpha A) = A f_2(\alpha, C_o, j, \frac{\partial p}{\partial t}, \text{prop.})$$

PARAMETERS - FROM DRIFT FLUX MODEL

$$j_g = \alpha(C_o j + V_{gj})$$

C_o = CONCENTRATION PARAMETER

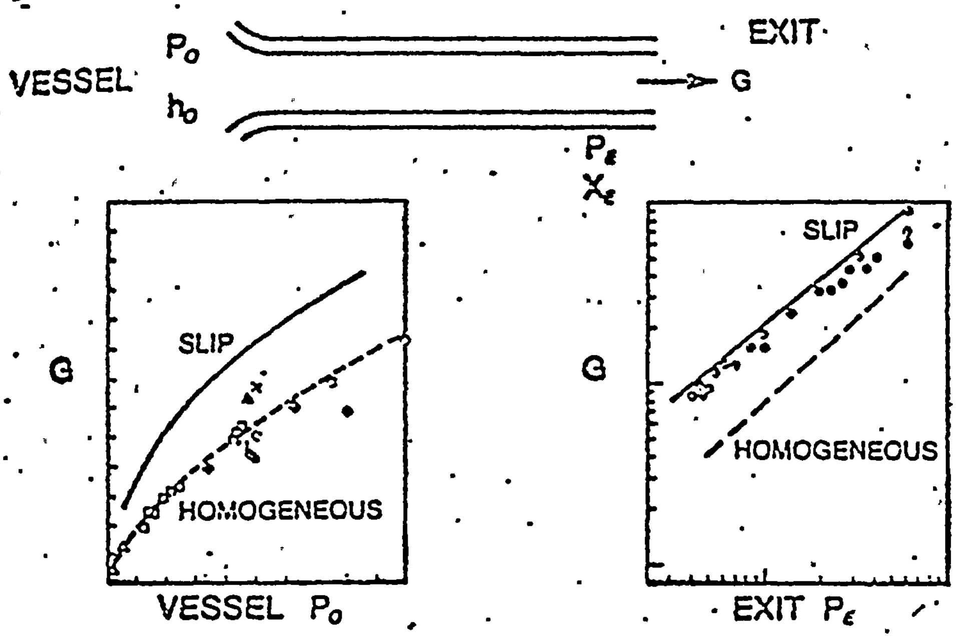
V_{gj} = DRIFT VELOCITY

WORK IN PROGRESS

- HOMOGENEOUS CRITICAL FLOW MODEL (LAMB, SAFE CODES)
- REFLOOD MODEL (REFLOOD CODE)
- BLOWDOWN HEAT TRANSFER MODEL (SCAT CODE)

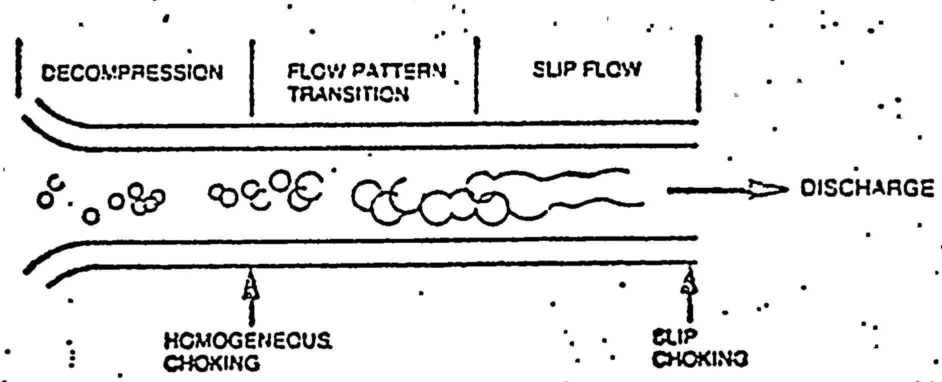
HOMOGENEOUS CRITICAL FLOW MODEL

THE DISCREPANCY



HOMOGENEOUS CRITICAL FLOW MODEL (cont)

TWO CHOKED CONDITIONS



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REFLOOD MODEL

- CONSOLIDATE SAFE2 AND REFLOOD CODES
  - CONSISTENT BOOKKEEPING OF
    - INVENTORY
    - LEVEL
    - PRESSURE
  - ELIMINATE NEED FOR "ARTIFICAL" ADJUSTMENTS AT SAFE/REFLOOD INTERFACE
- IMPROVED PREDICTION OF SYSTEM FLOWS
  - FLOW COASTDOWN TRANSIENT
  - PRESSURE DROP DRIVEN FLOW DISTRIBUTION
- INCORPORATE NEW DATA AND PHENOMENA
  - NEW CCFL CORRELATION AT UPPER TIE PLATE
  - CCFL AT BUNDLE INLET
  - CCFL "BREAKDOWN"
  - NEW BYPASS TO LOWER PLENUM LEAKAGE DATA

- BLOWDOWN HEAT TRANSFER MODEL

- LOW AND COUNTERCURRENT FLOW CAPABILITY
- CRITICAL POWER / BOILING TRANSITION TRACKING BY ROD GROUP
- STEAM AND "FALLBACK" COOLING
- CONSISTENCY WITH CORE HEATUP AND REFLOOD MODELS
  - LEVEL TRACKING
  - MULTIPLE ROD GROUPS
  - TRANSIENT GAP CONDUCTANCE
  - CCFL AT RESTRICTIONS

LOCA EVALUATION MODEL PROGRAMS

EFFECT ON PEAK CLADDING TEMPERATURE
(ONE SIGN: <50F — TWO SIGNS: 50-150F — THREE SIGNS: >150F)

• CHASTE CODE (CURRENT IMPROVEMENTS)	
— RADIATION	— —
— LOW FLOW FILM BOILING	— —
— CONDUCTION	—
• SAFE CODE (CURRENT IMPROVEMENTS)	— —
• HOMOGENEOUS CRITICAL FLOW	— —
• REFLOOD CODE	
— PRESSURE AT INTERFACE	+
— INVENTORY AT INTERFACE	—
— NEW CCFL AT UPPER TIE PLATE	+
— CCFL AT BUNDLE INLET	— —
— CCFL "BREAKDOWN"	— — —
— NEW LEAKAGE PATHS	—
• BLOWDOWN HEAT TRANSFER MODEL	— — —

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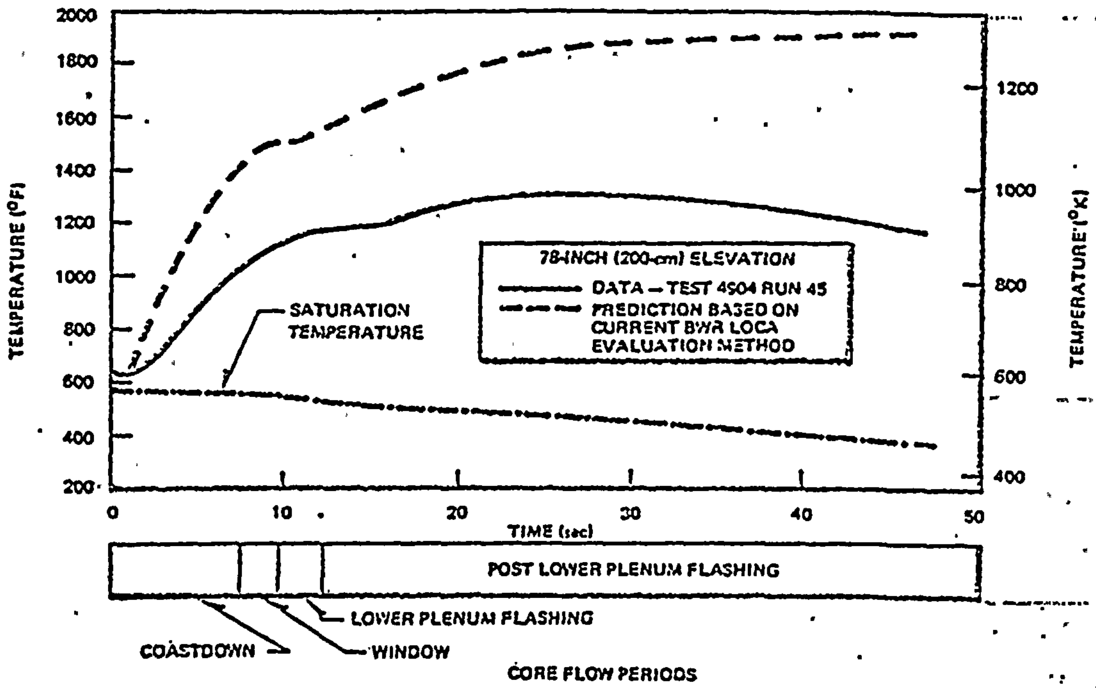

Figure 12. High Power Rod PCT for Peak Power Test

BLOWDOWN HEAT TRANSFER

APPENDIX K PREDICTION VS. BDHT DATA

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LOCA EVALUATION MODEL PROGRAMS

CONCLUSIONS

- WORK IN PROGRESS ON ALL PHASES OF MODEL

- NEW DATA AND MODELING SOPHISTICATION SINCE DECEMBER 1974:

  - PROVIDE BASIS FOR GREATLY IMPROVED PREDICTIO
  - INDICATE "PLUSSES AND MINUSES" WHICH WILL BE INCORPORATED
  - SHOW OVERALL CONSERVATISM & PROVIDE BASIS FOR REDUCING OPERATING RESTRICTIONS

- IMPROVEMENTS TO BE INTRODUCED IN COMPLETE AND SUBSTANTIAL "PACKAGES"

- FIRST "PACKAGE" IS READY FOR IMPLEMENTATION

  - CHASTE CODE
  - SAFE2 CODE