FIGURE 1 : SIMPLIFIED DESIGN PROCESS FLOW DIAGRAM

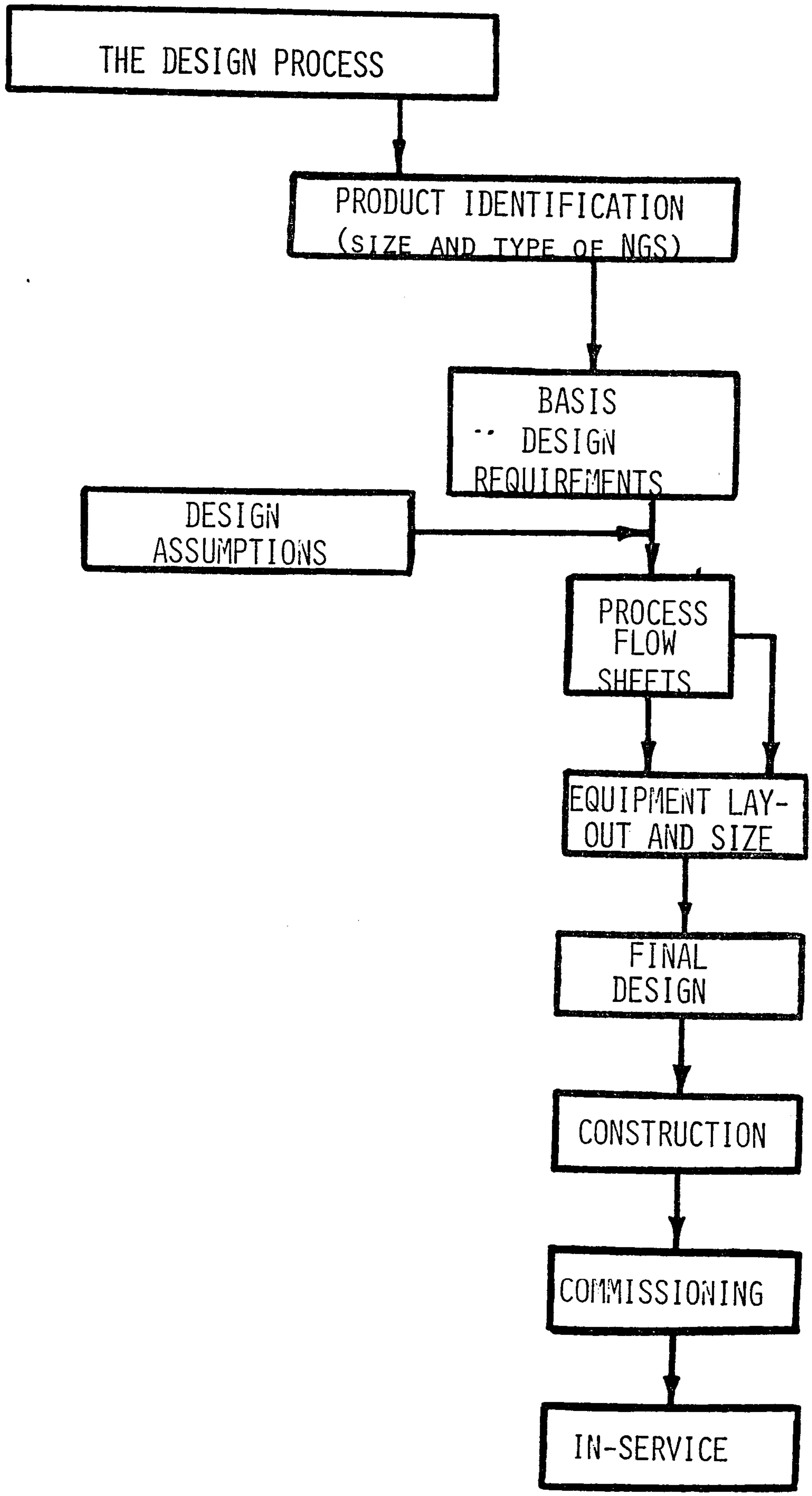
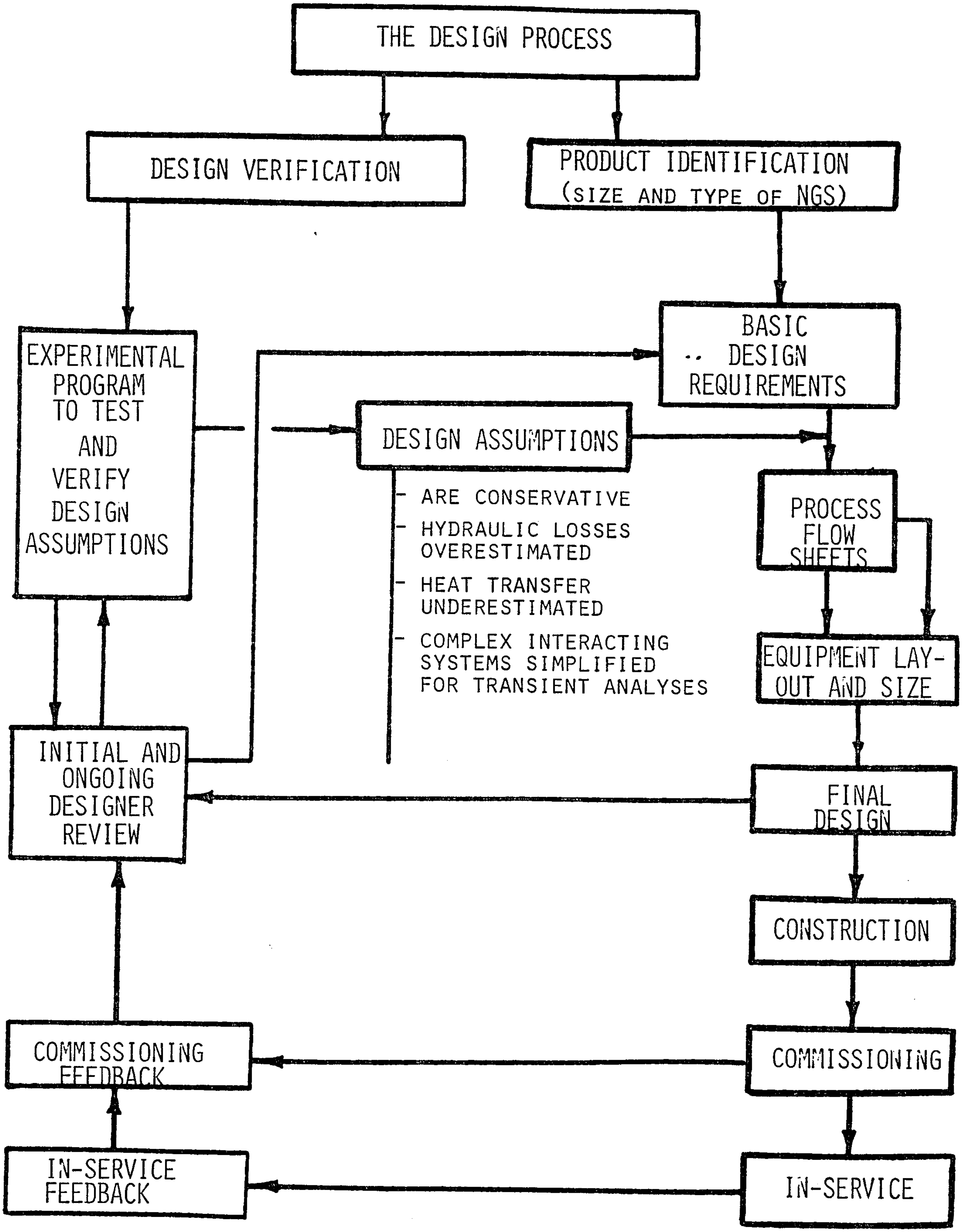


FIGURE 2 : SIMPLIFIED DESIGN PROCESS FLOW DIAGRAM WITH VERIFICATION



DESIGN VERIFICATION METHODOLOGY (CONT'D)

3. FEEDBACK FROM ACTUAL NUCLEAR STATIONS DURING COMMISSIONING AND IN-SERVICE OPERATION TO VERIFY DESIGN CODED

   - USE INFORMATION TO:

     A. VERIFY THE STEADY-STATE ISOTHERMAL HYDRAULIC MODELLING IS CORRECT.

     B. SHOW THE STEADY-STATE PERFORMANCE WITH HEAT TRANSFER IS CORRECT.

     C. USE THE DETAILED RESULTS FROM THE STEADY-STATE CODES AND MATCH THE TRANSIENT CODE STEADY-STATE PREDICTIONS.

     D. VERIFY THE TRANSIENT THERMAL HYDRAULIC MODELLING IS CORRECT.

KEY AREAS OF DESIGN VERIFICATION

: STEADY-STATE ISOTHERMAL HYDRAULICS

- TOTAL CORE FLOW
- CHANNEL FLOW DISTRIBUTION
- ADEQUATE FUEL COOLING

: STEADY-STATE HEAT TRANSFER

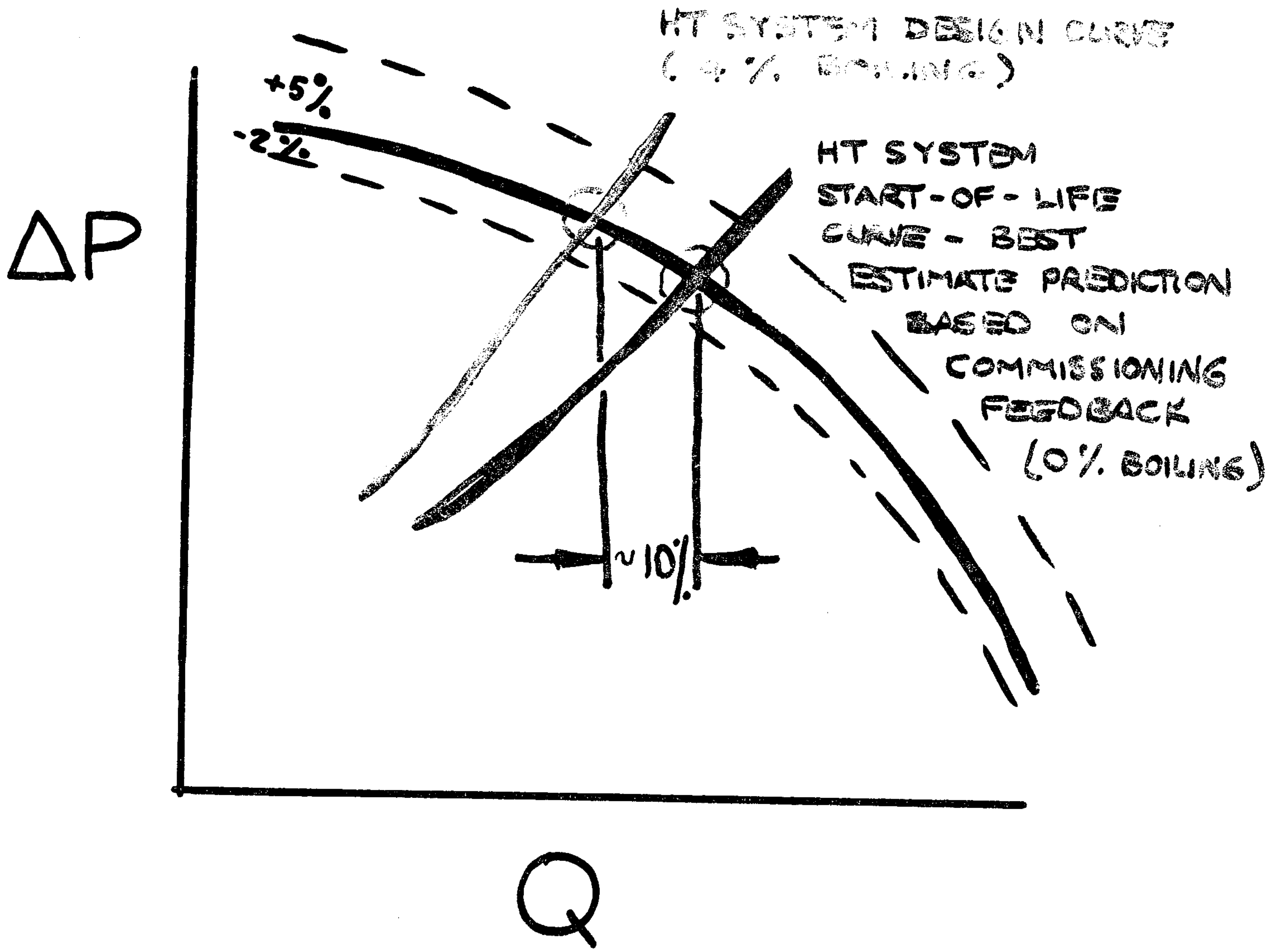
- TEMPERATURE/ENTHALPY DISTRIBUTION
- S/G HEAT TRANSFER
- EXTENT OF PRIMARY COOLANT BOILING
  * BOILING CLOSELY COUPLES HYDRAULICS AND HEAT TRANSFER THRU 2Ø ΔP MULTIPLIERS
  * IF NO BOILING, HYDRAULICS AND HEAT TRANSFER RELATIVELY INDEPENDENT.

: TRANSIENT THERMAL HYDRAULIC BEHAVIOUR

- REACTOR CONTROL
- HT SYSTEM, AUXILIARIES AND SECONDARY SIDE INTERACTIONS
- HT SWELL, RESPONSE TIMES, STABILITY.

SYSTEM OPERATING POINT

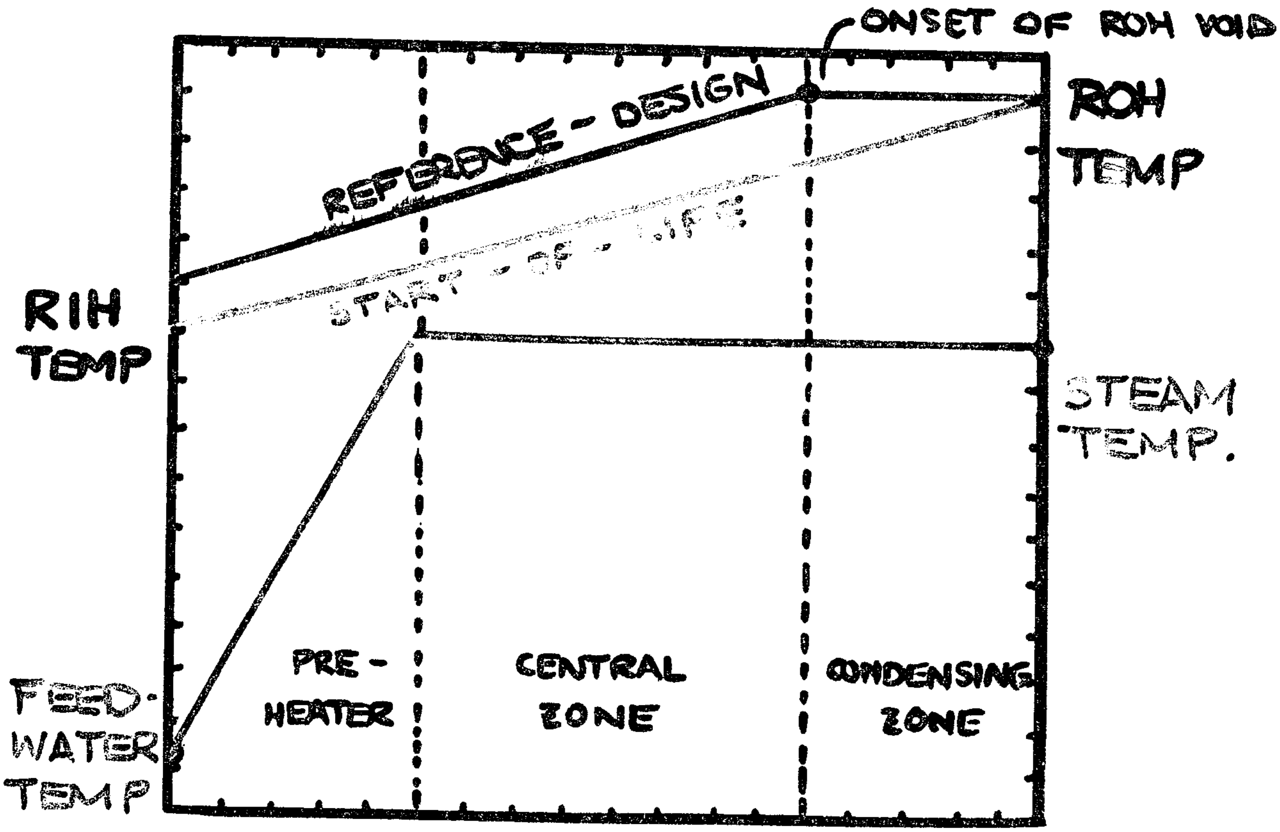
O DESIGN   O ACTUAL



DESIGN PUMP CURVE AND MANUFACTURING TOLERANCES

NTS

STEAM GENERATOR THERMAL PERFORMANCE



- flow up
- good heat transfer

KEY AREAS OF DESIGN VERIFICATION (CONT'D)

HT IS A LARGE SYSTEM COMPRISED OF COMPLEX COMPONENTS AND MANY INTERACTING AUXILIARY SYSTEMS.

MOST EASILY HANDLED USING LARGE COMPUTER CODES AS THERMAL HYDRAULIC DESIGN TOOLS.

STEADY-STATE ....NUCIRC
TRANSIENT ....SOPHT

DESIGN VERIFICATION THEN IS VERY MUCH INTERWOVEN WITH VALIDATION OF NUCIRC AND SOPHT.

IMPORTANT SINCE DESIGN CODES USED TO EXTEND OUR REALM OF EXPERIENCE TO COVER SCENARIOS WHICH CANNOT BE TESTED IN A LABORATORY OR DURING COMMISSIONING.

NUCIRC - MODELLING UNCERTAINTIES

HYDRAULICS:

: COMPLEX COMPONENT ΔP LOSSES,
E.G. S/G'S, FUEL, HEADERS

: PIPE AND TUBE INSIDE DIAMETER
MANUFACTURING TOLERANCES, $\Delta P \propto D^{-5}$

: HYDRAULIC LOSSES COEFFICIENTS TYPICALLY NO BETTER THAN $\pm$ 5% TO $\pm$ 10%

: COMPONENT INTERACTIONS

: PUMP MANUFACTURING TOLERANCES

: MODELLING/SYSTEM SIMPLIFICATION ERRORS

HEAT TRANSFER:

: S/G HEAT TRANSFER CORRELATIONS

: EXTRA HEAT TRANSFER AREA ADDED TO S/G

: PIPING AND EQUIPMENT HEAT LOSSES

: S/G DRUM AND ROH PRESSURE CONTROL DIRECTLY AFFECT HT BOILING

: POWER MEASUREMENT - ABSOLUTE AND DISTRIBUTION

NUCIRC - MODELLING UNCERTAINTIES (CONT'D)

COST OF THESE UNCERTAINTIES:

AN EXCESSIVELY CONSERVATIVE COMPUTED FLOW LEADS TO A LOSS IN POTENTIAL POWER OUTPUT:

1% IN FLOW → ~ 1 M$ PER YEAR.

SOPHT - MODELLING UNCERTAINTIES

PRESSURIZER BEHAVIOUR ..... TEMPERATURE & PRESSURE:

- CONDENSATION AND EVAPORATION ON INSURGE AND OUTSURGE.
- PHASE CHANGE.

STEAM GENERATOR:

- SWELL, SHRINK, RECIRCULATION
- HEAT TRANSFER WITH A PARTIALLY UNCOVERED TUBE BUNDLE.

BLEED CONDENSER:

- U-TUBE BEHAVIOUR
- CONDENSATION BEHAVIOUR

VALVES:

- CAPACITY
- STROKING TIME

SOPHT - MODELLING UNCERTAINTIES (CONT'D)

NODAL-LINK DISCRETIZATION:

- PROPOGATION OF FLOW AND PRESSURE DISTURBANCES
- NUMERICAL PROBLEMS

COST OF UNCERTAINTY:

GREATER MARGINS
LOWER LICENSABLE POWER

WHY IS DESIGN VERIFICATION NEEDED

AS A MINIMUM, TO VERIFY THE OVERALL DESIGN INTENT.

MORE SPECIFICALLY:

FOR THE STATION OWNER/OPERATOR:

: PROVES STATION IS OPERATING PROPERLY

: ELECTRICAL OUTPUT = WARRANTY

: FUEL BURN-UP NOT EXCESSIVE

: D_2O LOSSES SATISFACTORY

FOR THE LICENSING AUTHORITY:

: ASSURES THAT THE REACTOR CONTROL AND SAFETY SYSTEMS ARE ADEQUATE.

: THE RISK OF RADIATION EXPOSURE TO STATION STAFF AND THE GENERAL PUBLIC IS ACCEPTABLE.

DESIGN VERIFICATION ALSO SERVES TO VALIDATE DESIGN ASSUMPTIONS AND DESIGN CODE MODELLING.

WHAT ARE SOME OF THE BENEFITS

TO THE STATION OWNER/OPERATOR:

- EARLY DETECTION AND REPAIR OF DESIGN DEFICIENCIES, MINIMIZING REPAIR COSTS.
- POTENTIAL IMPROVEMENT IN THE POWER OUTPUT OF A STATION OR IMPROVEMENT IN ITS OPERABILITY (INCREASING MARGINS).
- SUPPORTS LICENSING AND SAFETY DOCUMENTS AND IN TURN CAN FACILITATE ISSUANCE OF AN OPERATING LICENSE.
- SUBSEQUENT UNITS ORDERED WILL BE IMPROVED.

TO THE DESIGN AUTHORITY:

- PROVIDES UPDATED DESIGN GUIDELINES, CRITERIA AND DATA BASES FOR FUTURE PROJECTS.
- POTENTIALLY IMPROVES OVERALL EFFICIENCY, OPERABILITY AND LICENSABILITY OF FUTURE STATIONS.
- ENHANCES PRODUCT MARKETABILITY.

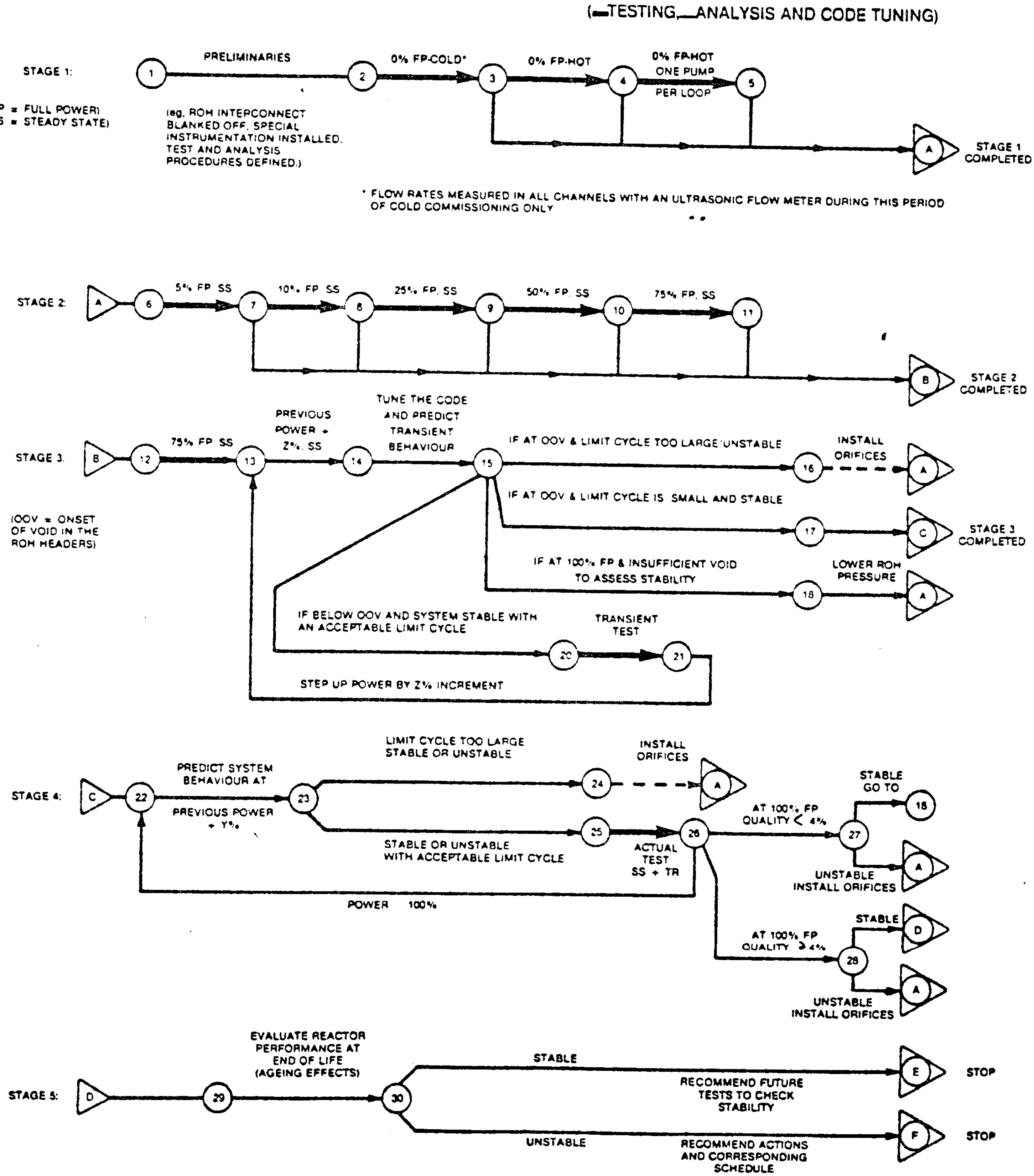
AN EXAMPLE - CANDU 600 H.T. SYSTEM COMMISSIONING

PROGRAM SPAWNED FROM H.T. STABILITY CONCERNS:

ADDED TO THE GENERAL COMMISSIONING PROGRAM, NOT PLANNED FOR DURING THE DESIGN PROCESS

METHODOLOGY	:	FIGURE 3
MEASUREMENTS	:	FIGURE 4
DATA TRANSMITTAL TO AECL	:	FIGURE 5
DATA PROCESSING AT AECL	:	FIGURE 6

FIGURE 3 : COMMISSIONING DESIGN VERIFICATION METHODOLOGY FOR THE CANDU HEAT TRANSPORT SYSTEM



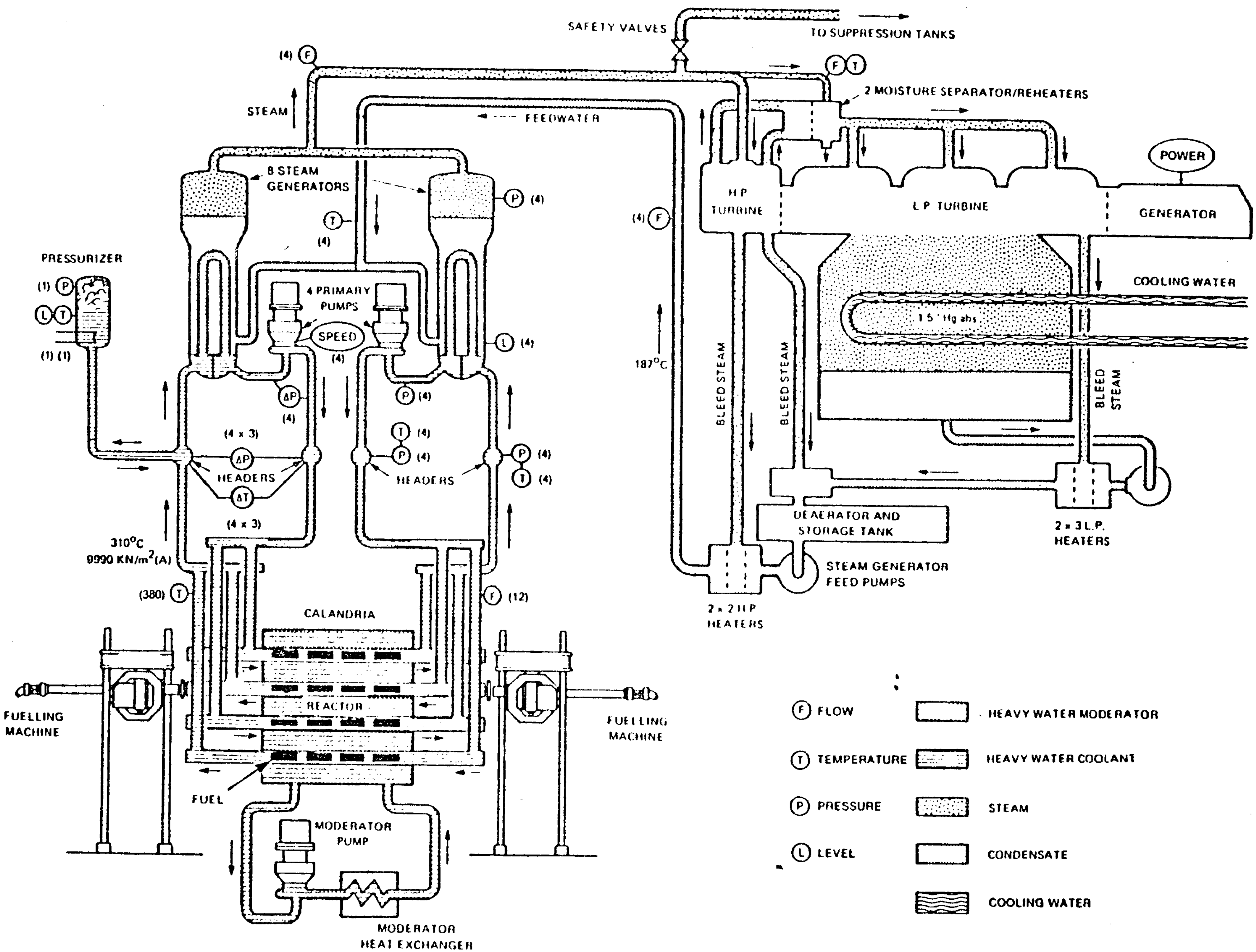


FIGURE 4 : COMMISSIONING DESIGN VERIFICATION MEASUREMENTS FOR A CANDU HTS

FIGURE 5 : EXAMPLE OF A DATA TRANSMITTAL SCHEME FROM A CANDU 600 TO AECL

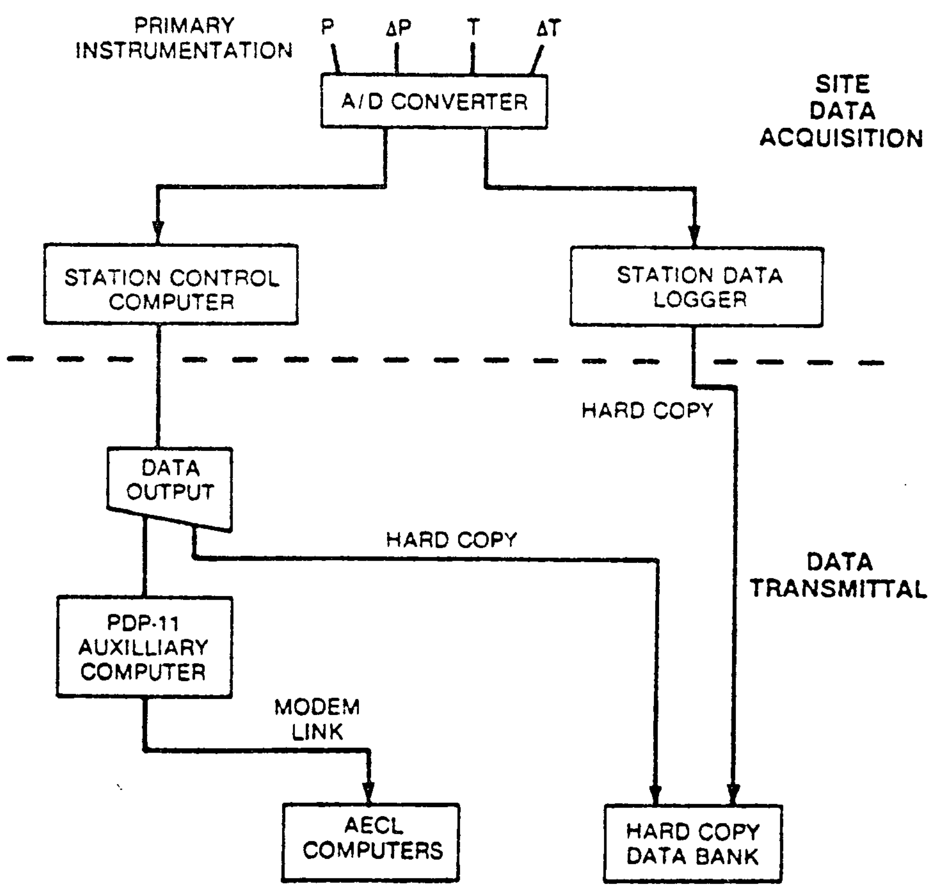
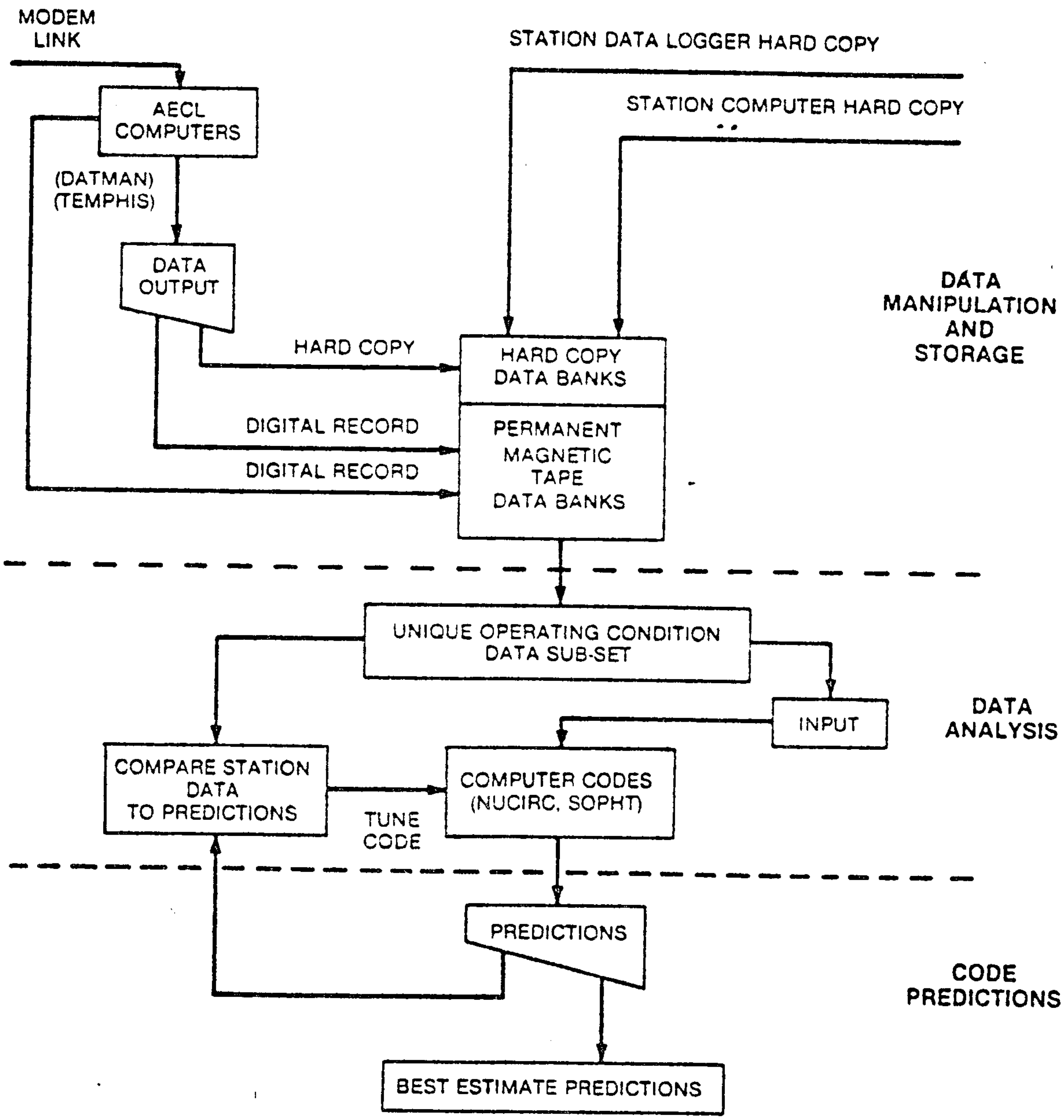
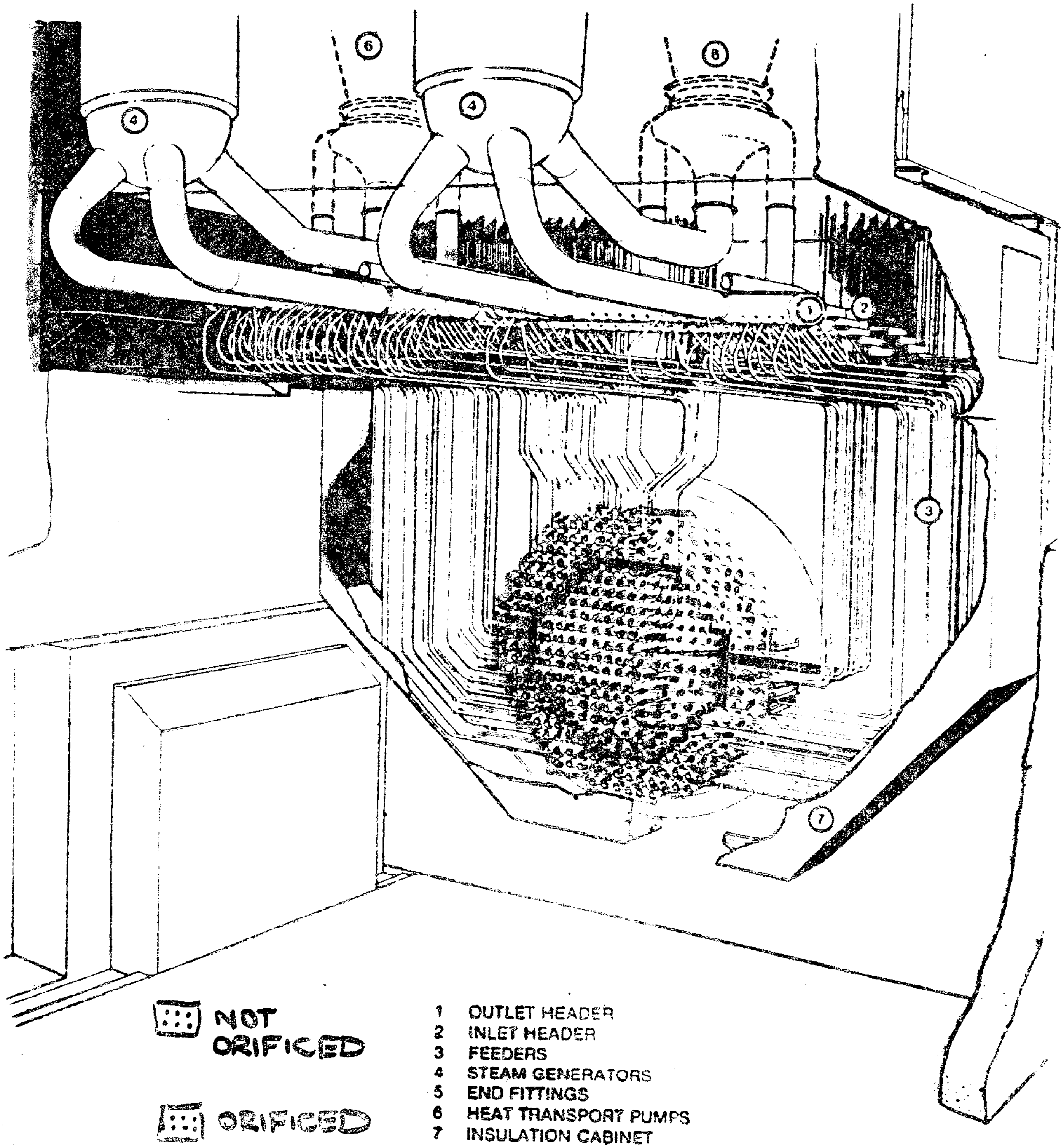


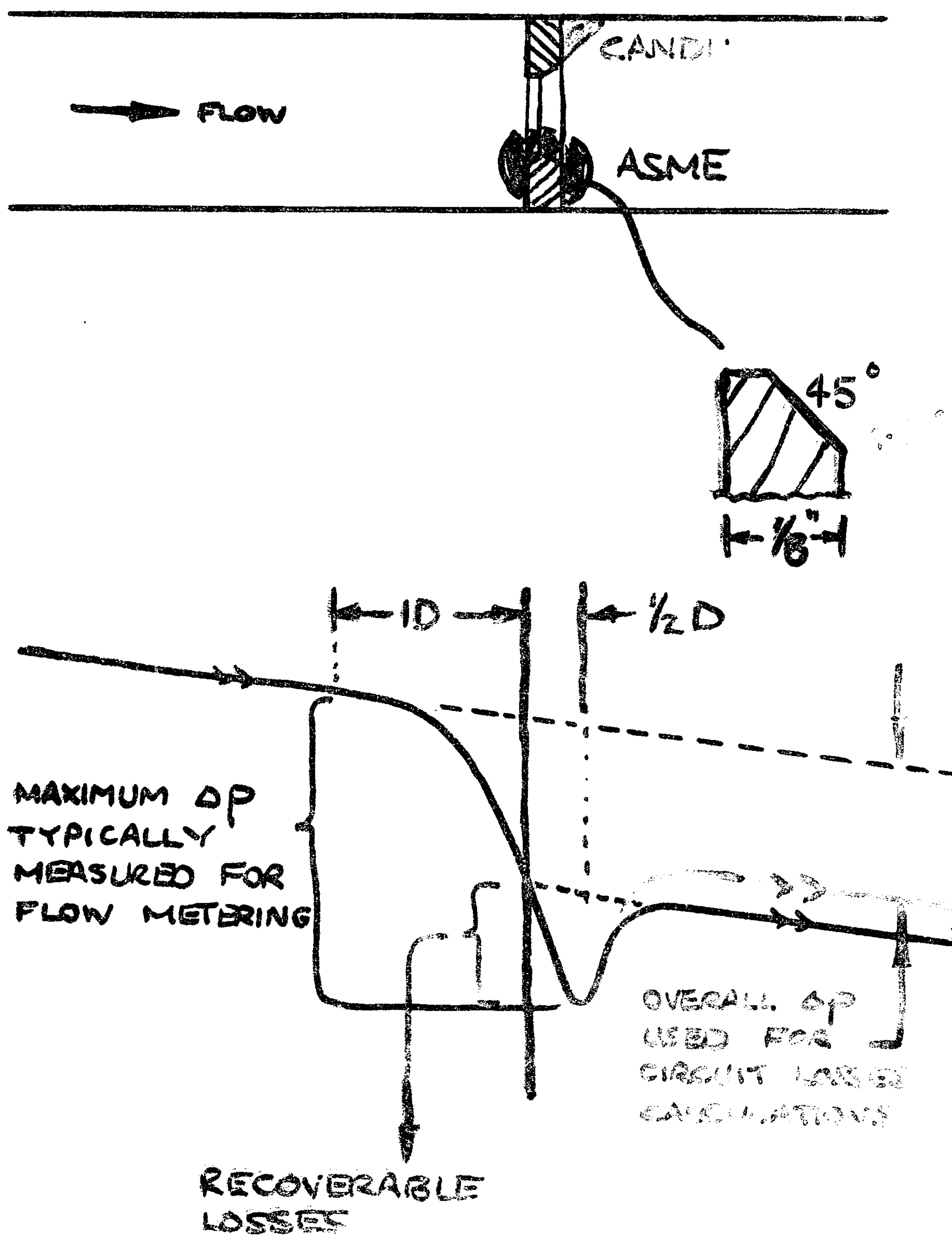
FIGURE 6 : EXAMPLE OF DATA PROCESSING AT AECL



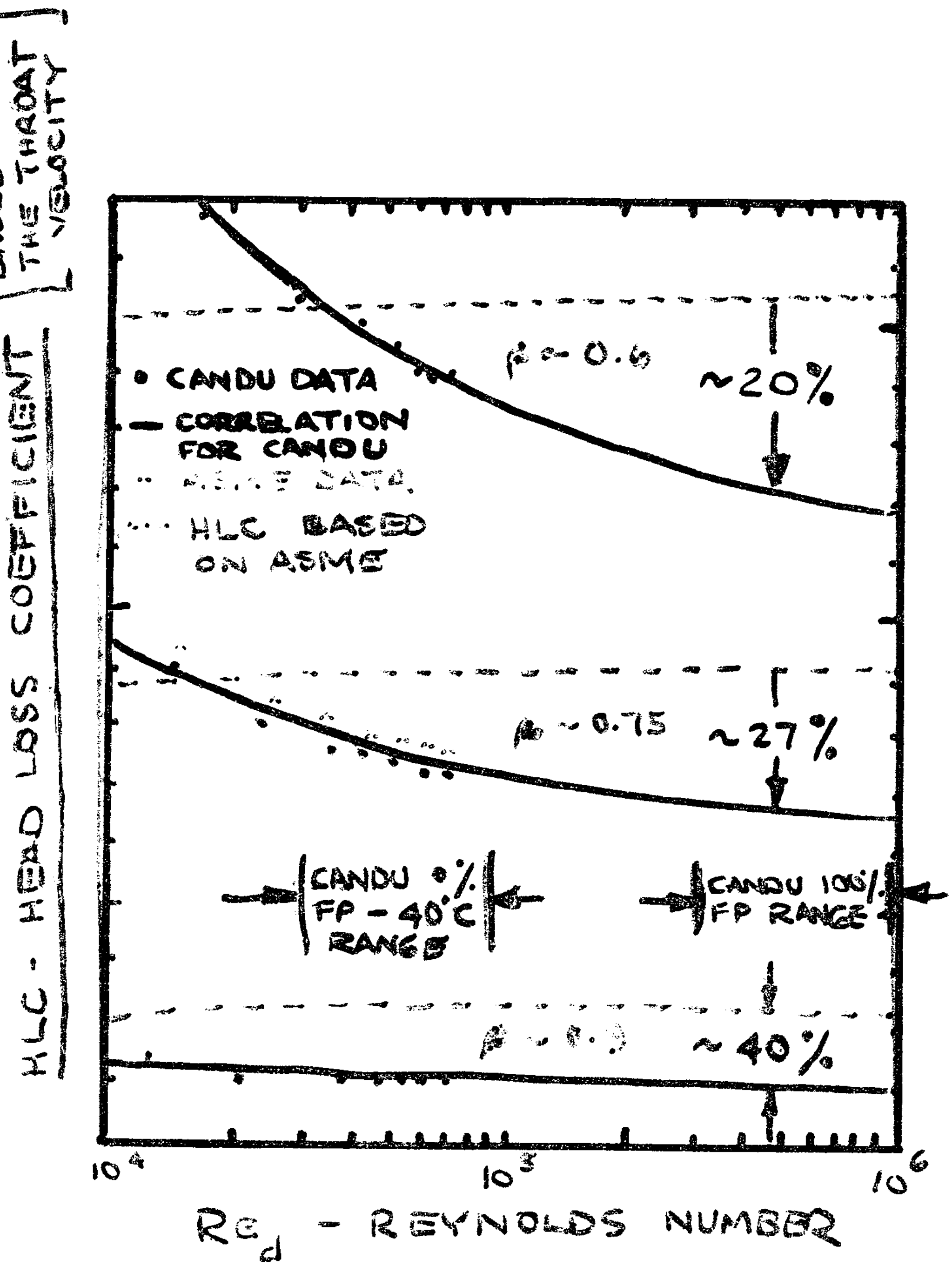


4
4
6
6
1
2
3
7
NOT ORIFICED
ORIFICED
1 OUTLET HEADER
2 INLET HEADER
3 FEEDERS
4 STEAM GENERATORS
5 END FITTINGS
6 HEAT TRANSPORT PUMPS
7 INSULATION CABINET

ORIFICE HYDRAULIC LOSSES



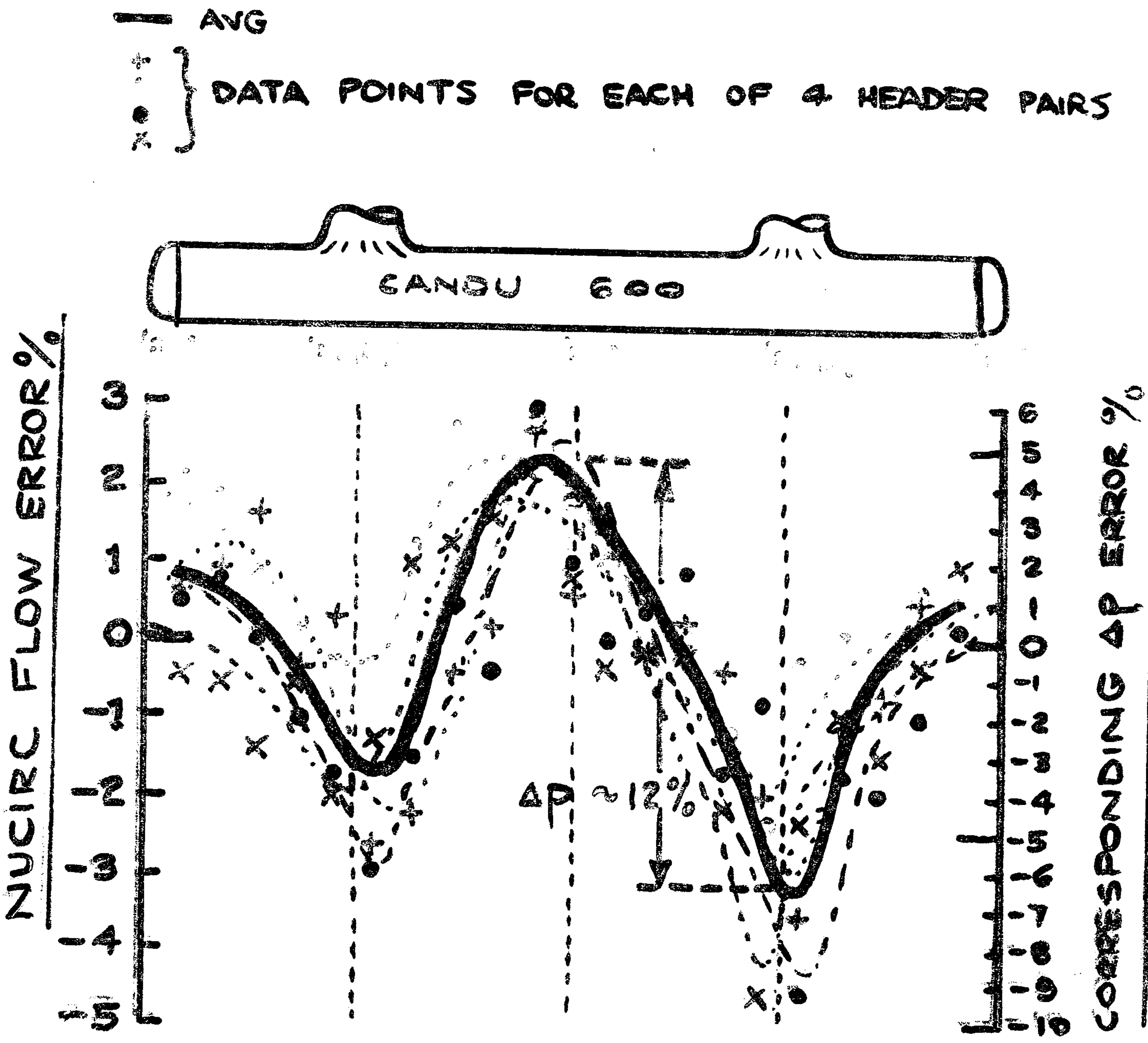
ORIFICE HYDRAULIC LOSSES



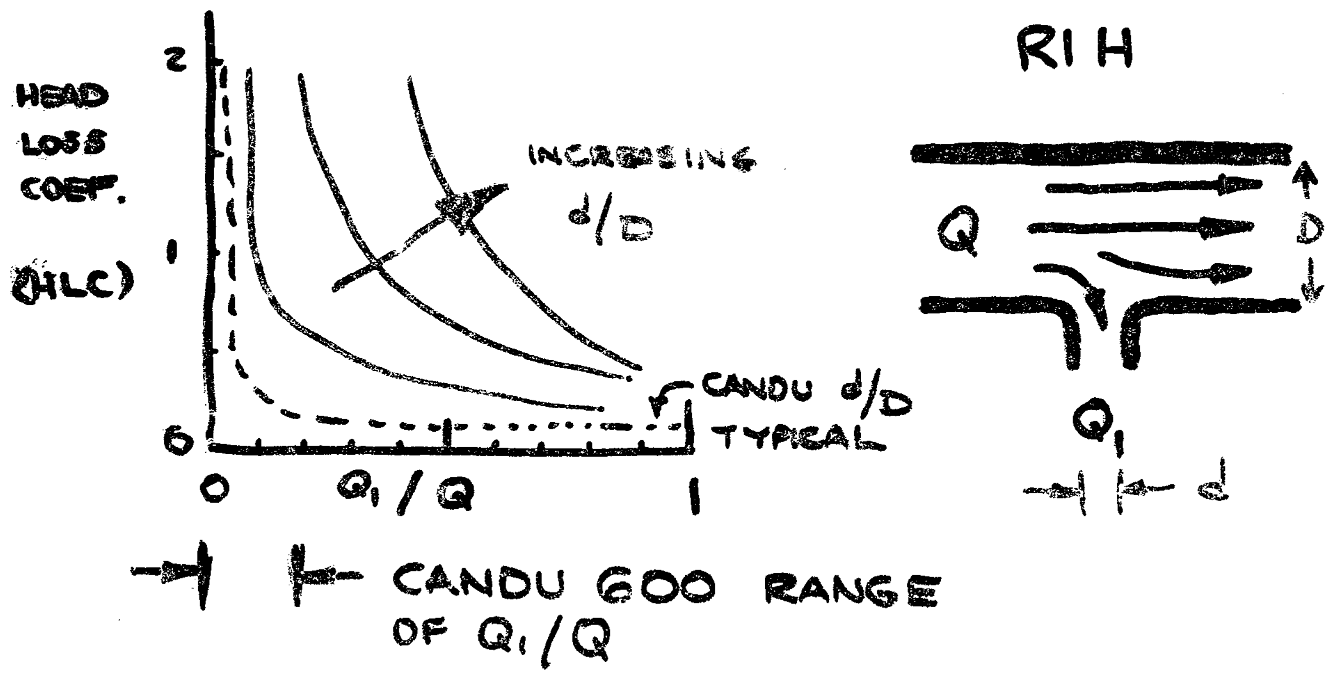
$$\Delta P = HLC\left(\frac{\rho V_d^2}{2}\right)$$

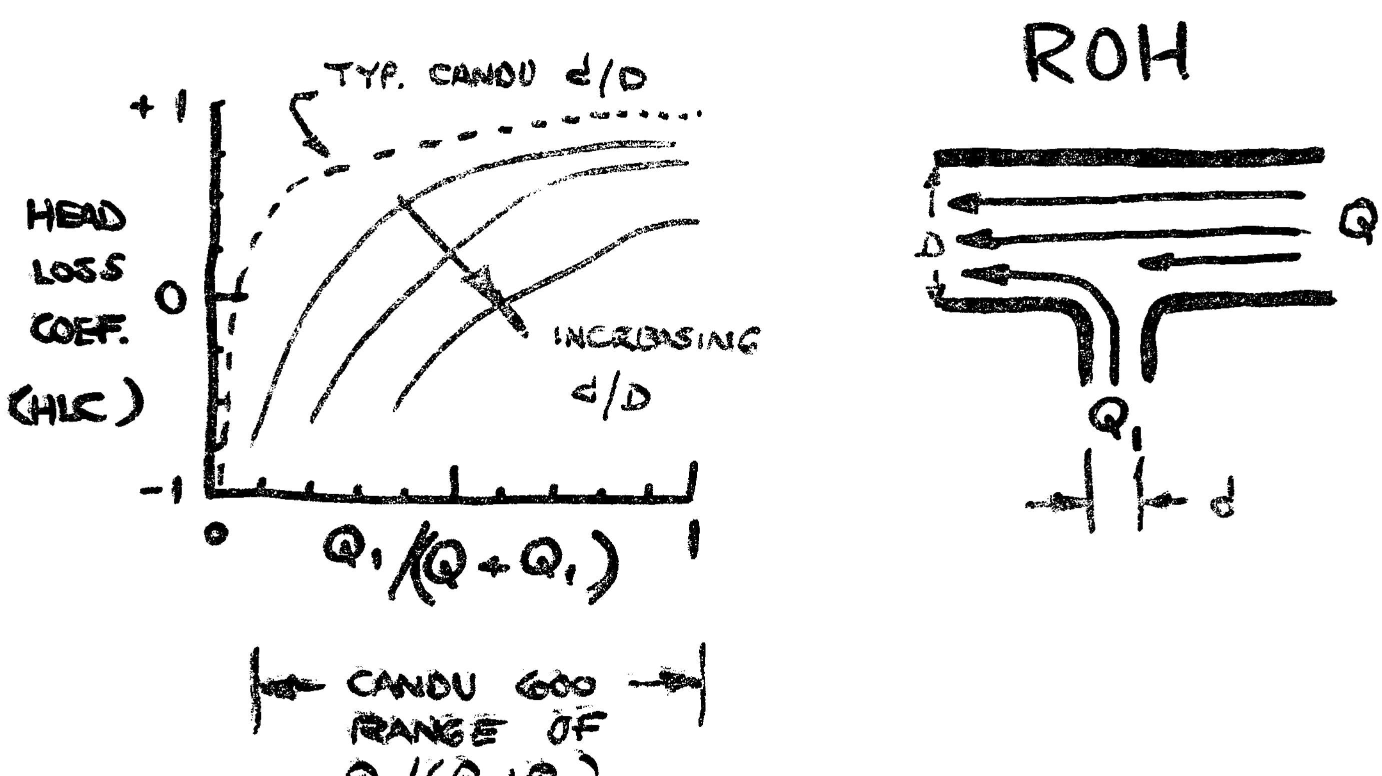
(+ ERROR NUCIRC OVERPREDICTS FLOW)

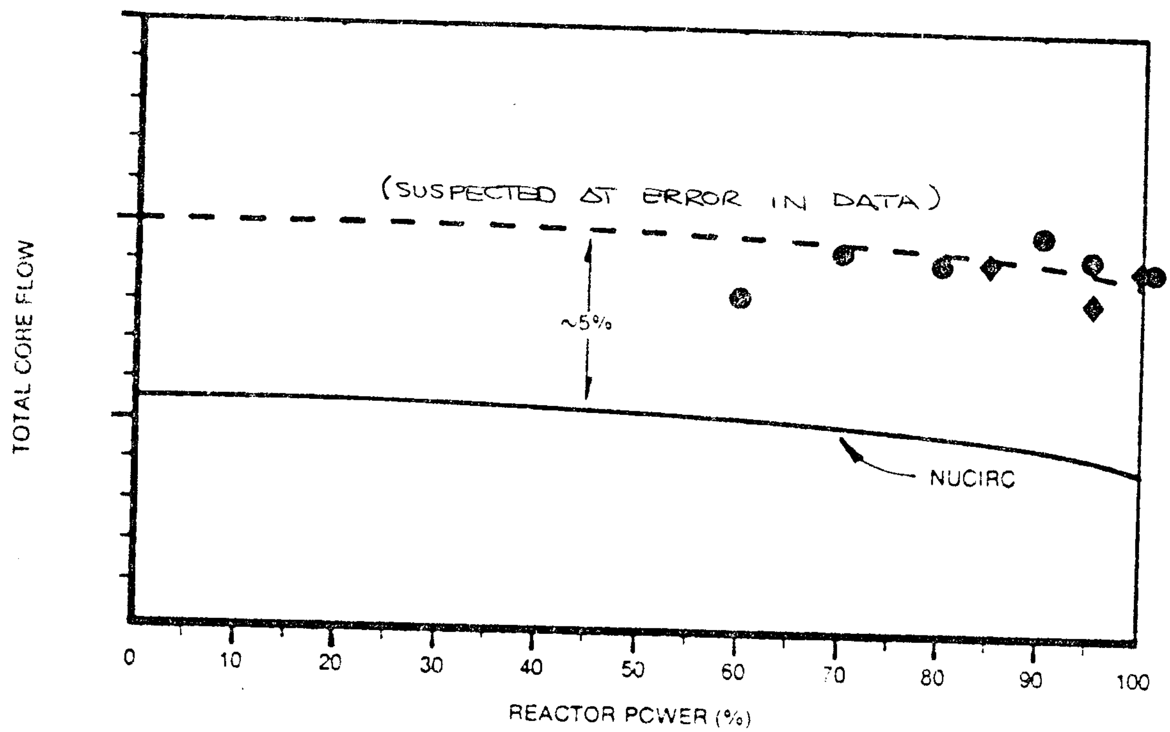
NUCIRC FLOW PREDICTION ERRORS AS A FUNCTION CHANNEL LOCATION ON THE HEADER



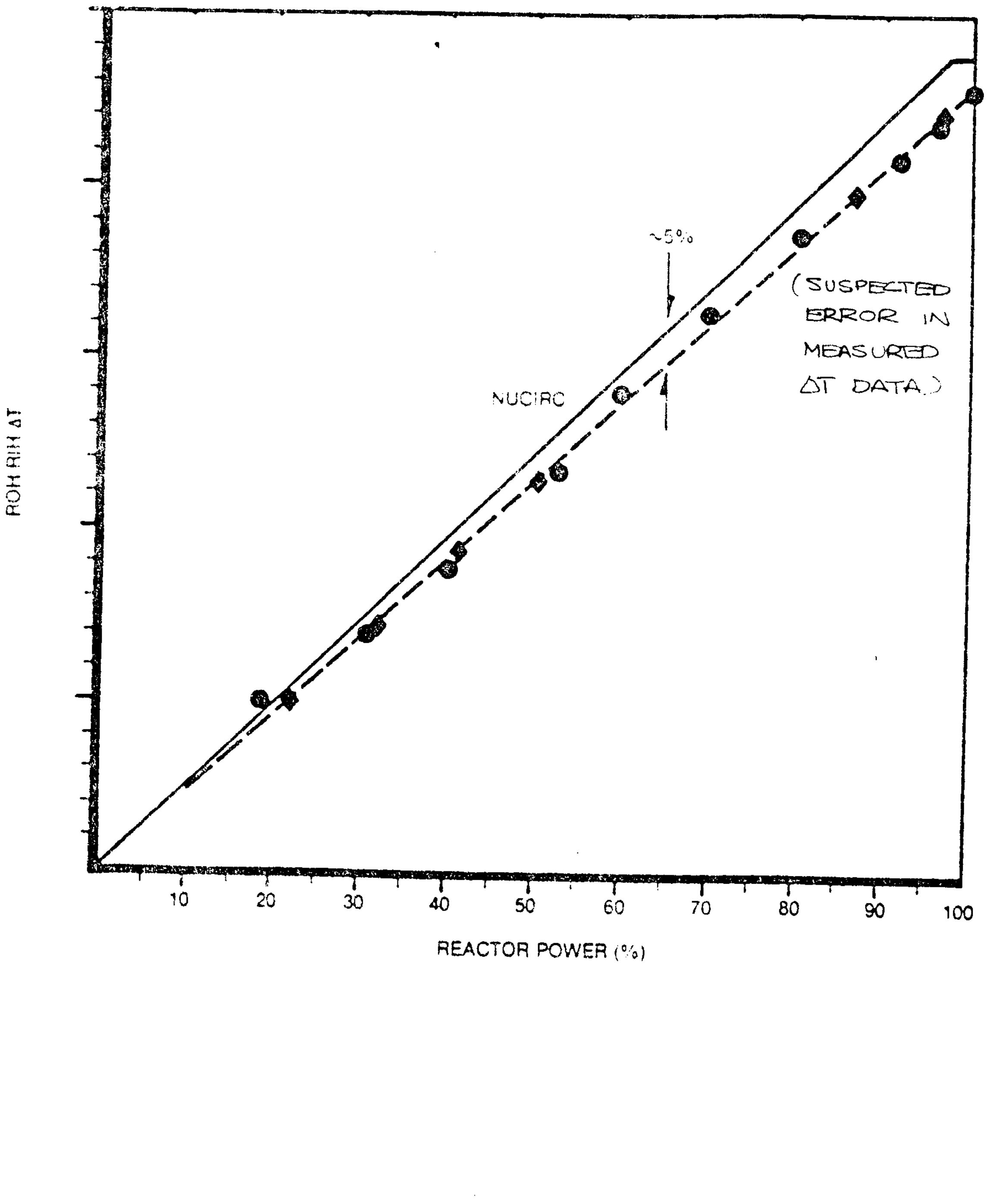
PRELIMINARY FINDINGS



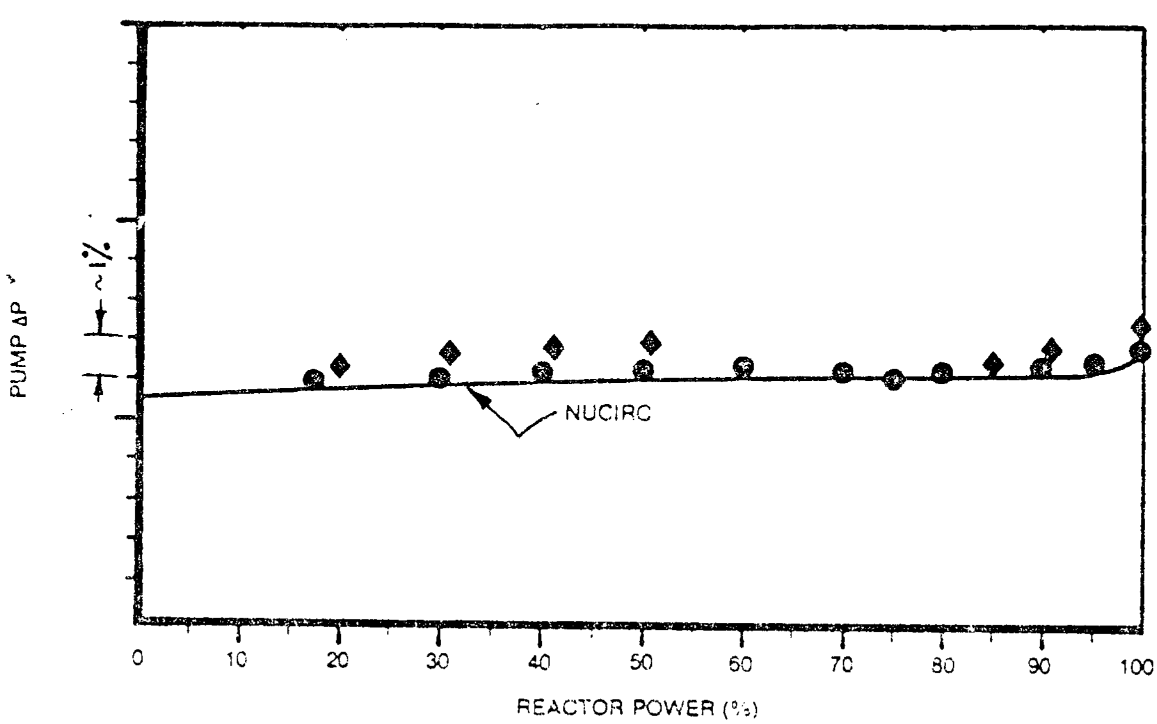


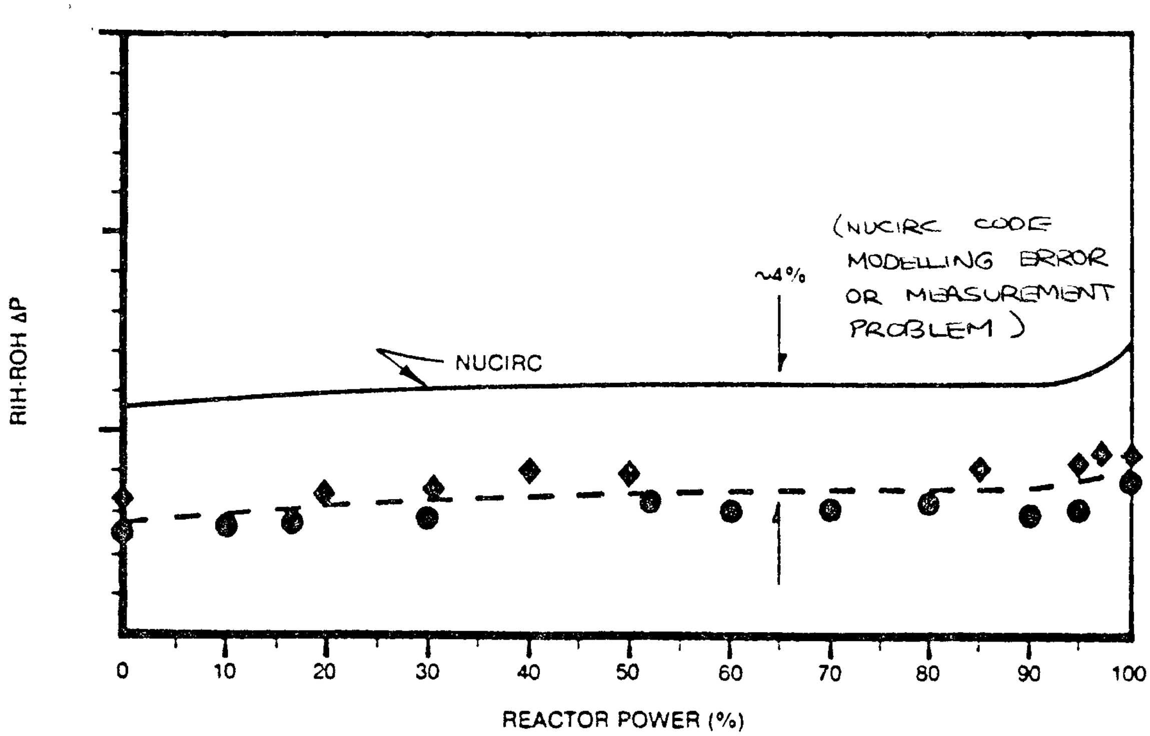


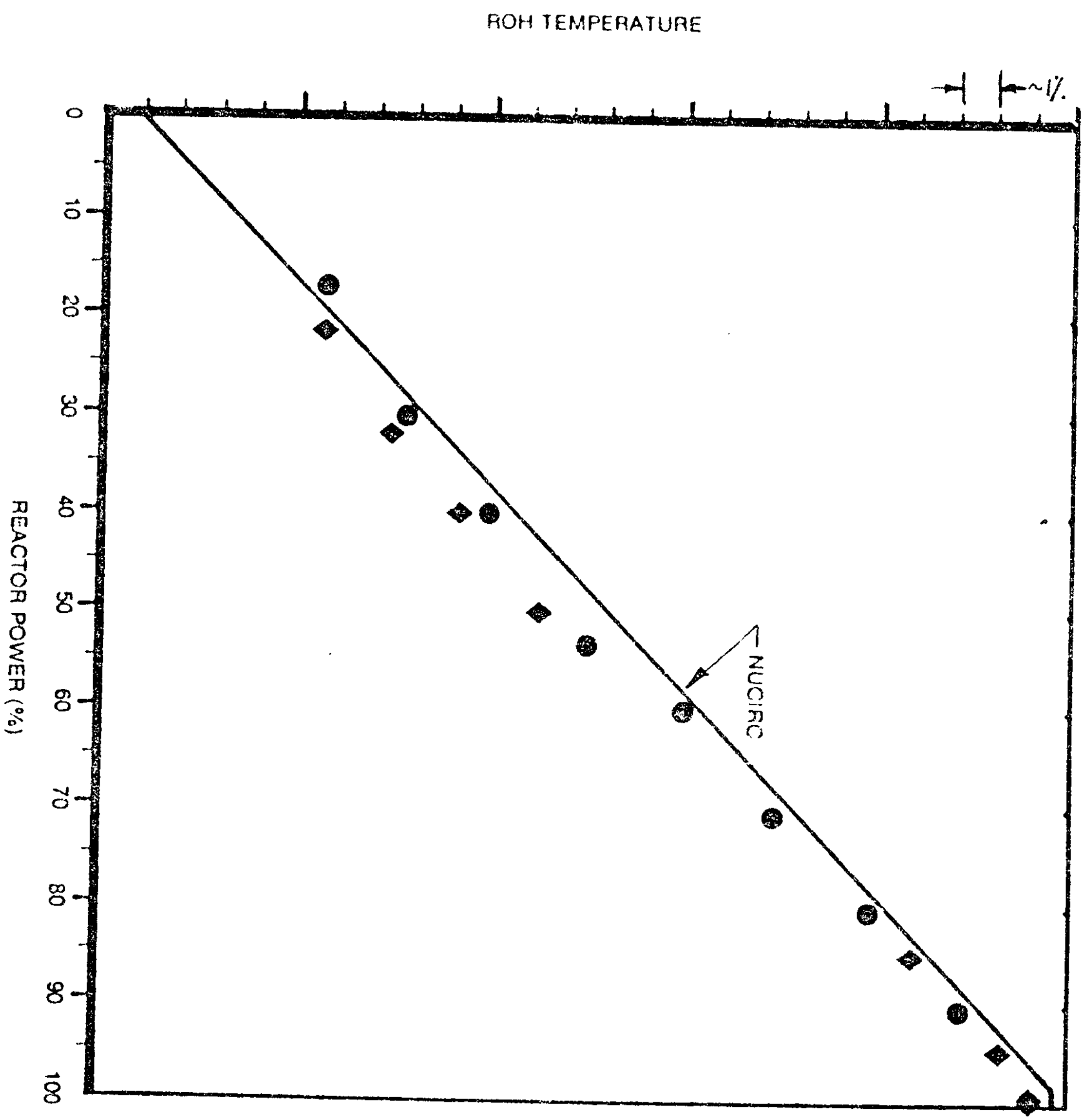
SITE DATA CALCULATED USING SITE MEASURED SECONDARY SIDE POWER AND HEADER TO HEADER ΔT:

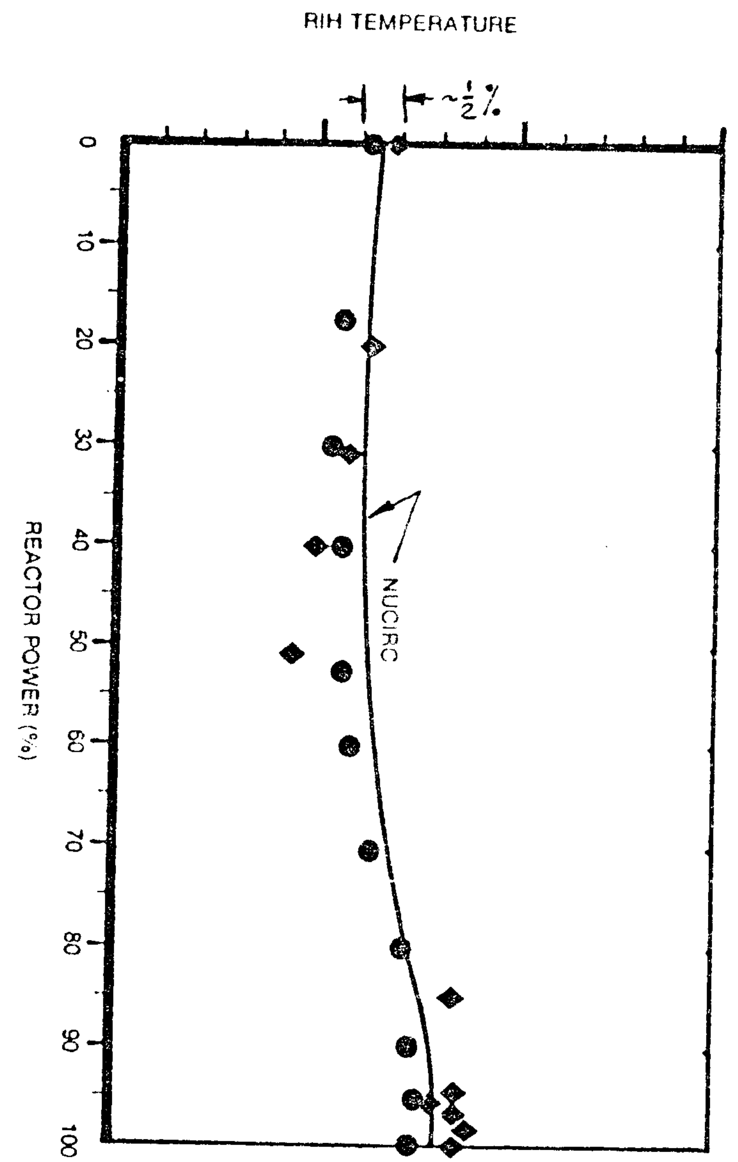


ROH RIH ΔT
NUCIRC
~5%
(SUSPECTED ERROR IN MEASURED ΔT DATA.)
10
20
30
40
50
60
70
80
90
100
REACTOR POWER (%)


PUMP ΔP
~1%
NUCIRC
0
10
20
30
40
50
60
70
80
90
100
REACTOR POWER (%)


RIH-ROH ΔP
(NUCIRC CODE
MODELLING ERROR
OR MEASUREMENT
PROBLEM)
~4%
NUCIRC
0
10
20
30
40
50
60
70
80
90
100
REACTOR POWER (%)


ROH TEMPERATURE
~1%
REACTOR POWER (%)
0
10
20
30
40
50
60
70
80
90
100
NUCIRC


RIH TEMPERATURE
~1/2 %
NUCIRC
REACTOR POWER (%)
0
10
20
30
40
50
60
70
80
90
100