AEA

AEA Technology

Technical Committe Meeting on Comparison of Best Estimate Methods for Judging Design Margins of Advanced Water-cooled Reactors

Lyon, France

18-21 October 1994

AEA Studies on Passive Decay Heat Removal in Advanced Reactors

J N Lillington

Objectives of UK Study

i. To identify, describe and compare different types of systems proposed in current designs.

ii. To identify key scenarios in which passive decay heat removal systems play an important preventative or mitigative role.

iii. To assess the adequacy of the relevant experimental database.

iv. To assess the applicability and suitability of current generation models / codes for predicting passive decay heat removal.

v. To assess the potential effectiveness of the different systems in respect of certain key licensing questions.

Licensing Issues

- Will a particular system initiate correctly and reliably from a range of different accident conditions?
- Is there sufficient decay heat removal capacity? Will a system operate as intended?
- Is there a potential for containment over-pressurisation?

Current Interests

Primary/Secondary passive decay heat removal systems

Passive Containment Cooling

Passive ECCS performance

Accident Scenarios

Intact Circuit Faults

- Secondary Condensing Systems
- Primary Condensing Systems

LOCAs

- Large break
  - accumulator injection
  - CMT discharge

- Small break
  - CMT discharge
  - ADS operation
- Accumulator injection

94/96 PROGRAMME

Primary/Secondary circuit

- To determine the limits on heat exchanger performance and margin to dryout for the current systems of interest
- Provide safety assessments for reference RHR system.
- Collaboration with CEA?

AEA Computer Studies

- RELAP5 used
- System level modelling
- Fine mesh scale effects e.g. in condenser and 3D effects not modelled. 1 D representation
- Primary Circuit / Containment Coupling not addressed. Study is only concerned with thermosyphon effects not containment pressurisation
- Condensing pool representation.

Secondary Cooling Circuit Deck

(SIR)

Representation of:-

- Primary heat input
- Steam generator
- Feedwater supply
- Steam dump
- Condensing pool
- Heat exchanger

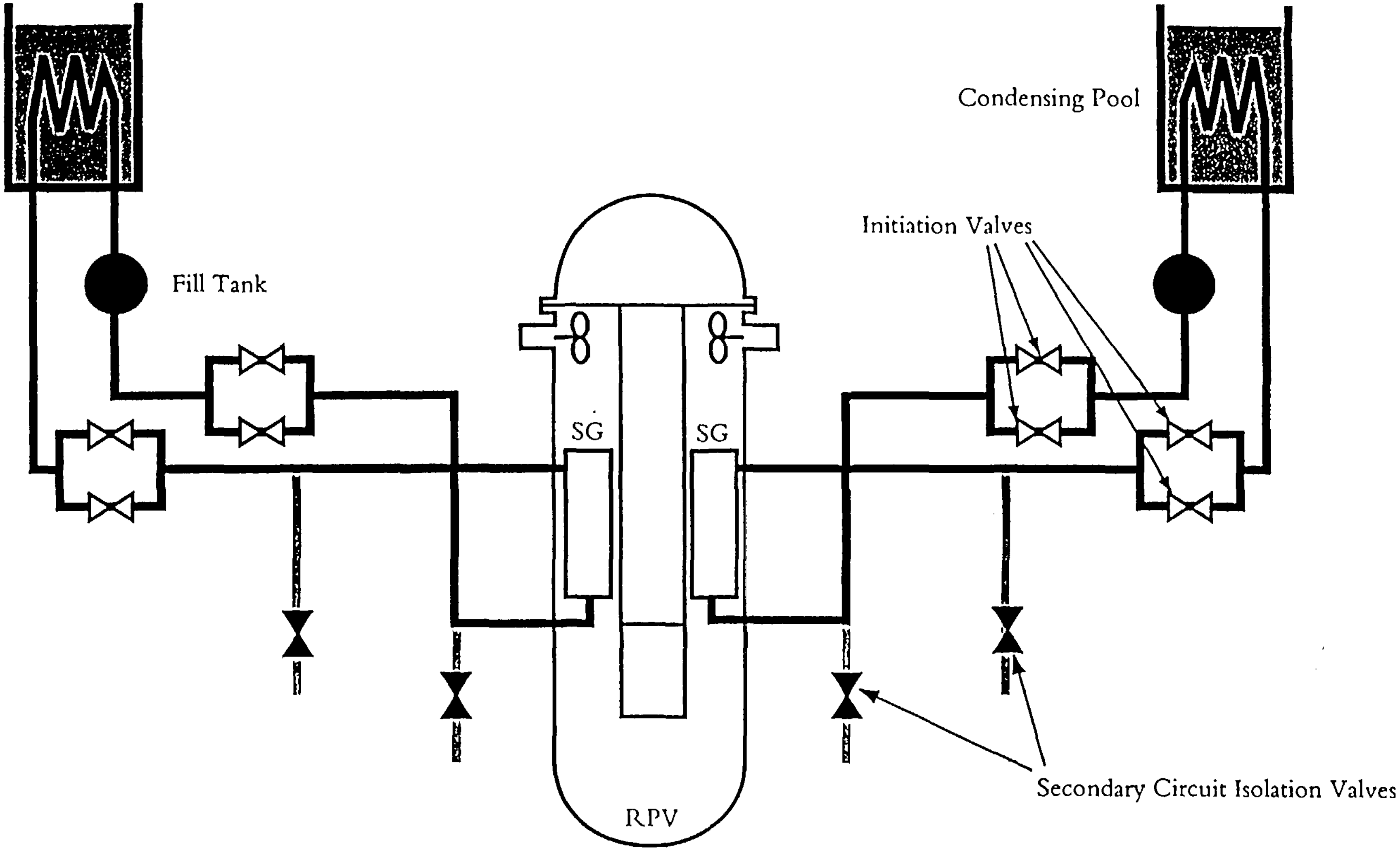
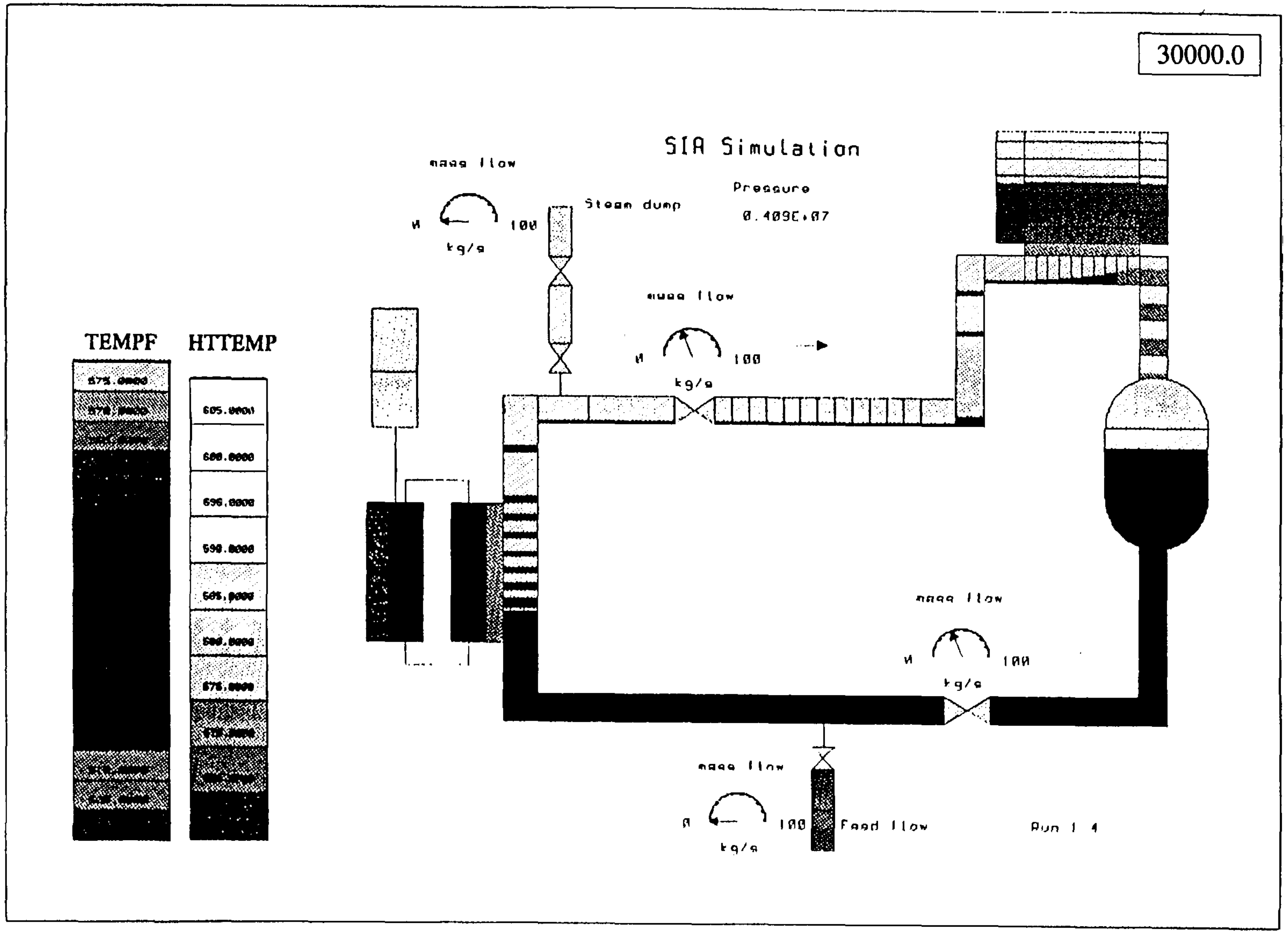


Figure 2 SIR - Secondary Condensing System (4 Loop, 2 Shown)


30000.0
SIA Simulation
Pressure
0.409E+07
Steam dump
mass flow
0
100
kg/s
mass flow
0
100
kg/s
mass flow
0
100
kg/s
mass flow
0
100
kg/s
Feed flow
Run 1 4
TEMPF
575.0000
570.0000
HTTEMP
605.0000
600.0000
595.0000
590.0000
585.0000
580.0000
575.0000

Primary Cooling Circuit Deck

(AP600)

Representation of:-

- 2 Hot Legs
- 4 Cold Legs
- Vessel & Fuel Rods
- Pressuriser & Surge Line
- Passive Heat Removal System & Valves
- Inside Containment Refuelling Water Storage Tank

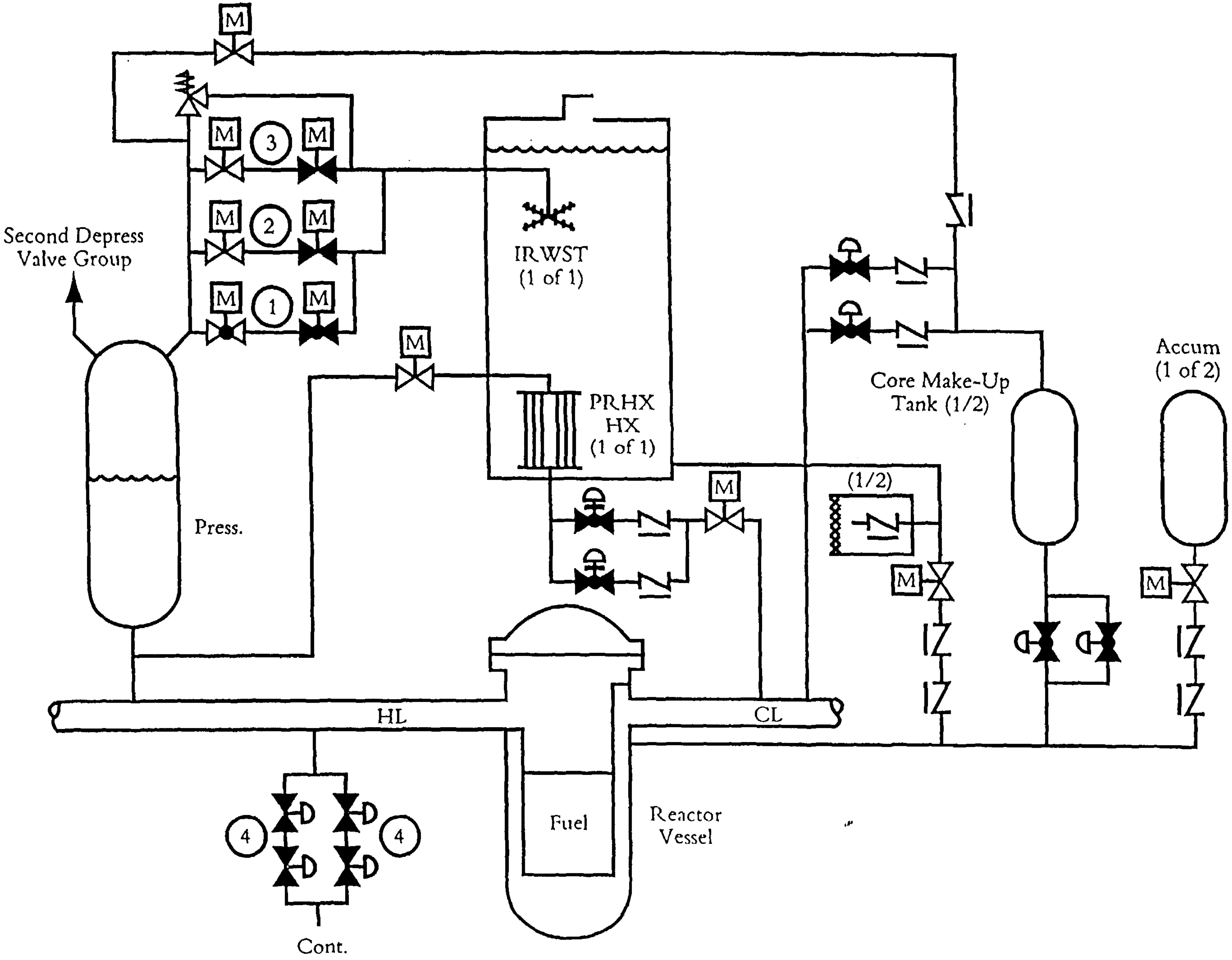


Figure 4 AP600 Passive Safety Injection System

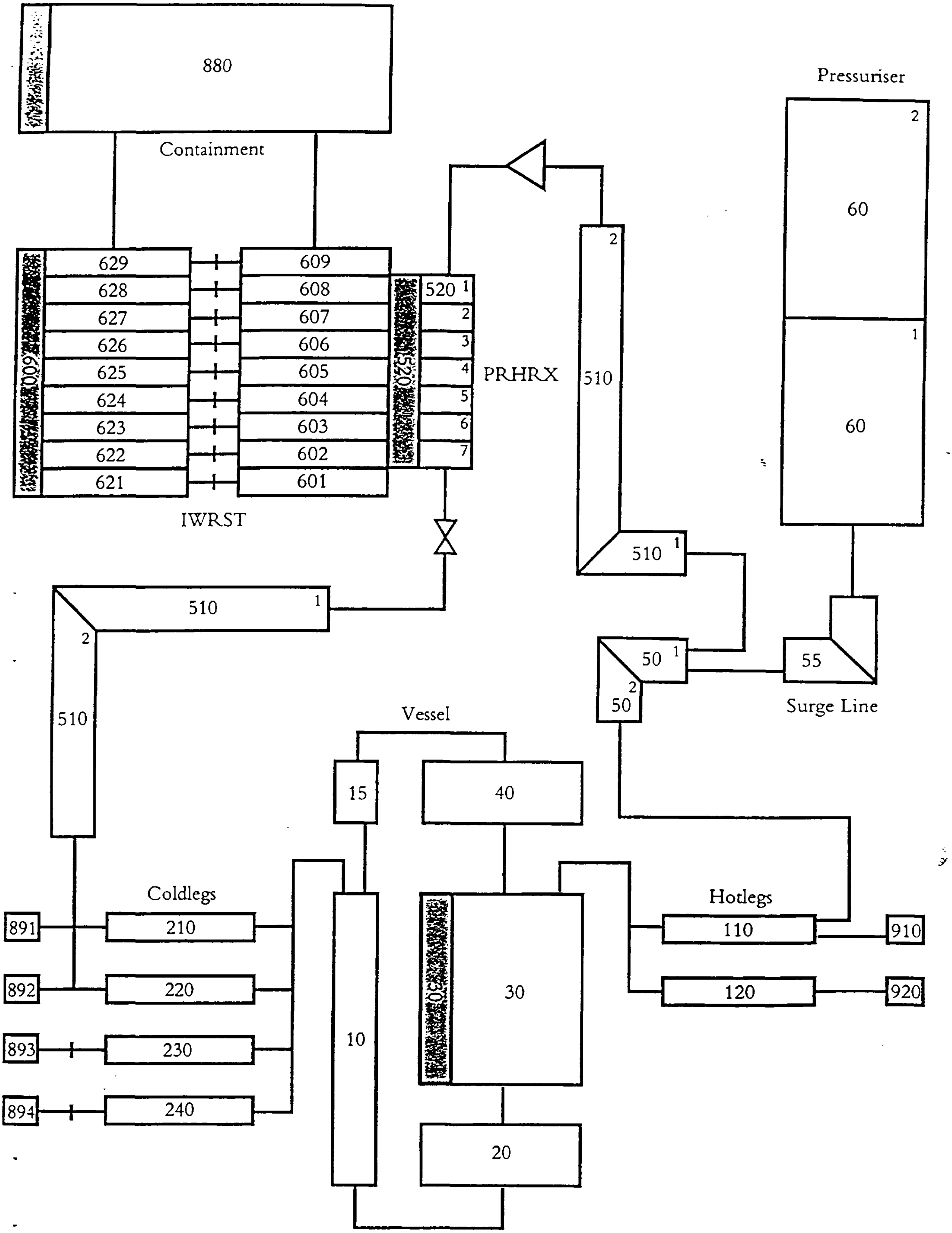


Figure 5 RELAP5 Noding Representation for AP600

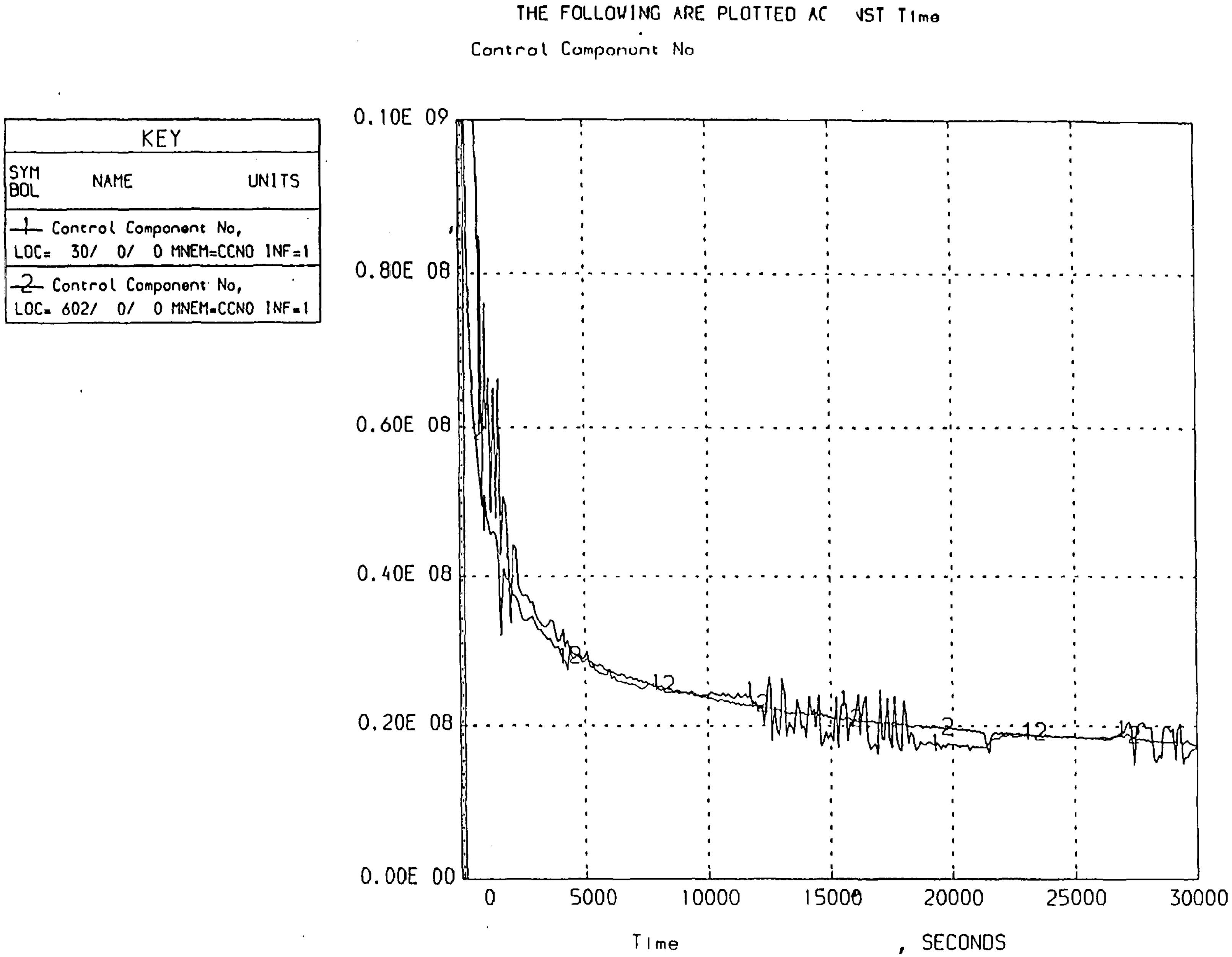


Figure 24 Heat to Circuit and to Pool: AP600 Simulation

Assessment of Condenser Pool Modelling

Background

- Difficulty with previous calculations in establishing stability
- Calculational results did not match experimental predictions.

Approach

- Model condensing pool as separate item
- For ease of modelling use electrical heat generation
- Include special components in model to establish initial conditions

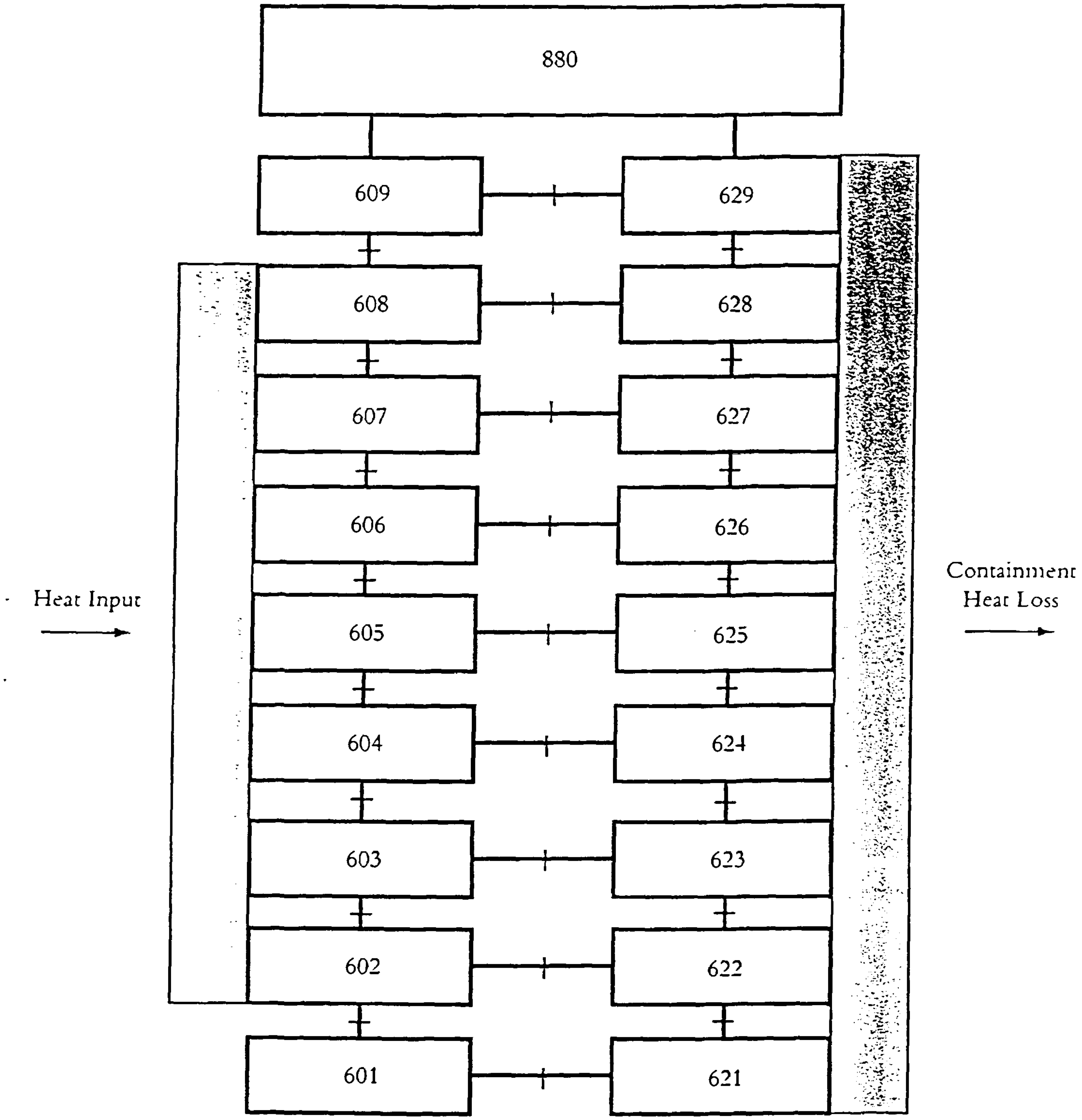


Figure 25 RELAP5 Nodalisation for Condensing Pool

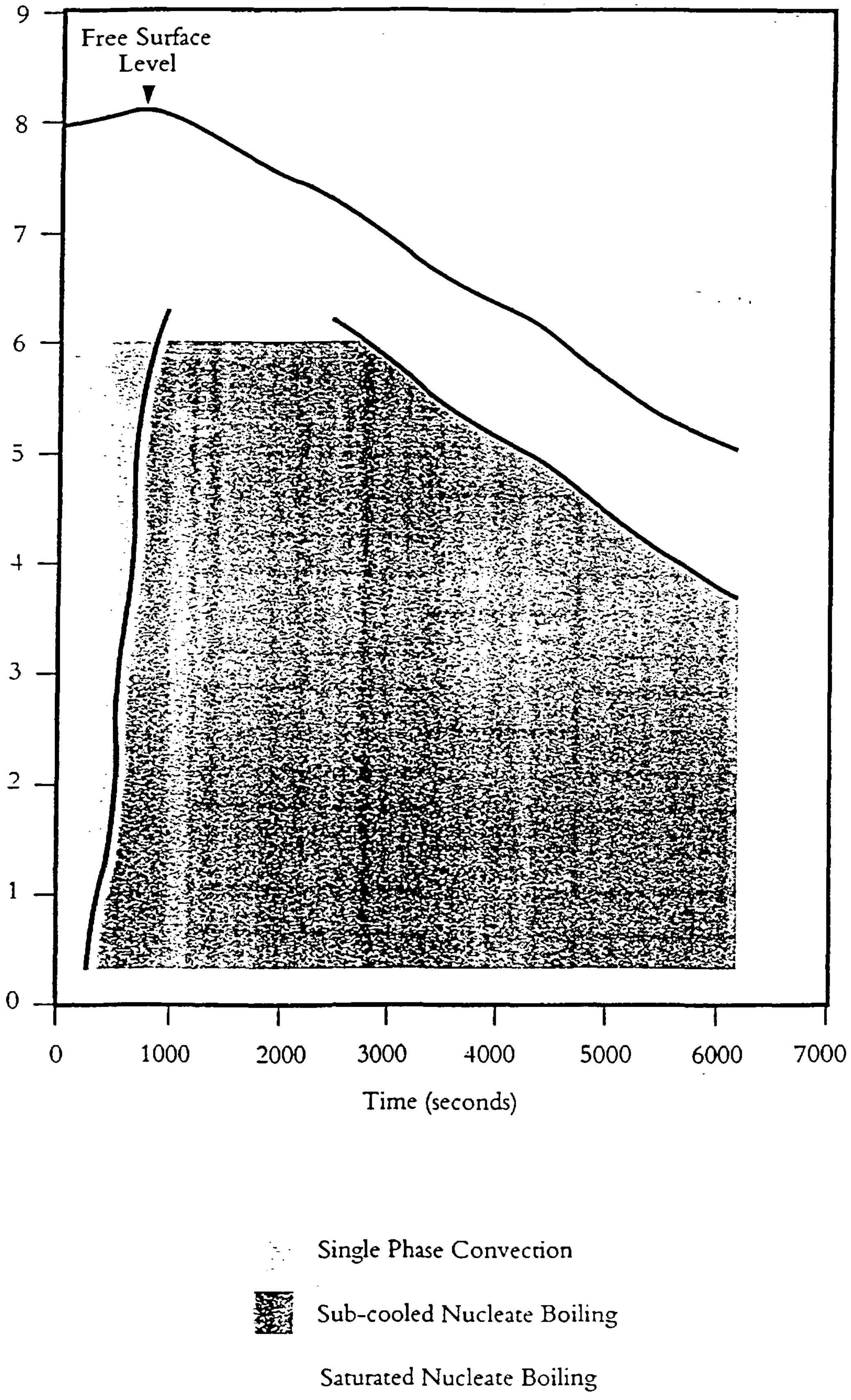


Figure 26 Heat Transfer Modes in Pool: AP600 Pool Simulation

Conclusions for Pool Modelling

- Relatively good predictions of the heat transfer can be obtained for a two column pool model.
- Internal flow/mixing losses must be estimated and included empirically in model.
- Stable initial conditions are difficult to achieve without including additional components, e.g, level controls, flow circulation etc, which can be isolated for the transient calculation.

Summary

- For intact circuit faults, thermosyphon loops appear to be effective even under two phase flow conditions but systems codes are not validated.
- Experimental Data are sparse and plant specific, many particularly APWR related are proprietary. There are common phenomena across ALWRs.
- System codes do not treat condenser pools adequately. Thermal mixing, noncondensable and 3D effects not modelled well. System codes should be benchmarked against validated CFD codes.
- Primary Circuit / Containment Coupling important. Integrated Code capability must be developed. (RELAP / CONTAIN?) .

94/96 Programme

Containment

Examine containment designs

- Double Concrete Containment
- Steel Containment

94/96 PROGRAMME (Continued)

Containment Heat Removal (Internal to External)

- To carry out analysis of selective ENEL data to improve understanding of compact heat exchangers and to validate predictive tools (eg. CFD codes)

- To benchmark an appropriate system code that includes primary circuit/containment feedbacks (eg RELAP/CONTAIN)

- To carry out in-depth analysis of the systems performance with respect to the licensing issues. Confirm/deny the conclusions from the preliminary 93/94 study.

- To consider implications of steel/concrete containment shells

Double Concrete Containments

European Licensing Requirements:-

- Double concrete containment, proposed by ENEL, rather than steel
  (Karlsruhe Workshop paper)

- Use of compact heat exchangers with non-condensable gases and steam natural circulation to remove heat

- AEA is collaborating with ENEL/ANSALDO

- AEA will do analysis
  1. to check flow paths and heat exchanger performance, and
  2. to validate codes.

- CISE experiments provide data

- CFD codes envisaged for analysis

94/96 PROGRAMME (Continued)

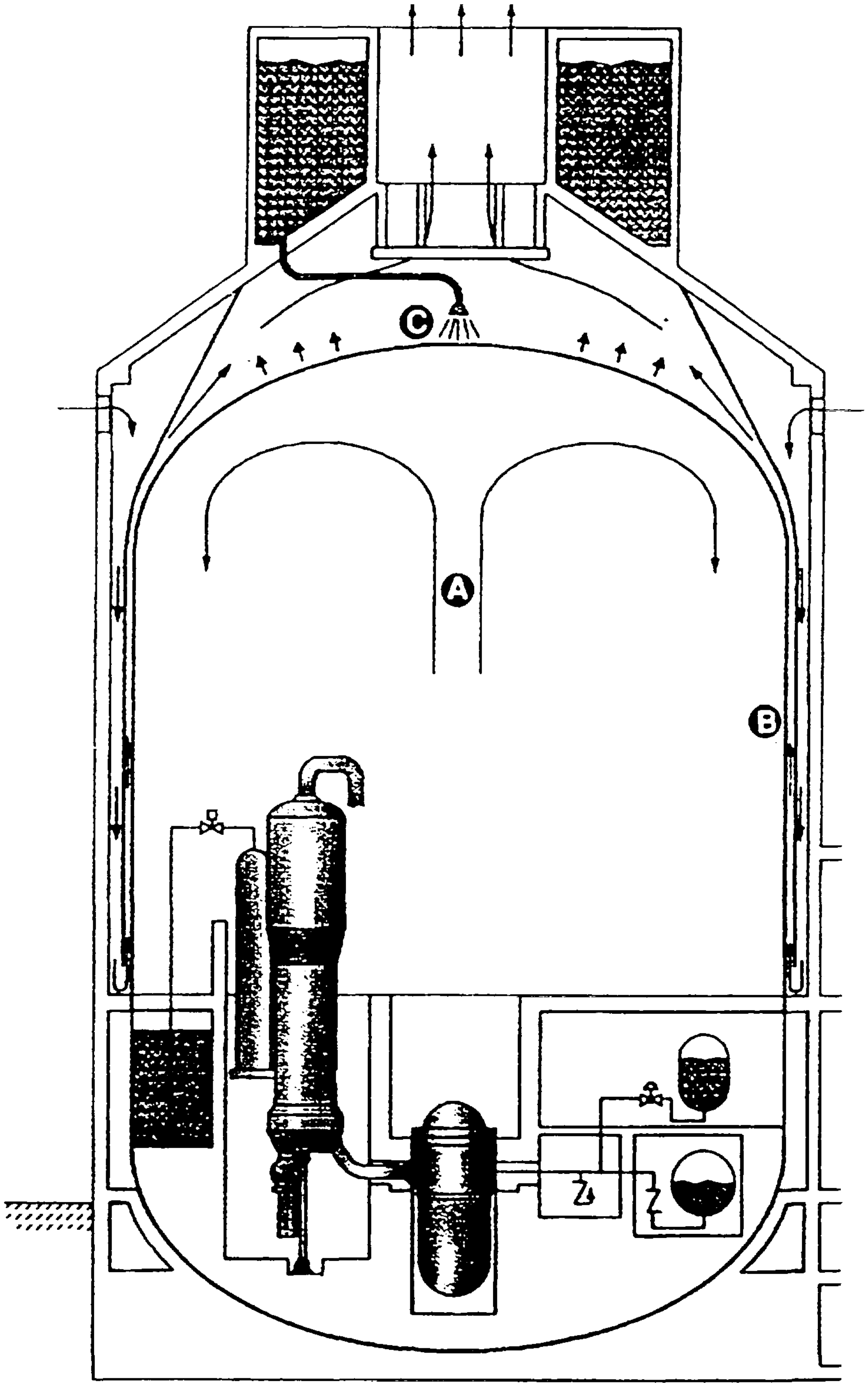
Ultimate Heat Sink

- To acquire new data and develop new models (if necessary) for heat transfer from University of Manchester experiments.
- To benchmark an appropriate computer code (eg CFD code) against these data/models
- To assess the reliability of containment external air cooled heat removal systems to initiate and their capacity to remove decay heat.

STEEL CONTAINMENT

Design

- AP600 includes vented annulus on outside of containment to enhance heat loss to environment.
- Outside of containment is water cooled.



In the AP600 passive containment cooling system, internal condensation and natural circulation transfer heat from the core to the steel containment (A). The containment is continuously cooled by natural circulation of air between the containment vessel and surrounding shield building (B). Initially, containment cooling is enhanced by releasing water from tanks above the containment (C).

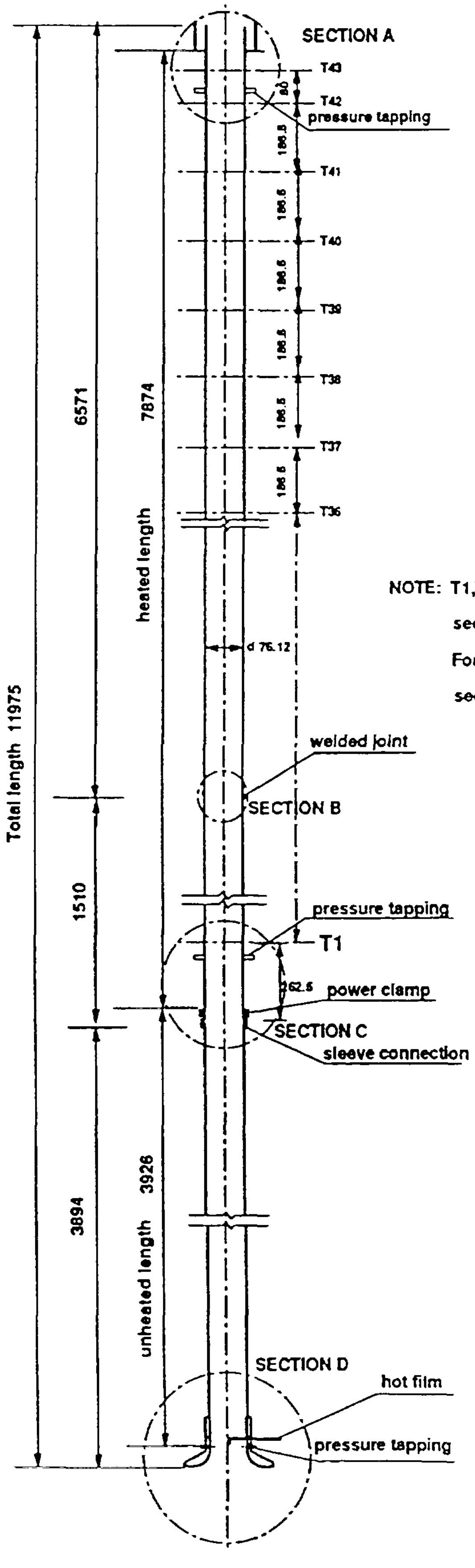
Experimental Study of Heat Transfer to Air in a Heated Pipe

Background

- Manchester University experiments show degraded heat transfer in upward buoyancy driven air flow in a long pipe.
  (J.Li. Ph. D. Thesis. University of Manchester 1994)

Current experimental programme.

- Extend experiments to include heat transfer with a water film falling in the pipe.
  (Funded by DTI)



NOTE: T1,T2, ... T43 - thermocouple positions,
see thermocouple arrangement.
For detailed arrangement in Section A, B, C, D,
see individual figures for these sections.

Unit: mm

Fig.3.2 Test section arrangement

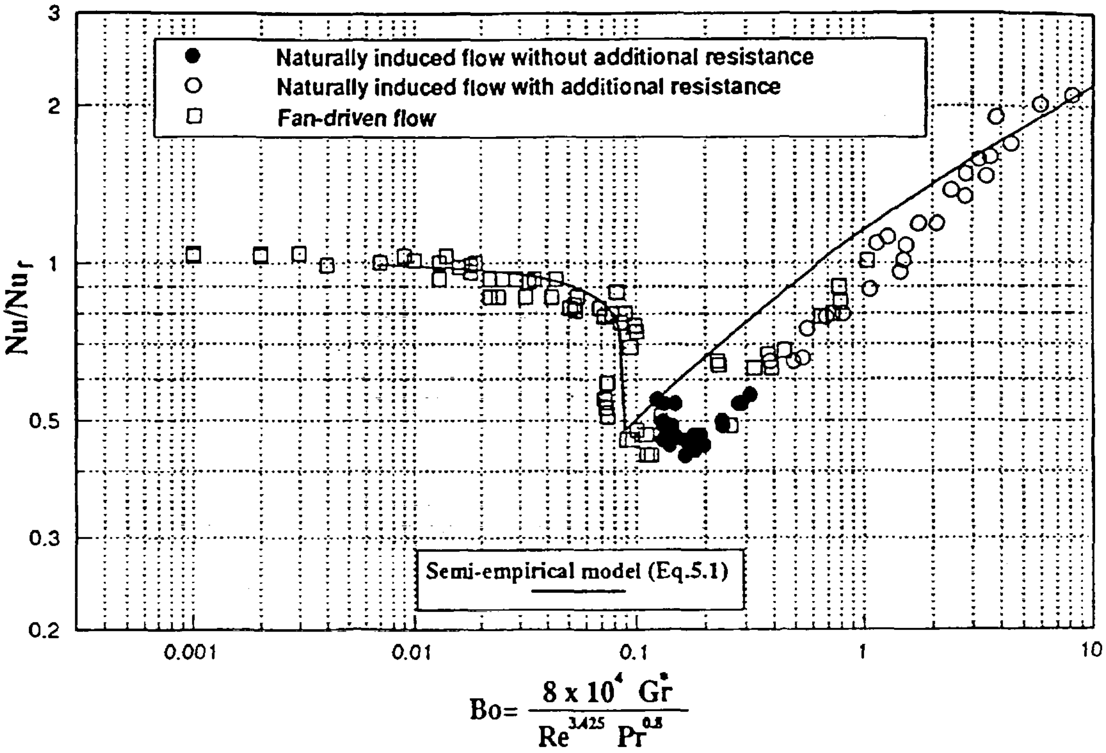


Fig.6.5 Upward flow mixed convection heat transfer for x/D=70.7 (with an unheated development section)

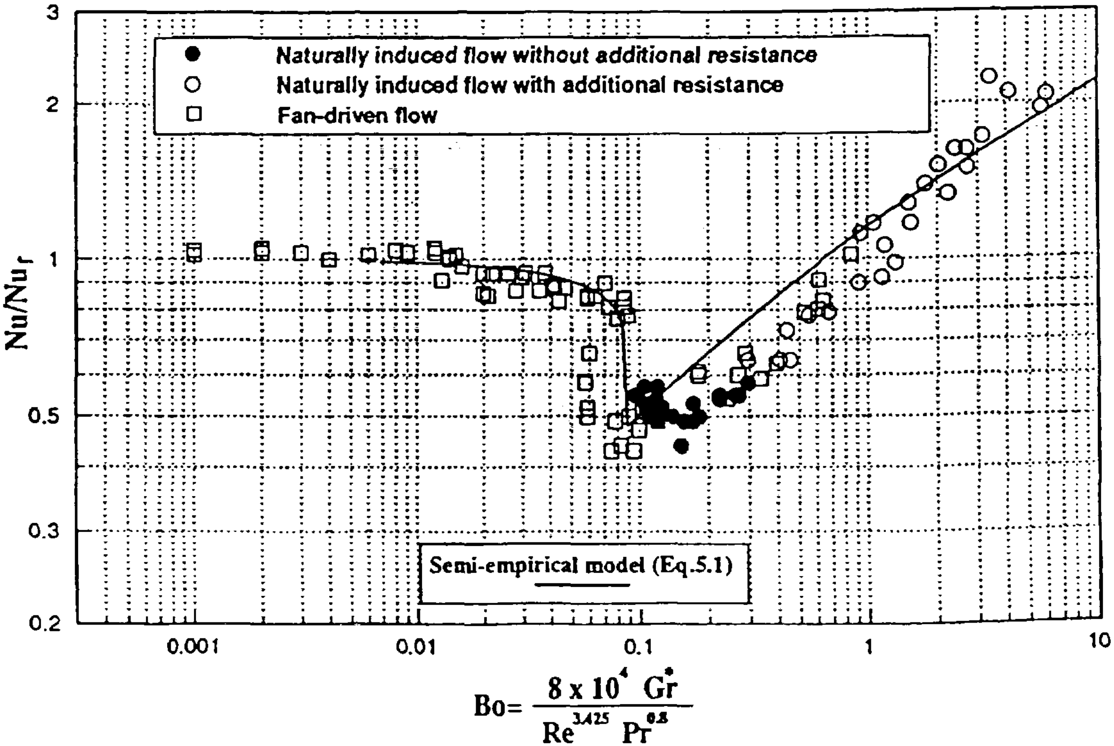


Fig.6.6 Upward flow mixed convection heat transfer for x/D=90.3 (with an unheated development section)

SUMMARY OF CURRENT AND FUTURE WORK PROGRAMME

Main aims are to:

- Address Generic Safety and Licensing Issues (not for specific design)
- Assess Passive Decay Heat Removal Systems
    - Primary Circuit
    - Passive Containment Cooling
    - Passive ECCS
- Demonstrate a Justified Analysis Capability
- Demonstrate Adequacy of Experimental Data-Base
- Continue European Collaboration (CEC 4th Framework?)