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CANDU 600 PRIMARY HEAT TRANSPORT SYSTEM THERMALHYDRAULIC COMMISSIONING

by

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SUMMARY

In this paper, the Primary Heat Transport System thermalhydraulic commissioning program and related computer code tuning for CANDU 600's is reviewed. This entails using the site data gathered during commissioning to "tune" or "lock-on" large predictive computer codes. Such tuning enables these codes to become site-specific codes, to allow more accurate predictions of the primary and some secondary side system performance.

The overall methodology of the program, concentrating on a rational and systematic procedure for code tuning, is described. The reactor instrumentation, data acquisition systems, and the data analyses programs are reviewed. Developments in tuning the steady-state code NUCIRC and the transient code SOPHT are also presented.

Finally, a summary of the results of this program to date and its usefulness to channel flow verification, CCP re-assessment and ROPT setpoints, stability commissioning, and reactor power calibration is noted.

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1.0 INTRODUCTION

Present licensing criteria and commissioning practice, require that during commissioning of CANDU reactors certain process measurements be obtained. These site-measured data are then used to tune process computer codes and thereby obtain the most accurate and up-to-date computer predictions (i.e. "best estimates") for reactor thermalhydraulic conditions.

These best estimate computer code predictions are used in channel flow verification studies, Critical Channel Power (CCP) assessments, for establishing Regional Overpower Trip (ROPT) set-points, reactor thermalhydraulic stability analyses, and for reactor power calibration.

Site data are being obtained at CANDU 600 MW stations with the co-operation of the utilities. The most extensive data are being obtained from Pt. Lepreau (New Brunswick Electric Power Commission), and G-2 (Hydro Quebec), with lesser amounts of data from overseas sites; Wolsung (Korea) and Cordoba (Argentina). Ontario Hydro is also performing some similar measurements, such as channel flow surveys and moderator flow measurements at Pickering-B and Bruce-B, and stability tests at Bruce-A.

The following is a brief description of the work performed by AECL CANDU Operations and the utilities for CANDU 600 MW Primary Heat Transport System thermalhydraulic commissioning.

2.0 DATA ACQUISITION

Figure 1 is a schematic of the CANDU 600 Primary Heat Transport (PHT) system, showing the two figure-of-eight loops, pumps, headers, steam generators and Reactor Outlet Interconnect (ROI) lines.

The ROI is designed to remove any instability in the PHT system (i.e. pressure, and flow oscillations) that could be caused by two-phase flow phenomena (i.e. steam quality) in the outlet headers. It should be noted that all CANDU 600's have this feature, but that the interconnect lines have been blanked off at Pt. Lepreau.

2.1 Site Instrumentation

Indicated on Figure 1, are the locations where pressures, temperatures, and flows are measured. Most parameters are measured using existing process instrumentation.

Pressures are measured using capacitance-type absolute and differential pressure cells. Absolute pressures are measured at the reactor headers and pump suction, and differental pressures are measured across pumps, outlet headers, inlet-to-outlet headers, and across the reactor outlet interconnect lines and orifices (when the interconnect is functional).

Temperatures are measured using platinum Resistance Temperature Detectors (RTD's). Temperatures are measured at the inlet and outlet headers, and on each outlet feeder pipe. Differential temperatures are measured across the inlet-to-outlet headers.

Each of the 380 feeder flows were measured during zero power cold commissioning by using ultrasonic flow meters. At reactor power conditions, 12 channels instrumented with orifice meters are monitored to record the flows in these channels.

At the steam generators, some secondary side data are also measured. These include steam pressures, steam flows (via elbow taps), steam drum levels, blowdown flows, feedwater and reheater drains flows and temperatures. Feedwater flows have been measured using the installed venturimeters, and also by ultrasonic flowmetering.

Other parameters recorded include pump speeds, pressurizer pressure, temperature and level. A complete list of measured parameters is given in Table 1.

Approximately 500 parameters (380 of which are outlet feeder temperatures) may be recorded during steady-state plant operation using the existing site digital control computers.

For transient tests a data logger has been added to record approximately 50 parameters for steady-state "snap-shots" before and after transients, and about 16 parameters every 0.2 seconds during the transients.

2.2 Data Transmission and Processing

Figure 2 is a flowsheet showing how the data are transmitted and processed. Parameters are measured, and the instruments' analog output signals are sampled and digitized by the station computers (DCC's) and data logger. The digital data are processed through a PDP-11 minicomputer, the data then being transmitted via modem link to AECL's computers (CDC 6600, CYBER 720) to be stored temporarily in a computer file. Data from the data logger can also be telecopied to AECL, and miscellaneous data such as the ultrasonic feeder flow survey can be sent as hardcopy.

Figure 3 is a flowsheet which depicts how the data are transferred at AECL onto permanent computer files from the temporary holding file. The permanent computer file is in effect a data bank of CANDU 600 thermalhydraulic commissioning information. Temperature maps and a PHT system data summary table are reduced from the data. The PHTS summary table is structured to provide NUCIRC and SOPHT computer code programers with all the necessary input data to run computer simulations with the site data.

3.0 DATA ANALYSES

The zero power cold ultrasonic feeder flow measurements allowed the loop flows and total core flow to be determined by simple summation of the individual feeder flows. The individual feeder ultrasonic flow measurements are believed to be accurate to within 5%, and if there are no systematic errors, the loop flows are accurate to within 0.3%. Loop to loop flows agree to within 0.7%. Therefore, it is conservative assuming no systematic error, that the core flow measurements are accurate to within 1%.

Channel flow measurements are restricted to the 12 instrumented channels, for zero power hot, and for reactor powers above 0%, due to temperature limitations on present ultrasonic flow meters and inaccessability to piping once criticality is reached.

Nevertheless, core flows at power can be accurately determined by computer code predictions, and the accuracy of the predicted flows is demonstrated by comparison of the predicted and measured instrumented channel flows.

4.0 COMPUTER CODE TUNING

The steady-state thermalhydraulic computer code NUCIRC (NUclear CIRCuit), and the transient computer code SOPHT (Simulation Of PHT), are both used in the design and analyses of CANDU primary heat transport systems. In this work, it is necessary to tune each of these codes.

NUCIRC is tuned to obtain the steady-state pressures, temperatures, and flows measured at sites. NUCIRC can model each reactor channel for given header-to-header conditions. Header-to-header conditions can also be predicted by NUCIRC using 25 representative channels to model a half-core (i.e. one loop).

SOPHT is tuned to obtain the transient pressures, temperatures, and flows measured at sites. SOPHT generally uses a single channel representation for each pass through the core in a four-quadrant (i.e. two-loop) model. Therefore, it is necessary to determine the average core flow/power characteristic using NUCIRC, and then model the SOPHT single channels accordingly.

4.1 NUCIRC Code Tuning

NUCIRC is a design code, and as such, conservatism has been necessarily incorporated into its correlations (e.g. pressure drop, Critical Power Ratio CPR ≡ Critical Channel Power/Nominal Channel Power). The currently available commissioning data allows for removal of some of this conservatism.

At the outset, we established the ground rules that changes would only be made to the computer programs when the change could be supported by sound engineering practices; and when data clearly indicated that a change was necessary, and that the result of the change would be conservative from a CPR point of view.

A three stage tuning process for NUCIRC, utilizing all available data was employed as follows:

STAGE 1 - The overall core hydraulic resistance was adjusted.
- Some external circuit resistances were adjusted to achieve the correct flows and pressure distribution.
- Core resistances between the headers were re-adjusted to improve core flow distributions.

STAGE II- Adjust heat transfer correlations and models (e.g. an improved steam generator model is incorporated).

STAGE III-Predict onset of void (i.e. steam quality) in the outlet headers and compare to plant data. Discrepancies would require retuning or remodelling.

Adjustments made to NUCIRC include the following:

- an improved fuel pressure drop model
- lower inlet header to feeder entrance pressure loss factor
- lower orifice overall pressure drop
- revised pump head/flow characteristics
- improved steam generator pressure loss factors
- use of clean steam generator tubes.

The result of this tuning is that the core hydraulic resistance has been matched closely to site values. The external circuit hydraulics have been adjusted to yield core flows and header-to-header pressure drops within 0.5% of site measured values. At 100% full power conditions the tuned code predictions of header-to-header pressure drop and RIH temperature are within 0.5% of the previous design values. The tuned core flow is predicted to be 2% above the previous design value at full power conditions.

4.2 SOPHT Code Tuning

SOPHT code tuning is basically a four stage process that draws heavily on the code tuning experience with NUCIRC. These stages are as follows:

STAGE I - Incorporate the improved resistances and models found necessary in NUCIRC tuning.

STAGE II- Adjust heat transfer correlations and models.

STAGE III-Predict onset of void in the outlet headers and compare to plant data. Discrepancies would require retuning or remodelling.

STAGE IV- Perform dynamic simulations and compare with tests at site (e.g. pressurizer steam bleed valve opening to provide a system "kick") to determine system stability. Adjustments to the void-quality relationship or other retuning/remodelling may be required.

Results to date indicate that the onset of void occurs near 100% power, and only a few channels appear to have reached saturation temperatures. In order to obtain sufficient void in the outlet header for stability testing, provision has been made to lower the outlet header pressure at 100% full power.

5.0 APPLICATIONS

5.1 Channel Flow Verification

During cold flow commissioning, it is necessary to determine if any channels have restrictions which lower the flow. Ultrasonic flowmetering is performed to measure the flow in every channel. The measured flow in a channel is compared to NUCIRC flow predictions as well as to the measured flow in its "twin" channel. This procedure has been found to be well worth the effort. Channel flow restrictions caused from foreign objects left in the PHTS during construction (e.g. measuring tape, wire brush) have been detected and successfully removed.

5.2 CCP/ROPT Re-assessment

Critical Channel Powers, and Regional Overpower Trip set-points were re-assessed for CANDU 600's. A CCP analysis code based on a version of NUCIRC was being used for the CCP analysis at the same time that tuning of our NUCIRC version was underway. This provided an opportunity to incorporate the latest "best-estimates" of header-to-header conditions based on available site data for the CCP analysis. This work has been completed to the satisfaction of the Atomic Energy Control Board (AECB). A final iteration to re-assess ROPT margins will be done after 100% power data have been analyzed and NUCIRC tuning finalized.

5.3 PHTS Stability Commissioning

As described above, Primary Heat Transport System stability commissioning will be performed. SOPHT code tuning will result from analyses of the site transient data. The thrust of this work is to confirm if the ROI lines are necessary, and if required, to determine that ROI resistance is sufficient to dampen any instability. A further study will be to determine the effect of reactor aging (e.g. steam generator tube fouling, pressure tube creep) on PHTS stability.

5.4 Reactor Power Calibration

It is necessary to determine reactor power accurately. Reactor power may be determined from primary side flows and enthalpies, from secondary side flows and enthalpies, and from electrical power output. These power measurements should all balance. However, the commissioning experience to date is that different sites each appear to have different discrepancies between their power measurements. The accepted practice is to take the most conservative power measurement from a CCP point of view as being accurate. Unfortunately, this practice may unnecessarily penalize the station from operating more efficiently, if the conservative power measurement is wrong. We see resolution of station power discrepancies as having potential for high economic pay-back to the utilities. Together with utilities, we have already embarked on programs to resolve these questions.

5.5 NUCIRC and SOPHT as Operations Codes

SOPHT was originally written at Ontario Hydro to be an operations tool or nuclear steam supply system simulator. However, it has been also used extensively as a design tool and as a safety analysis tool. NUCIRC was written at AECL for use as a design tool only. We are now proposing that the tuned versions of NUCIRC and SOPHT could be used as accurate operations programs. The codes could be stripped down to allow them to be adapted to site computers, as many of the design related routines would be of no use in operations. The advantage would be that each station would have their own NUCIRC and SOPHT codes tuned to that station, and benchmarked to the present work.

6.0 SUMMARY

Site data are being obtained during commissioning at CANDU 600 MW stations. These data are being used to tune the design computer codes NUCIRC, and SOPHT. The tuned computer codes allow the most accurate and up-to-date predictions for reactor thermalhydraulic conditions.

These best estimate predictions are used in channel flow verification studies, CCP assessments, for establishing ROPT set-points, PHTS stability analyses, and for reactor power calibration.

Ultimately, these codes once fully tuned, and benchmarked could be used as operations programs.

TABLE 1: LIST OF MEASUREMENTS

SYSTEM COMPONENT	PARAMETER (Number of Measurements)
PHT ROH #1 #3 #5 #7	ROH Temperature (4)
PHT ROH #1 #3 #5 #7	ROH Pressure (4)
PHT RIH #2 #4 #6 #8	RIH Temperature (12)
PHT RIH #2 #4 #6 #8	RIH Pressure (4)
PHT RIH-ROH #2-#3 #4-#1 #6-#7 #8-#5	RIH-ROH Differential Temperature (12) RIH-ROH Differential Pressure (4)
PHT ROH-ROH #1-#3 #5-#7	ROH-ROH Differential Pressure (2)
PHT Pump P1 P2 P3 P4	Pump Suction Pressure (4) Pump Head (4) Pump RPM (4)
PHT Outlet Feeders	Outlet Feeder Temperature (380)
PHT Instrumented Channels	Channel Flowrate (12)
PIC Pump 1 Pump 2	Feed Pump Suction Pressure (2) Feed Pump Discharge Pressure (2) Feed Pump Discharge Temperature (2)
PIC Feed Flow	Feed Flowrate (1)
PIC Bleed Flow	Bleed Flowrate (2)
PIC D_2O Storage Tank	Level (1)

TABLE 1: LIST OF MEASUREMENTS (Cont'd)

SYSTEM COMPONENT	PARAMETER (Number of Measurements)
PIC Pressurizer	Pressure (1) Temperature (1) Level (1)
PIC Degasser Condenser	Pressure (1) Temperature (1) Level (1)
Steam Generators	Feedwater Temperature (4) Feedwater Flowrate (4) Steam Drum Pressure (4) Steam Flowrate (4) Steam Drum Level (4) Indicator For Blowdown (4) Reheater Drain Temperature (1) Reheater Drain Flowrate (1)
ROI Lines	Interconnect Orifice ΔP (4) ROH-ROH ΔP (2)
F/M Room	F/M Room Temperature (4)

TOTAL NUMBER OF MEASUREMENTS = 498

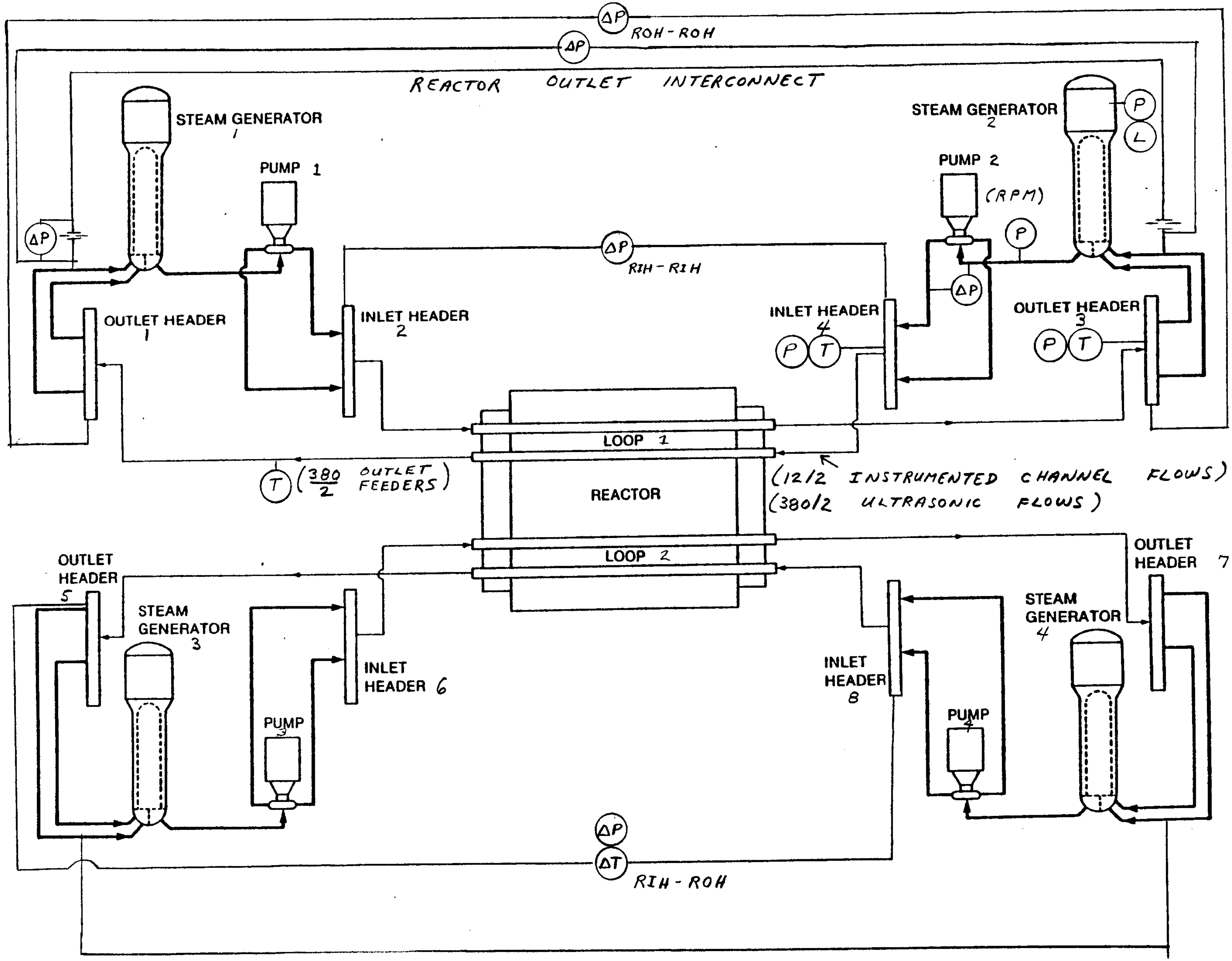

FIGURE 1.1 CANDU 600 PRIMARY HEAT TRANSPORT SYSTEM

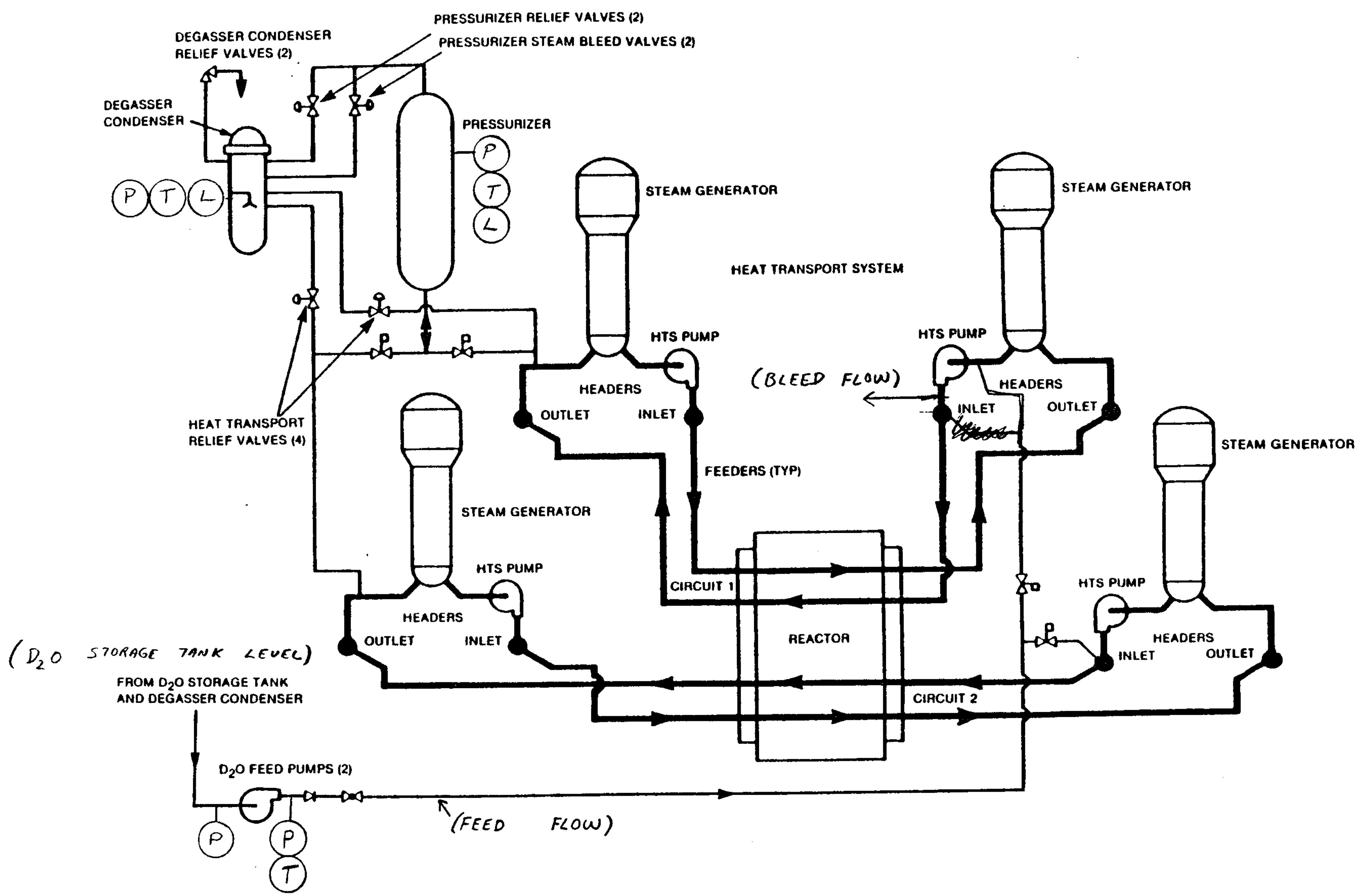

FIGURE 1.2 HEAT TRANSPORT PRESSURE AND INVENTORY CONTROL SYSTEM

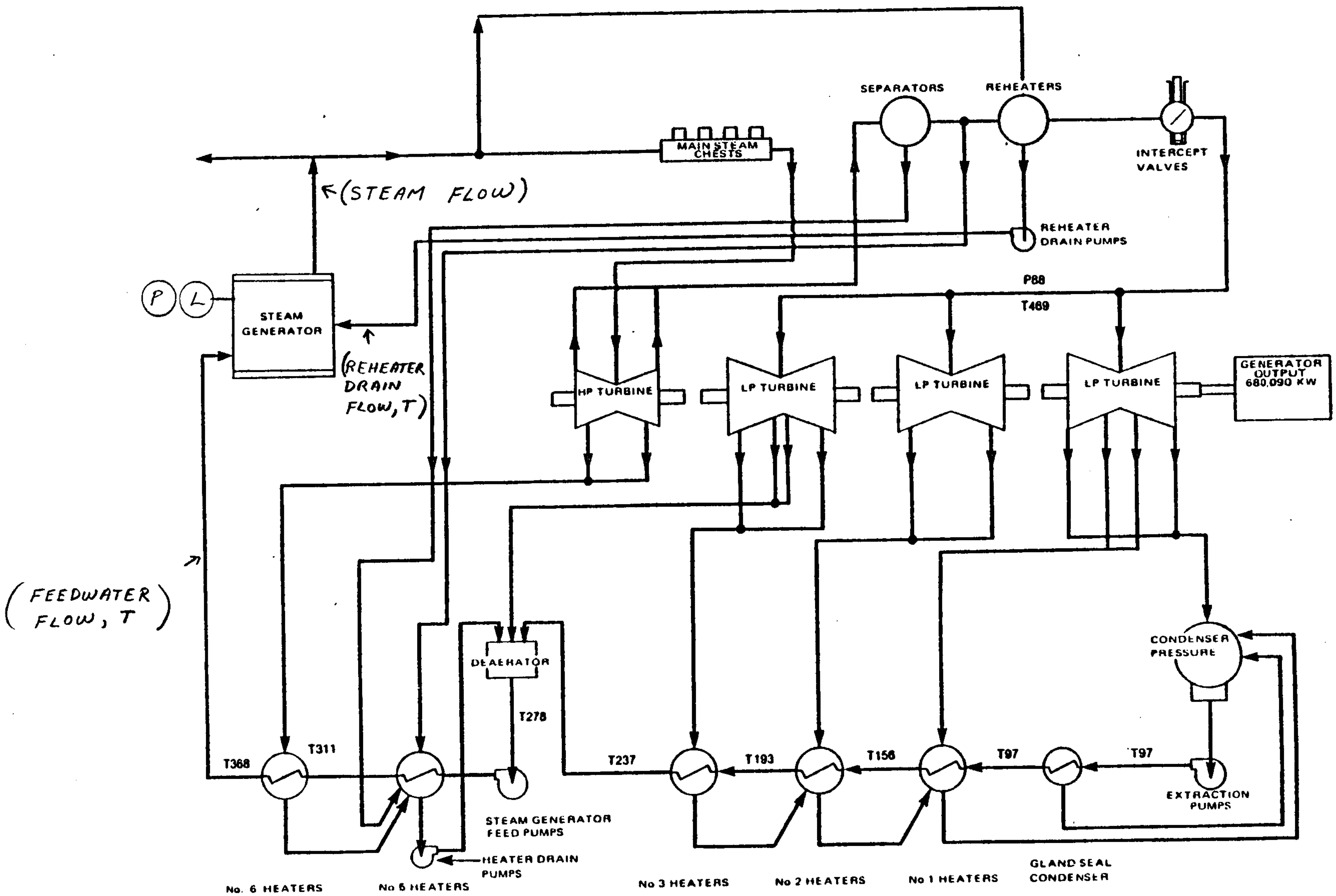

FIGURE 1.3 SECONDARY SIDE FLOW DIAGRAM

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FIGURE 2. DATA TRANSMISSION AND PROCESSING

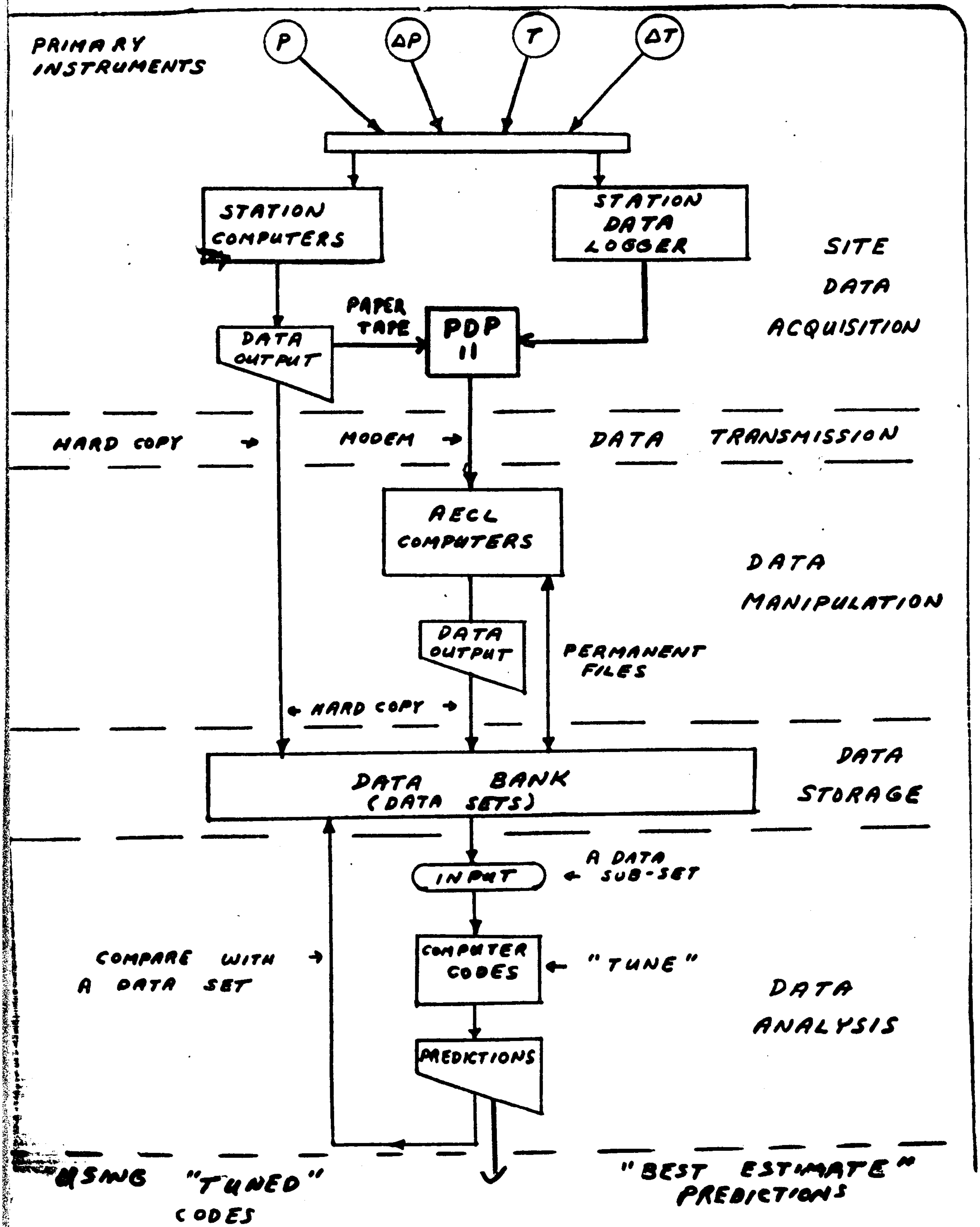

FIG. 3 AECL STORAGE AND PROCESSING OF STATION DATA