Chapter 7 The Design Process

This chapter describes, in a general sense, the process of Process Design. Emphasis has been placed on establishing the philosophy of the design in a more meaningful way. Specific topics discussed include: other groups that the process designer interfaces with, documentation, design tools, Quality Assurance and design evolution.

7.1 Introduction

The process or methodology used to design systems is evolving along with the evolution of the systems being designed. Herein, the more dominant and permanent features of the present process are outlined. Because the process involves the complete design, from first concept to resolving operating problems, the designer should be involved in all aspects to ensure a timely and meaningful resolution of existing problems and future designs. This dual requirement is the root of the conflicting demands on the designer's time:

solve today's problems while providing good future designs.

Evolving management philosophy, advances in regulatory and code requirements, advances in analysis and design capability and changing
design / operating requirements are some of the reasons why problems persist.

We can never hope to eliminate completely the future occurrence of such problems. But we can strive to reduce their probability of occurring or, failing that, their impact on our product. There are two general ways to proceed, perhaps in parallel:

(1) Establish improved design practices (i.e., avoid future problems by being more certain of what we design today).

(2) Design more margin into our new plants to yield a more robust design (less interdependence of critical systems and more margin to engineering limits) which will give a station design that is more tolerant to future perturbations.

The following is the interaction situation applicable to the process systems area. A similar principle should be applicable to other areas. There are three aspects of process system design:

1) <u>Process Methods</u> - for providing the methods and methodology to carry out the design process. This covers:

- identification and documentation of analysis concepts
- identification and documentation of design guides
- identification and documentation of design tools
- tool design, development and benchmark verification

- training other staff in methods.

2) Process Development - for ensuring that the application of these methods is appropriate. This covers:

   - identifying the specific correlations to use for heat transfer and pressure drop calculations
   - coordinating lab testing that is needed to improve the design
   - interpreting feedback from sites (tests plus commissioning).

3) Process Design - (Heat Transport Systems, Safety Systems, Moderator Systems, Heat Exchanger, Pressure Vessels, Rotating Machinery, etc.) - responsible for carrying out the design; i.e., the production aspects. Figures 7.1 and 7.2 illustrate the interaction of these three aspects.

Problems and new ideas can and will arise from any area. Each task has to be assessed on its own merits and a plan laid out at that time as a function of the schedule, the task and the resources (including manpower and talents).

The concept stage involves the establishment of the main ground rules for the design. These include:

1) Seismic basis;
2) Codes and Standards, regulations;
3) Power required;
4) Man rem and reliability targets;
5) Degree of standardization and extent of generic basis.

The optimization stage includes consideration of:

1) Broad brush treatment of thermalhydraulics;
2) Economic equations;
3) Engineering constraints

   a) velocity,
   b) critical power rates,
   c) Heat Transport System (HTS) quality, X,
   d) pressure tube thickness,
   e) fuel burnup,
   f) physical dimensions,
   g) pressures,
   h) temperatures,
   i) manufacturing limits.

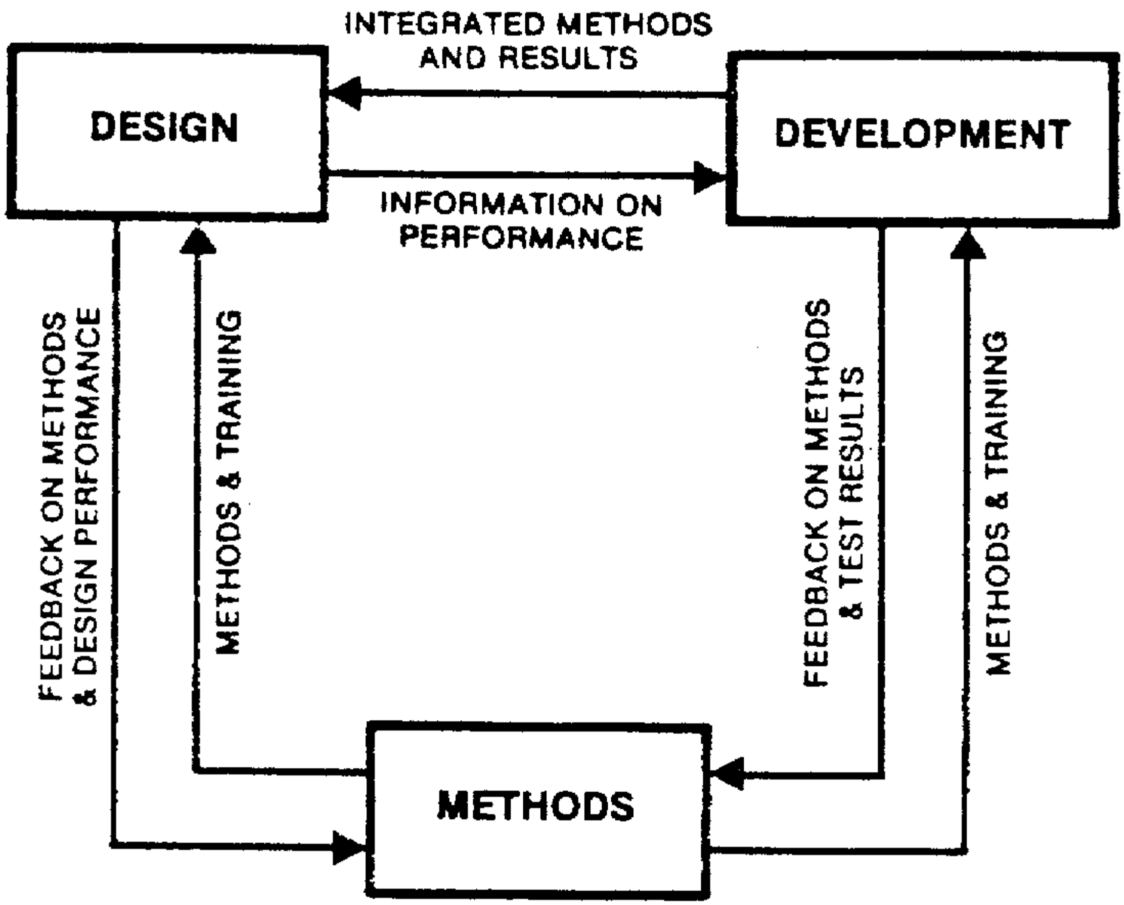

Figure 7.1 General interaction process

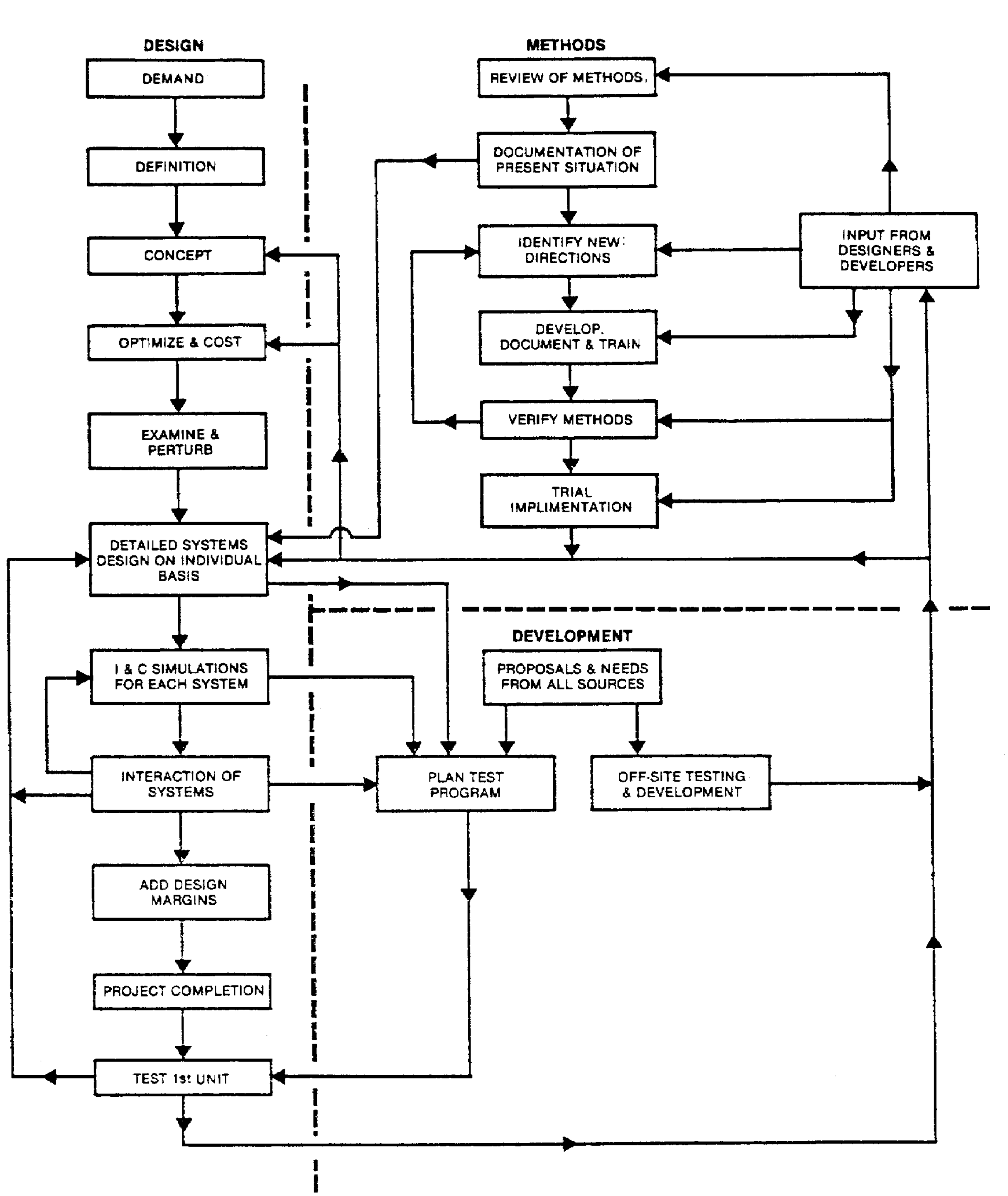

Figure 7.2 Details of the interaction process

7.2 Interaction with other Groups

There are eleven main groups that the process designer interacts with:

1) other designers,
2) manufacturers,
3) project teams,
4) clients
5) regulatory groups,
6) commissioning teams,
7) operations,
8) analysis support teams,
9) laboratories,
10) quality assurance,
11) balance of plant.

Other design groups include:

1) reactor physics,
2) thermalhydraulics (safety aspects),
3) layout,
4) piping and stresses,
5) instrumentation and control,
6) fuelling machine,
7) other process system designers,
8) component designers,
9) structures (civil).

The reactor physics groups are concerned mainly with core design. One of the main interfaces between the PHT process system designer and the core designer is the void-reactivity and temperature-reactivity feedback to the core. That is, the void fraction and temperature of the coolant in the core affects the dynamic parameter of the core, reactivity. The core designer will also be interested in the moderator temperature and thus will interact with the moderator process designer.

The groups dealing with thermalhydraulic aspects of safety primarily need to know what the physical characteristics of the system are before they can carry out the safety analysis. These analyses centre on pipe breaks and loss of heat sink which jeopardize heat removal from the core. The primary heat transport system is, naturally enough, the centre of attention. Detailed fault trees or Safety Design Matrices (SDM's) dictate the analysis to be done. Other process systems are naturally involved. For instance, the moderator can act as a heat sink and for some stations is an integral part of the shutdown safety system.

The layout groups, as the name implies, resolve the many tradeoffs required to achieve an economical layout with due consideration given to maintenance and man rem. The task is not at all trivial considering the complex nature of CANDU with many systems for power production (process, nuclear core, secondary side, pressure and inventory control, instrumentation and control, alternate heat sinks, etc.). Thus the layout groups require the physical dimensions and weights of the process system.

The piping and stress groups ensure integrity of the process system boundaries (pipes). Naturally, these groups require knowledge of the pressures, temperatures and flows under steady and transient conditions as input to their design work.

Instrumentation and control (I & C) groups naturally need to know the characteristics of the systems they control. Full process simulations or simplified versions are used, depending on the need of the I & C designer.

The fuelling machine designer needs the thermalhydraulic characteristics of the primary heat transport system at the point of interface: the endfitting. Fuelling machine injection flow, and hydraulic ram design are items of interaction between the process and machine designers.

Other process systems of interest to the HTS designer are:

1) Moderator,
2) Shutdown Cooling,
3) Pressure and Inventory Control,
4) Endshield Cooling,
5) Purification.

Component designers include:

1) Pumps,
2) Valves
3) Heat exchangers (including steam generators),
4) Pressure tubes,
5) Endfittings,
6) Vessels (such as pressurizers).

Finally there are the civil designers who provide the structures to support the components and systems.

All of the above design groups must interface to settle on a design suitable from all design points of view. To some extent, the process optimization code, AESOP, deals with this process of arriving at a suitable design. It is merely the starting point, however, for interaction between groups. Heavy reliance is placed on past practise and generic or repeatable design features. Standardization to some degree is essential since economics do not permit a design from scratch for each design. The concept of utilizing proven components is central to a stable advancement on the learning curve of process design. Controlled innovation and advancement is the governing philosophy.

Interaction with manufacturers (of pumps, heat exchangers, etc.) is essential for proper process design. Because of knowledge already gained from interaction with the manufacturer, it is usually not necessary to contact the manufacturer during the conceptual and optimization stages. Once the broad brush thermalhydraulics has been established, then the manufacturers are involved to some degree. Full involvement usually does not occur until the call for tenders.

Process designers are usually in contact with project teams on a continual basis from the time after a detailed design is completed (with the issue of the design description) to the completion of project work. The project team ensures the successful implementation of the design.

Client interaction occurs throughout the life cycle of a plant, starting with the demand or need for a station. Interaction usually centres around meeting their requirements for a timely and adequate design. Some involvement is required for training and analysis liaison. If the client has a large technical staff, this second involvement dominates, usually because the client assumes responsibility for some systems.

Regulatory groups include the Atomic Energy Control Board, MCCR, or other provincial regulators of non-nuclear aspects of mechanical design. Interaction with commissioning teams is required for the feedback to the designer and for the feedforward to the adequate commissioning of a station.

Operational feedback is another essential source of design information. In addition, operational problems are often resolved with the help of the designer through design modification or analysis clarification.

The designer is usually in close contact with analysis support teams which include outside computer and computer code support teams as well as in-house analysts and computer codes. For the process designer, the process equations involved are invariably a derivative of the equations discussed in part 2 of this course.

Laboratories provide the designer with essential information on fundamental elements of the process design. Topics range from valve capacity certification to verification of fundamental equations.

Quality Assurance (Q/A) teams provide in-house verification of the design process in its totality through the process of design reviews, guidelines and procedures and, to some extent, training and information liaison. Although programs provide essential overviews and coordination of the assurance of quality, the fundamental responsibility for quality lies with the designer.

Since AECL does not handle the balance of plant (non-nuclear components), it is necessary to interact with the balance of plant (BOP) supplier which could be a consulting firm such as CANATOM, or a client, such as Ontario Hydro.

This brief discussion of the groups that the designer interacts with, illustrates the complexity of the design process. Interaction with any or all occurs at each stage of the process. This makes for a highly dynamic process. The dynamics of the process cannot be preordained as in a computer program. Required are individuals who have knowledge of, and wisdom in the ways of, the design process so that they can act appropriately as the need dictates.

7.3 Design Documents

Proper documentation is a key element of the design process. Without it the growth along the learning curve is severely hampered. It provides some degree of insulation from staff turn-over and some measure of continuity and evolution. Since many people are involved in the development of a CANDU station, adequate documentation is required to span the space and time inherent in the design process and beyond. Quality Assurance guidelines and the regulatory bodies require it, as do other groups which require design documentation as the building block for their work. The documentation list includes:

1) Design Requirements (DR),
2) Design Description (DD),
3) Station Data Manuals,
4) Design Manuals (DM),
5) Safety Reports,
6) Technical Descriptions (TD),
7) Generic Design Deviations (GDD),
8) Supporting memos, design calculations, studies & reports,
9) Commissioning Procedures,
10) Equipment Dockets.

The Design Requirement is a statement of just that. No attempt is made at any description of the design details, but invariably the requirements are written with the system history in mind. The Design Description gives the details of the final design. There is no legal requirement at present for a single document covering the design philosophy or methodology, although such documentation is necessary. At present, supporting memos, design calculations, studies, design guides and reports plus generic design deviations provide this philosophy.

The Station Data Manual provides a convenient listing of key data on the system. The DR, DD and Data Manual are the main documents handed over to Project Engineering by the system designers. The Project team then combines these to form the Design Manual.

Technical Descriptions are comprehensive reports written by the designer for prospective clients. Safety Reports are provided by the safety groups, while commissioning procedures are provided by the projects, both with support from the designer. Life cycle equipment dockets are maintained at the site by the site owner.

7.4 Design Tools - Overview

The optimization code used is AESOP (formerly CAP73). From this code, the first cut at PHT conditions is obtained (See figure 7.3). Applying engineering judgement, these first estimates are modified in a search for a more practical set of design conditions. AESOP can be used in a perturbation mode to assess these altered conditions from the point of view of economic feasibility. During these stages, considerable consultation with most of the groups of Section 7.2 takes place to ensure design feasibility. The extent of consultation depends, naturally enough, on the degree of deviation from past design. With this phase completed, detailed calculations can begin.

The computer codes, SOPHT, NUCIRC, and BOILER are presently used for detailed design calculations. Prior to SOPHT, an AECL acquisition from Ontario Hydro, the code HYDNA was used. From the preliminary feeder layout and process conditions, the Reactor Inlet Header to Reactor Outlet Header pressure drop, $\Delta P_{H-H,}$ can be estimated using NUCIRC for the channel with the worst flow, power and resistance combination from a pressure drop point of view. From this $\Delta P_{H-H,}$ the other feeders can be sized. BOILER is used, in parallel, to estimate the heat transfer area or heat transfer performance of the steam generators given inlet enthalpy and pressure from AESOP (or more precise updates from NUCIRC). The system geometry is given to the full circuit version of NUCIRC for a steady state simulation of the primary heat transport system. Refined estimates of pump head and flow requirements are usually made at this stage. Alternatively, the steady state version of SOPHT can be used. SOPHT is also used in the transient version with preliminary control systems to analyze transient behaviour. The whole process is iterative, with engineering judgement supplied throughout to guide the analysis.

Typical output from AESOP is:

1) Thermal core power or heat transferred to the coolant, Q;
2) Shape factors for the radial core power and coolant flow, β_p and β_f (average to maximum, typically ~0.85);
3) Maximum channel flow (typically ~25 kg/s based on a limit of 10 m/s);
4) Critical Power Ratio;
5) Reactor Outlet Header (ROH) quality (typically 4% or less);
6) Number of fuel channels;
7) Fuel channel length;
8) ROH Pressure;
9) Reactor Inlet Header (RIH) Temperature;
10) Rought estimates of ΔP_{H-H}, heat losses, etc.

These data input to SOPHT, NUCIRC and BOILER allow the detailed calculations to proceed.

NUCIRC is used to size feeders according to a selection among criteria of constant enthalpy at the ROH, constant critical power ratio (CPR) in each channel, constant channel flow or some variant of these criteria. Feeder sizing is done ensuring parallel channel flow stability. Interaction with the stress analyst and layout groups ensure feasibility of design. Figure 7.4 gives an indication of the degrees of interaction generally required.

SOPHT is generally used in the steady state to give overall circuit pressure, temperature and quality profiles and in the transient mode for transients such as:

1) Reactor Trip
2) Turbine Trip
3) Class IV Power Failure
4) Stepback
5) Power Manoeuvring
6) Rapid Cooldown

and other transients. These transients have a two-fold purpose: as input for stress analysis and to assess performance to ensure adequate net positive suction head (NPSH) for the PHT pumps, sizing of surge lines and other process design needs.

7.5 Quality Assurance

Quality is the essence of good design and is the responsibility of the individual. As such, quality cannot be split off from the design process; it is the design process. However, some measure of assurance of quality is attained by specific guides, as follows.

Quality in all phases of a nuclear power plant from concept to operation has always been recognized as a requirement. In recent years, a more formalized approach has been necessary. This had its beginnings in the manufacturing industries and we now have a series of four standards (CSA Z299 series) for the quality assurance of manufacture of nuclear equipment. Other standards are being initiated under the CSA N286 series. They consist of:

CSA N286.0 General Requirements for Q/A of Nuclear Power Plants
N286.1 Q/A of Procurement
N286.2 Q/A of Design
N286.3 Q/A of Construction & Installation
N286.4 Q/A of Commissioning
N286.5 Q/A of Operation
N286.6 Q/A of Decommissioning.

As required by the N286.2 Design Quality Assurance Standard and the current AECL Quality Assurance Manual, it is AECL's policy to establish and implement Design Verification programs for all work. Ontario Hydro and other utilities also adhere to these or similar standards.

Design Verification is the confirmation that design meets specified requirements. It is the responsibility of each designer to obtain appropriate design verification, and to file evidence of the verification in Section 290 of the Technical Documentation System. Design verification is good engineering practice. The Design Verification Branch in the Engineering Quality Assurance Department, Design and Development Division monitors and coordinates design verification programs and helps to ensure that overall project design verification requirements are met.

However, standards by themselves are not sufficient. There must be an attitude which recognizes the necessity and importance of Q/A by all those who must comply by these standards. With the proper attitude, there will come commitment, and with commitment, quality will result. There is the danger, already voiced by many, that we are being swamped by paper and bureaucracy in our Q/A programs. It is clear we must show common sense in minimizing the paper and bureaucracy while retaining the quality.

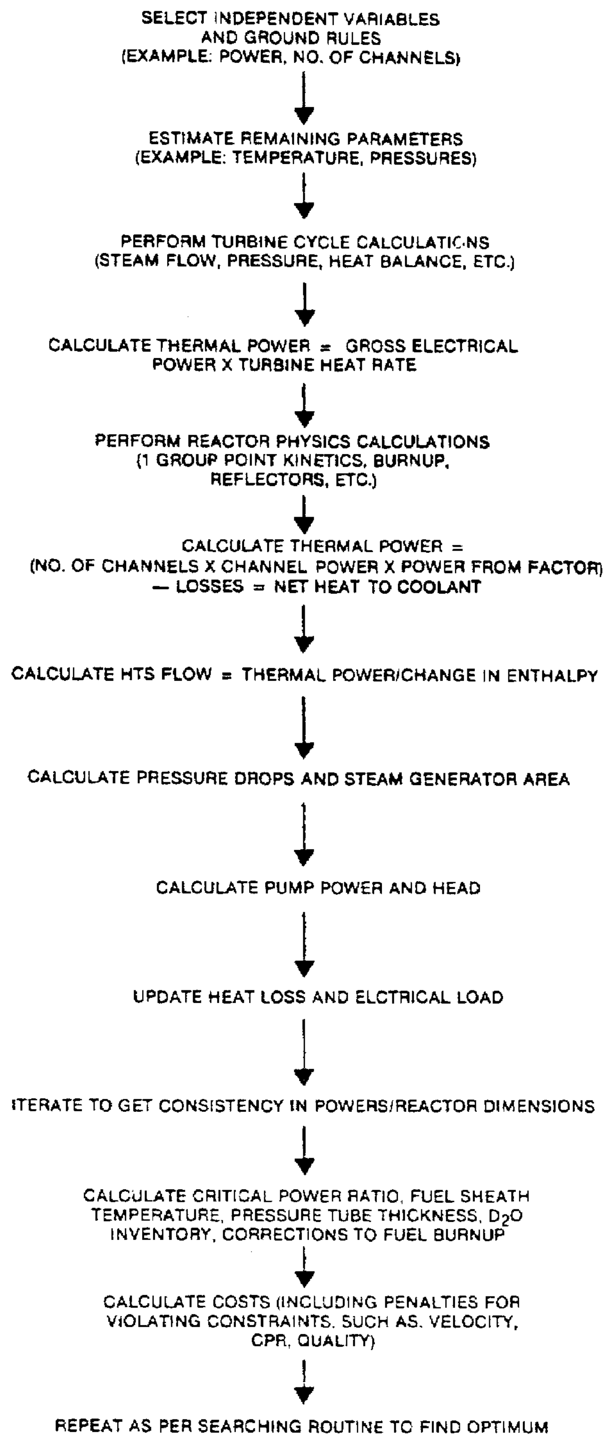

Figure 7.3 Optimization Scheme

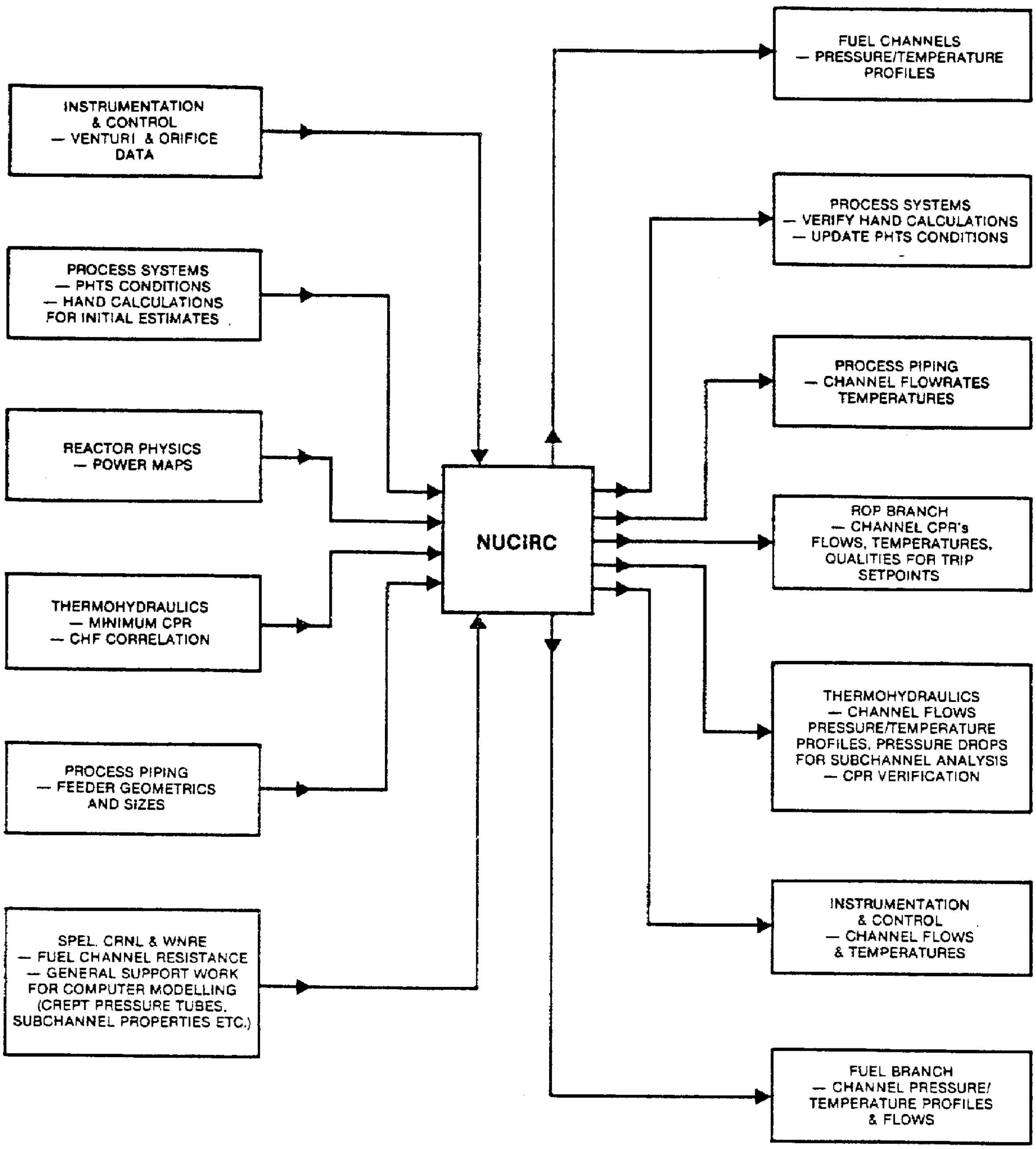

Figure 7.4 NUCIRC interaction