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L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

R&D IN CONTROL, INSTRUMENTATION, AND ELECTRONIC SYSTEMS AT CRNL

R&D pour le contrôle, l'instrumentation et les systèmes électroniques à Chalk River

E.O. MOECK, A.J. STIRLING and G. YAN

Chalk River Nuclear Laboratories Laboratoires nucléaires de Chalk River

Chalk River, Ontario

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Résumé

Les recherches et développements pour le contrôle, l'instrumentation et l'électronique concourent au perfectionnement de la conception des centrales nucléaires CANDU et aux travaux de R&D des Laboratoires nucléaires de Chalk River. Les programmes en voie de réalisation dans ces domaines sont décrits dans ce rapport. De nombreuses études ont pour but de répondre à un besoin d'amélioration de la performance des centrales nucléaires CANDU soit par l'accroissement de la capacité des centrales, soit par l'application des technologies et des idées nouvelles afin d'obtenir des systèmes améliorés et moins coûteux. Certaines études, comme le développement de transducteurs de pression en réacteur pour les essais de combustible doivent être achevés en quelques mois. D'autres études, comme par exemple celles touchant les instruments relatifs aux pertes de vapeur d'eau lourde peuvent rester en phase de développement au laboratoire au cours d'une année ou deux. Les développements plus complexes concernant par exemple les contrôleurs multivariables, les systèmes de sécurité informatisés et les détecteurs avancés de neutrons peuvent se poursuivre pendant plus de quatre ou cinq ans. Ce délai s'applique également à la conception et à la réalisation de nouveaux systèmes de sécurité et de contrôle pour le réacteur de recherche NRU. D'autres projets nécessiteront plus de cinq ans pour devenir pleinement opérationnels. Les nouveaux systèmes pour la détection et la localisation du combustible défectueux et le réseau complet d'information avec données réparties, pouvant s'appliquer aux centrales nucléaires de l'avenir, entrent dans cette catégorie.

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ABSTRACT

Research and development in control, instrumentation, and electronics is part of the refinement of the CANDU power plant design and of the R&D work at the Chalk River Nuclear Laboratories. The programs presently being carried out in these areas are described in this report. Many of these projects originated in response to a potential for performance improvements in CANDU power plants and are aimed at extending plant capabilities and applying new technology and ideas to achieve better and less expensive systems. Some of these projects such as the development of in-reactor pressure transducers for fuel testing are to be completed in a matter of months. Others, for example heavy water vapor loss instruments, will have gone through the laboratory development phase within a year or two. More sophisticated developments such as multivariable controllers, computer-based safety systems, and advanced neutron detectors will continue over 4 or 5 years. This time scale also applies to the design and implementation of new control and safety systems for the NRU research reactor. Still others will require more than 5 years to be fully operational. New systems for the detection and location of failed fuel and a total information network with distributed intelligence, to be applied to future power stations, fall into that category.

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INTRODUCTION

R&D in control, instrumentation, and electronics at the Chalk River Nuclear Laboratories (CRNL) has a tradition extending back for 35 years or more. The need for such R&D is self-evident in an environment where scientists and engineers are continuously carrying out new experiments and looking for better ways of solving difficult problems. Our scientists and engineers quickly adopt innovations appearing in the scientific literature or in the marketplace, to enhance their own work, and in turn generate ideas and inventions that add to the world-wide fund of existing knowledge and techniques.

The CANDU power reactor concept, which originated at CRNL in this climate of scientific and technical excellence, clearly proves that good ideas, that are

- based on sound scientific principles,
- adopted by responsive public utilities, and
- supported by a manufacturing industry that thrives on high technology,

can be of lasting benefit. However, even good ideas are often overtaken by better ones. Ongoing R&D in control, instrumentation, and electronic systems for CANDU power plants is described in this report.

Development of multivariable controllers and of a computer-based safety system for power reactors, the design of new control and safety systems for the NRU research reactor, and the hybrid computer used for this work, are described under the heading of Control and Safety Studies. The section entitled Instrumentation R&D describes the work being carried out in support of specialized instruments for CANDU power plants. This includes miniature neutron detectors, systems for detecting and locating failed fuel, heavy water monitors, and reactor moderator chemistry instruments. The instrumentation section also describes monitors that are being developed so that R&D programs at CRNL can proceed. These include thermocouples made of special radiation resistant materials, devices to measure the diameter of fuel rods inside a test reactor, and instruments to study the characteristics of flowing steam/water mixtures. The section on Electronic Systems describes work in progress on an information network, for future power reactors, in which localized computing power is distributed to locations at or very close to the application. One aspect of this information network is a medium for two-way communication. Work is in progress on the application of cable television technology, and in the future, fibre optics, for this purpose. Finally, the program to develop the Reactor Data Network (REDNET) is described. This network of 11 computers will greatly improve the acquisition and processing of data from experiments in the NRX and NRU reactors.

CONTROL AND SAFETY STUDIES

Background Information

The early Canadian reactors, namely, NRX and NRU at the Chalk River Nuclear Laboratories, WR-1 at the Whiteshell Nuclear Research Establishment, and the first power reactor, NPD, at Rolphton, are relatively simple from the control and safety viewpoints. Each of these reactors has a conventional control system that regulates the reactor power to a setpoint, and a safety system that automatically shuts the reactor down should sensors indicate that pre-defined limits are being exceeded. The experience gained from the operation of these reactors formed the basis of the Canadian philosophy of power reactor design and operation, namely, that independent, automatic safety systems must be provided to shut the reactor down and maintain core cooling in the event of a potentially unsafe reactor condition. This philosophy has been imbedded in the reactor licensing criteria which now also stipulate that two independent and diverse shutdown systems must be provided for power reactors.

Compared to the early experimental, demonstration, and prototype reactors, the commercial CANDU reactors of 500 to 800 megawatts electric output are complex plants requiring sophisticated control and safety systems. Three factors contribute to this increase in complexity.

(i) Because of its large size, the reactor core can behave like several loosely coupled small reactors. Hence distributed instrumentation, control, and safety systems are required to accommodate this behaviour.

(ii) The role of these reactors in some electrical grids is changing from base-load operation to daily load cycling. This duty must be accommodated, for example, in the design of the control system.

(iii) To generate electricity at low cost to the consumer, each nuclear plant is designed to maximize its power output, within prescribed safety parameters. To operate such a plant at its design point, the status of the safety parameters and of the reactor must be known accurately at all times.

To accommodate these factors and to meet other requirements, e.g. data logging, processing, and display, the designers adopted digital computers and made them indispensable to the operation of the plant. Dual control computers, one active, the other on standby, are used to control CANDU generating stations. There is no manual backup controller; if both computers are inoperative, the reactor is shut down. The operating history of this scheme is outstanding, and during the 1973-78 period, only trivial production losses (less than 0.2%) are attributed to the simultaneous unavailability of any pair of computers at the 4-reactor Pickering Generating Station [1]. The operating record at the Bruce Generating Station is equally good. Even though the existing control and safety systems at CANDU generating stations are reliable and effective, they will be superseded by more advanced systems in future reactors. There are three reasons for this evolutionary change:

(i) The rapidly advancing electrotechnology and development of new sensors and instruments dictate that new equipment and techniques be adopted in the design of each new generating station, to benefit from these improvements.

(ii) Introduction of digital computers into the safety systems, which at present do not employ computers, promises to increase the reactor output and still provide protection which is as good as or better than before.

(iii) Recent developments in the discipline of multivariable control show a potential for improved plant performance.

R&D in the above areas is carried out in the Reactor Control Branch at CRNL, as described in the following paragraphs.

Multivariable Control for CANDU Power Plants

Nuclear power plants, like most plants in the chemical and process industries, are multivariable, that is, they have several outputs (pressure, temperature, flow, power, etc.) that must be controlled, and several inputs (valve opening, neutron-absorber position, fuel supply, etc.) that may be adjusted. These systems are called interactive because each input may affect several outputs. Controllers for these plants have traditionally been designed by conventional single-variable methods, treating each control loop as independent in the initial design. Interactions are then accommodated empirically, via simulation techniques. More rigorous design methods promise to lead to better control in these multivariable designs.

In recent years, significant advances have been made in the understanding of multivariable systems, particularly in Great Britain [2] and the United States [3]. Multivariable design methods are now being successfully applied to conventional power stations, but nuclear power applications have been limited since most countries do not use computers for reactor control. However, several simulation studies have been made, with promising results [4,5], and it is expected that multivariable control will be applied in the near future.

An R&D program in multivariable control, with a twofold objective, has been underway in the Reactor Control Branch since 1976. The first objective is to develop computer codes and simple mathematical models of the nuclear plant for the design of multivariable controllers capable of improving the regulation and transient response of CANDU power plants. The second is to design such controllers and to develop a detailed model of the plant, suitable for testing the controllers. To date, a survey of design methods for multivariable controllers has been carried out [6], several such methods have been programmed on an interactive computer, e.g. [7], and several mathematical models of plant subsystems have been derived, e.g. [8,9]. During the next 4 to 5 years, mathematical analyses and simulations by computer will continue, to meet the stated objectives. We will continue to co-operate with the designers in the AECL Engineering Company to ensure that they benefit fully from this work.

Intelligent Safety System for Future CANDU Reactors

CANDU reactors must be operated so that, with a high degree of confidence, no fuel anywhere in the core is at its melting temperature. Because the fuel temperature cannot be measured directly, it is inferred from other measurements, notably the neutron population density, i.e. neutron flux. To prevent hot spots from occurring anywhere in the reactor core, many ($\sim$100) miniature neutron detectors are positioned throughout the reactor, and their signals are divided into two groups and fed to two independent safety systems where they are compared with pre-calculated trip setpoints. Should two or more trip points be exceeded, and should the 2-out-of-3 logic in either safety system determine that the trips are valid, the reactor is shut down. The trip setpoints are pre-calculated during the design stage, but the detector outputs are adjusted several times per week, to conform with calculated flux/power shapes which take into account the irradiation histories of the fuel bundles. If the detector signals and other information about the reactor status could be processed in on-line computers, we believe that the reactor output could be raised within the same safety envelope as presently specified, i.e. no fuel melting.

From a world-wide viewpoint, the use of computers in safety systems is a new concept which has been developing over the last 5 years or so. Many groups are talking and thinking about it and designing computers into the safety systems of new reactors. However, few have actually built reactors with computers as a vital element in their safety system. One exception is Combustion Engineering [10] which has designed, and is now delivering, partially computerized safety systems. The computers are required to provide two trips: DNBR (departure from nucleate boiling ratio) and LPD (local power density). The rest of each system is built using solid state logic. In addition, there are many computerized systems available, for light-water or gas-cooled reactors, which perform monitoring and/or operator information functions. These systems also compute many of the same variables required for trip purposes.

An R&D program is underway in the Reactor Control Branch, in collaboration with the Applied Mathematics and Electronic Systems Branches, to develop and demonstrate an Intelligent Safety System, for future CANDU-PHW* reactors, that will continuously track thermal power production in all fuel channels and transmit a trip signal to the shutoff devices only when necessary to prevent fuel melting. Work to date has centred on the definition of the system concept and the feasibility of using minicomputers to carry out the large number of calculations. As presently envisaged [11], a typical safety system will have triplicated safety computers and a fourth supervisor computer, as shown in Figure 1. The supervisor computer will receive all relevant data about the reactor, i.e. signals from neutron detectors, refuelling information, control device positions, flows and temperatures in instrumented fuel channels, etc., and calculate the thermal power production in all fuel bundles. Since there are ~5000 fuel bundles in a large reactor, these calculations will require an hour or more of minicomputer time. This detailed information will then be condensed into a small number of key parameters (matrix coefficients). The operator in charge of the safety system will then examine the results

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*Pressurized Heavy Water

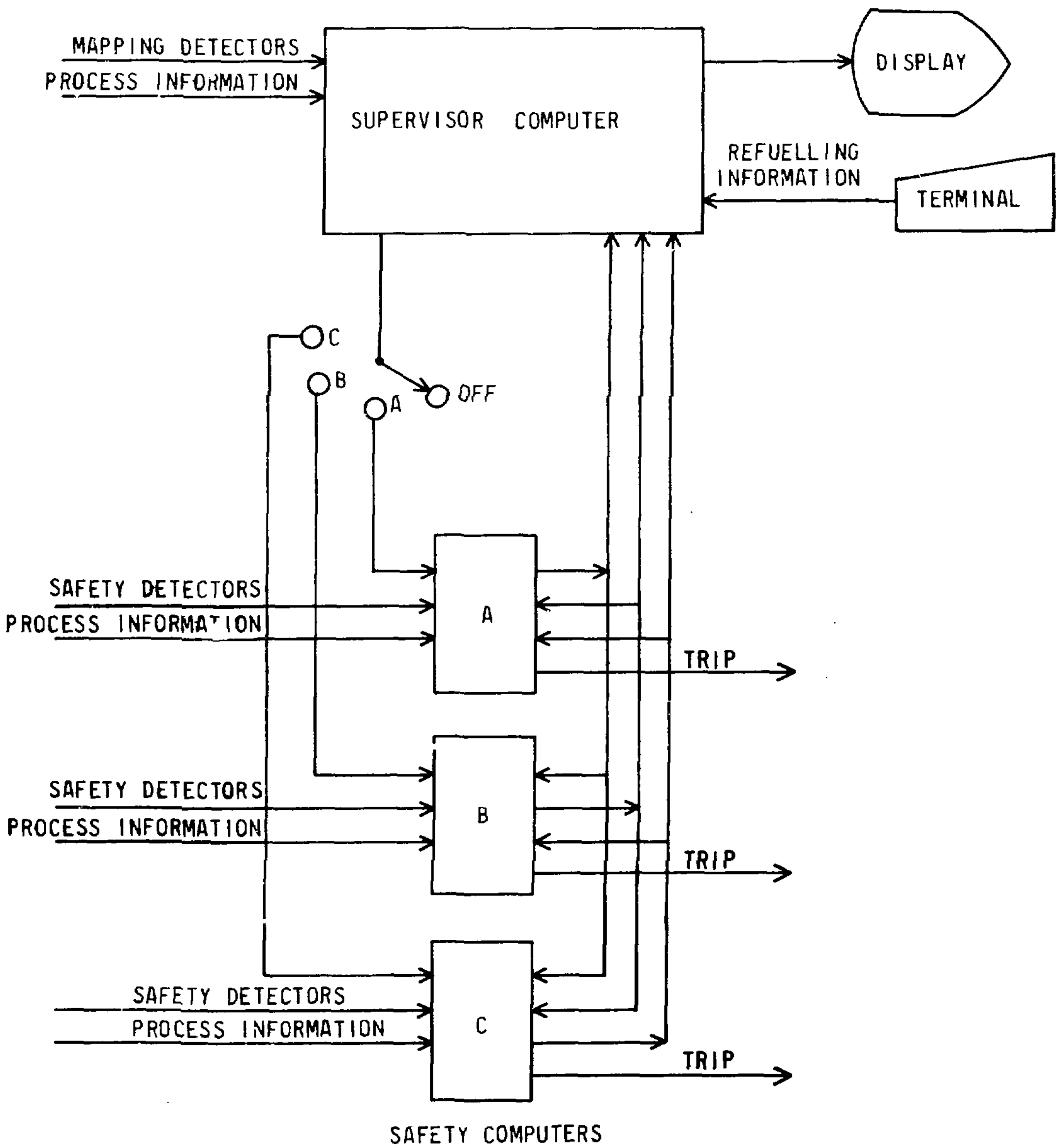

FIGURE 1 SCHEMATIC OF INTELLIGENT SAFETY SYSTEM

of these calculations, and if satisfied with them, download the key parameters into the three safety computers, one set at a time. We expect that new coefficients will be downloaded typically several times per day, for example, upon refuelling or during power maneuvers. The safety computers will use these parameters, together with inputs from neutron detectors and other process variables, to decide whether the reactor is operating within limits. This decision will be made approximately 10 times per second.

Work is presently underway on the software to be installed in the supervisor computer. During the next 5 years, a demonstration of the Intelligent Safety System will be designed, procured, and put into operation. Instead of a reactor, the demonstration will use a detailed mathematical model of the reactor. Also, a supervisor computer and one of the triplicated safety computers will be included. Data links, having the required isolation and uni-directional transmission properties, will be procured to make the demonstration as realistic as possible. Many normal and abnormal reactor conditions will be simulated on this demonstration.

The AECL Engineering Company is also working on a computer-based safety-system concept, intended for CANDU power plants that are currently under construction. In their concept, the design logic of existing safety systems, and some improvements, will be implemented in computers. Thus their efforts are directed towards a present need, whereas the Intelligent Safety System program is aimed at future CANDU reactors.

To recapitulate, the Intelligent Safety System program is part of a world-wide trend in which computers are used in more and more industrial applications, including nuclear power plant control, monitoring and safety. Our approach has a closer resemblance to the monitoring computer systems, currently in use on light-water or gas-cooled reactors, than to the micro-computer based safety systems favoured by foreign designers.

New Control and Safety Systems for NRU

The NRU research reactor at CRNL has been in operation for 23 years and continues to be an indispensable facility for R&D and the production of radioactive isotopes. Many of its control and safety subsystems are approaching their end-of-life and need to be replaced. Since the electronic sub-systems are based on vacuum tube technology, replacement is becoming difficult, if not impossible. As an interim measure, vacuum tube circuits are being replaced with equivalent solid-state analog circuits.

A design and development program is underway, the objective of which is to conceive, design, and implement new control and safety systems for NRU, incorporating the latest ideas in control devices and methods. Exploratory work is in progress, its aim being to delineate the scope of the project and produce a preliminary study report before the end of 1981. Once approval to proceed is given, detailed analyses, design, and development will be carried out and new equipment will be procured, installed, programmed, and commissioned. Completion of the project is anticipated to be in 4-5 years' time.

Our present thinking centres on installing individually controllable absorbers around one test site in the reactor, called an in-reactor loop, in which fuel engineers irradiate experimental fuel bundles up to 4 cm outside diameter and 3 m long. The unique aspect of this loop will be that the neutron flux in the fuel bundles will be controllable to close tolerances, regardless of flux perturbations elsewhere in the reactor. Miniature neutron sensors will also be installed along the test site, to provide automatic regulation of the local neutron flux and to accurately record the irradiation history of the experimental fuel. A preliminary design of the loop flux regulating system, carried out in collaboration with the Process Systems Design Branch, looks promising. Also, the first round of calculations carried out by the Reactor Physics Branch has produced acceptable figures for the absorption strengths of the local neutron-control absorbers and for the resultant range of fission power in the fuel. Further along in the program, the reactor control and safety systems will be examined and redesigned, with current and future technology in mind.

Dynamic Analysis Facility

In the above three R&D programs, the emphasis is on computers, for the design of multivariable controllers, simulation of CANDU power plants and NRU reactor systems, processing of data from a detailed reactor simulation, etc. Most of these activities are carried out on the Dynamic Analysis Facility [12] which presently consists of two digital computers, two analog computers, and the necessary interprocessor links, data storage, input, and output peripherals, illustrated in Figures 2 to 4. The system was acquired in 1975 March, and, with continual upgrading of its software and hardware as well as proper maintenance, is expected to serve the needs of the analysts for years to come.

INSTRUMENTATION R&D

Background

Most high technology enterprises rely heavily on complex instrumentation. Since nuclear radiation is not detectable by the human senses, specialized sensors have been essential

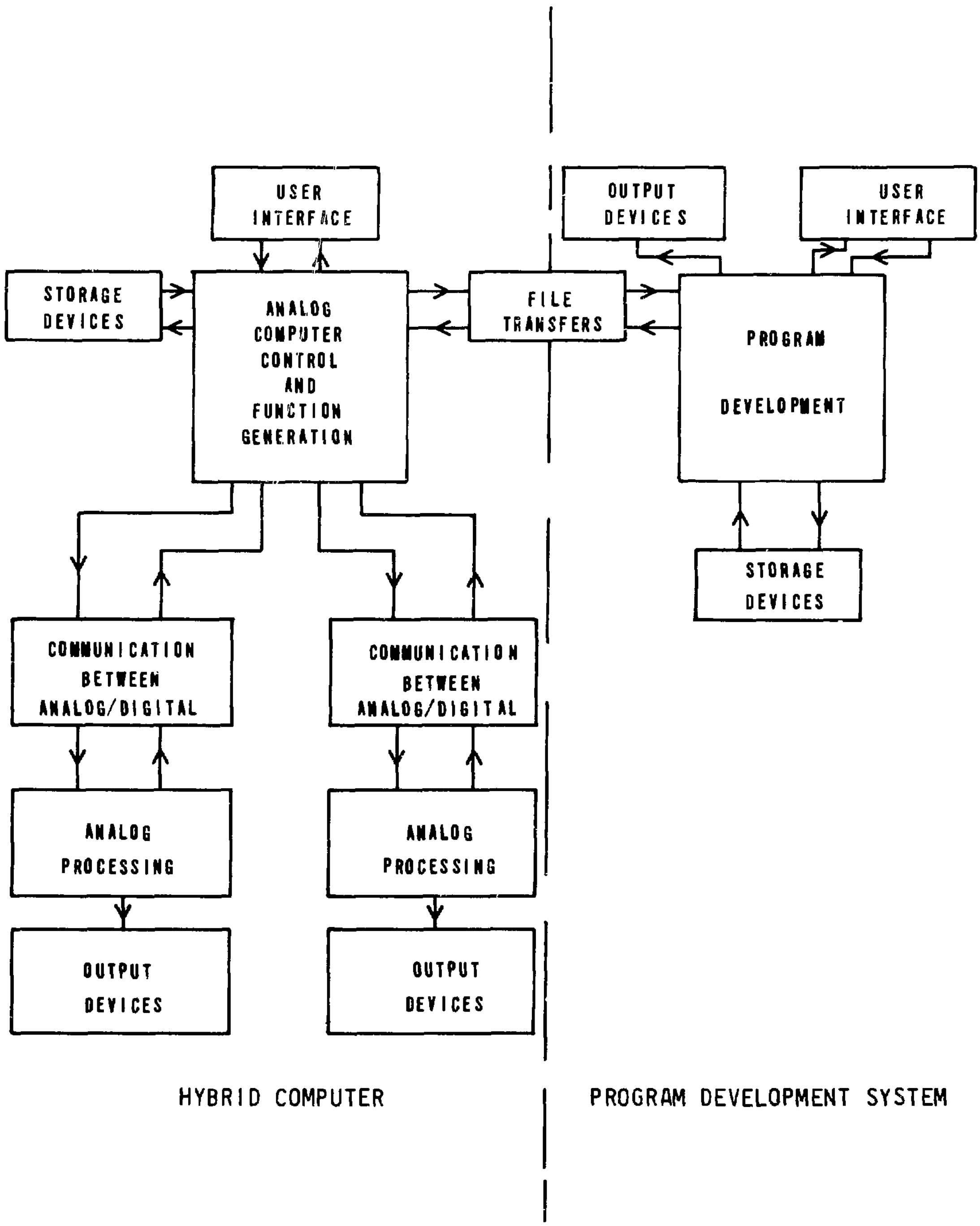

FIGURE 2 FUNCTIONAL DIAGRAM OF THE DYNAMIC ANALYSIS FACILITY

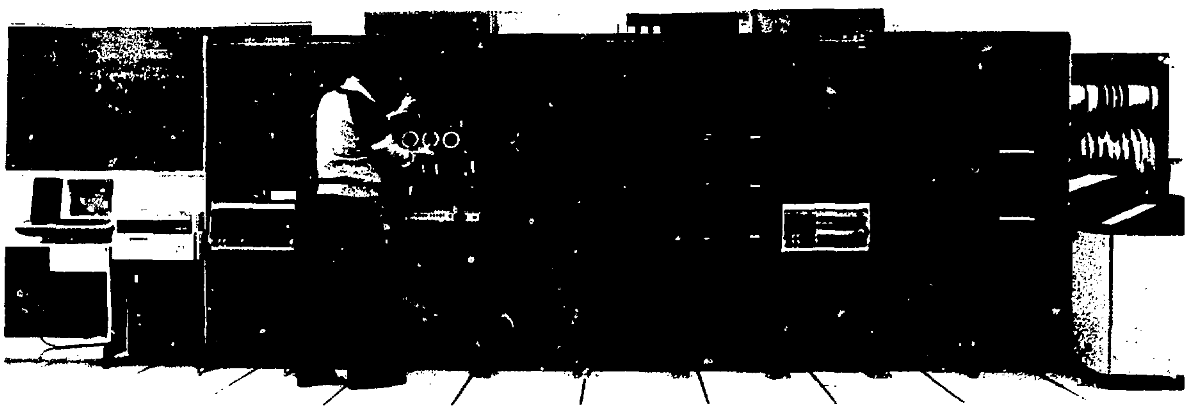

FIGURE 3 THE TWO DIGITAL COMPUTERS IN THE DYNAMIC ANALYSIS FACILITY

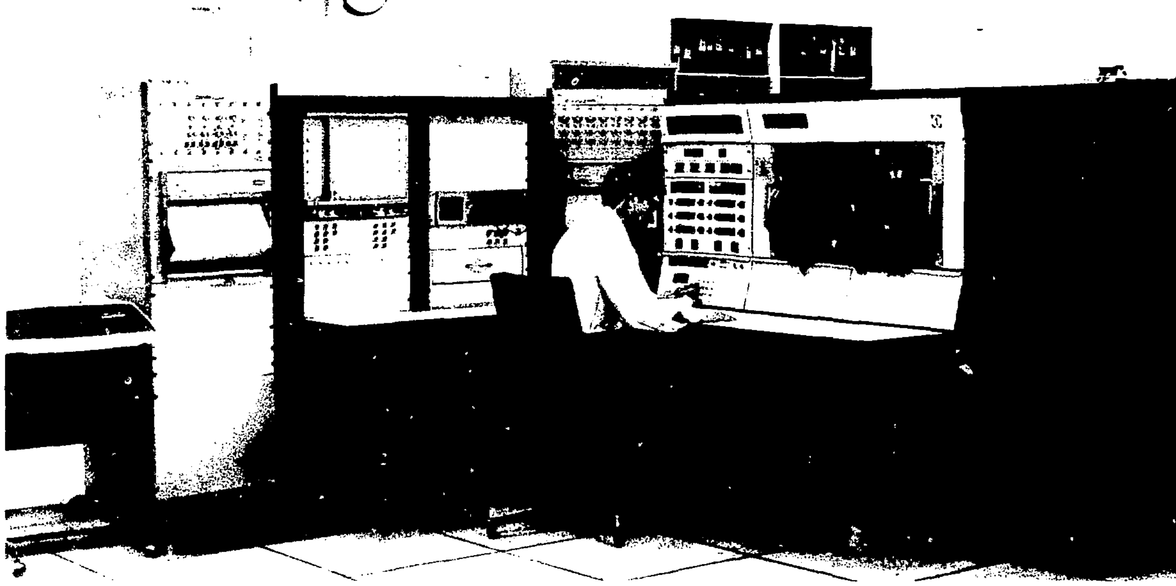

FIGURE 4 ONE OF THE TWO ANALOG COMPUTERS IN THE DYNAMIC ANALYSIS FACILITY

to the industry since the earliest electrometers and Geiger counters. Today, in the 4-unit Bruce Nuclear Generating Station there are about 6000 sensors [13], transmitting vital plant data to the control computer, control room, or to automatic actuators.

Many of the sensors in a nuclear station are also used in the electrical and chemical industries, and can be purchased from commercial suppliers. Others are needed in all nuclear power stations (irrespective of type), and the world market is large enough to support one or two manufacturers. Some, however, are specific to a particular reactor type or plant design, and generic development work in support of these must be the responsibility of the reactor supplier.

The specialized instruments in a nuclear power station cover

- health monitors to protect the public, employees and the environment,
- neutron detectors to monitor nuclear core conditions,
- process monitors in the systems for heat transfer, coolant chemistry, etc., and
- safeguards instruments to monitor material inventories to fulfill international non-proliferation treaty obligations.

Besides designing and procuring CANDU reactors, AECL manages a significant program of R&D to improve the fuels, materials, and mechanical components used in the nuclear industry. Experiments at the forefront of development inevitably require special measuring instruments which have never been used before. It is therefore necessary to develop instruments in support of the nuclear R&D program as well as for CANDU reactors. While many of the same engineers and scientists design instruments in several of these categories, only the reactor and process monitors, and the R&D instruments are mentioned here. The remainder are covered in companion documents describing other aspects of the AECL program.

Potential Benefits

The overall aims of the instrument development program are

- to provide instruments essential to the operation or sale of nuclear reactors,
- to reduce the cost of nuclear electricity,
- to improve safety, or
- to meet regulatory requirements designed for public and environmental protection.

Neutron Detectors

The generation of heat in a nuclear reactor is regulated by sensing the neutron population, i.e. neutron flux, processing this information, and then adding or subtracting a neutron-absorbing material to maintain the flux at the desired level. In large CANDU reactors, as many as 200 neutron sensors, called self-powered flux detectors, are used to obtain an accurate measure of the neutron flux throughout the reactor, for control and safety purposes.

A self-powered flux detector is a coaxial cable of small diameter, i.e. 1 to 3 mm, that generates an electrical current proportional to the neutron and gamma-ray fluxes to which it is exposed. Figure 5 illustrates a typical detector and its constituent parts [14,15]. The operating characteristics of self-powered detectors, that is, sensitivity, dynamic response and burn-out rate, depend on the materials chosen for the manufacture of the detectors and on the environment in which they operate, i.e. neutron flux, gamma-ray flux, temperature. Thus,

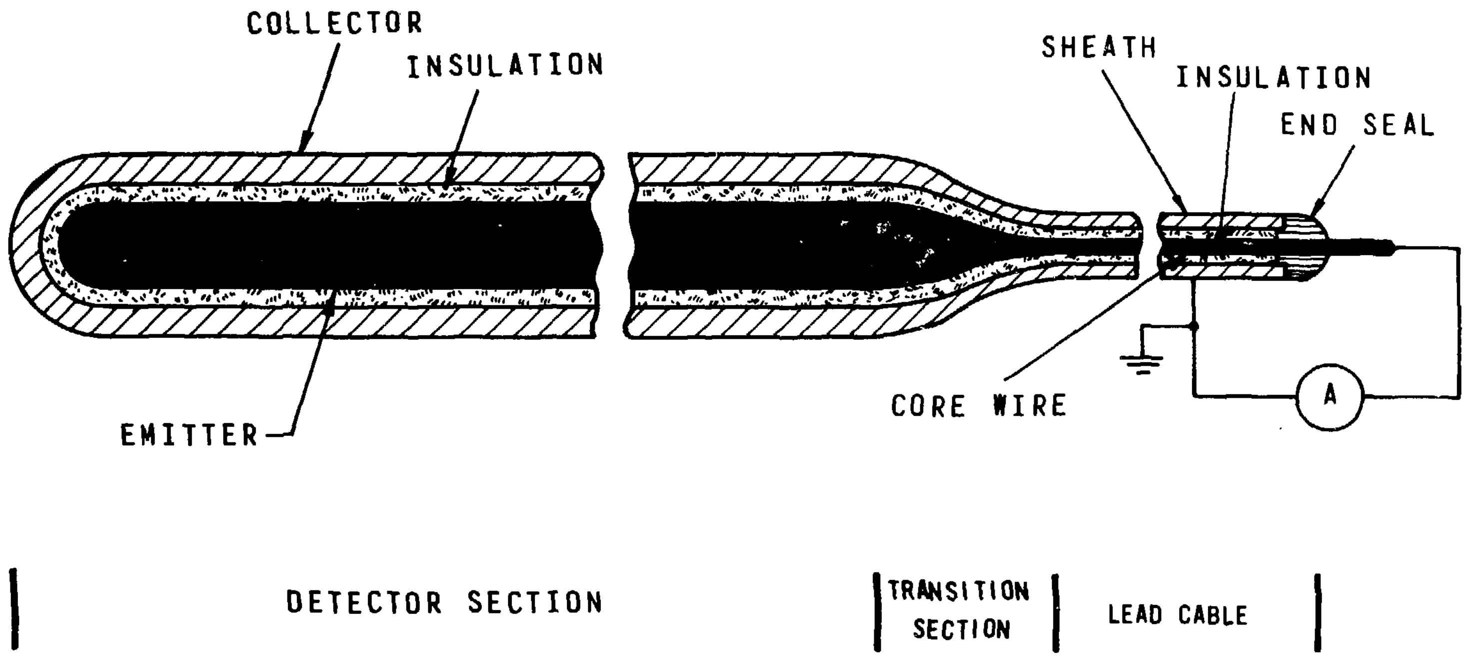

FIGURE 5 SCHEMATIC OF A SELF-POWERED FLUX DETECTOR

our work is aimed at developing detectors specifically for, and understanding their operation in, CANDU reactors. Our detectors are generally not well suited for use in light water reactors and vice versa. Early designs of our detectors had emitters made of vanadium or cobalt, while in more recent designs platinum, platinum-clad Inconel, or Inconel are used instead of cobalt. The search for better materials continues.

An R&D program has been underway at CRNL for many years, the objective of which is to refine our understanding of existing detectors, to develop new detectors with superior properties, and to devise techniques for calibrating detectors in situ, to meet control and safety requirements. Present effort is directed towards experiments with detectors of the type to be used in the Bruce B Nuclear Generating Station. This work is jointly funded by Ontario Hydro and CRNL. We intend to ask Ontario Hydro and the Engineering Company for continued support of this program which, over the next 4 or 5 years, will centre on the long-term irradiation of prototype detectors in the NRU reactor. In parallel with this program, CRNL is conducting experiments and mathematical analyses of detectors made of other materials. The incentive for this work rests on the following argument: even though the detectors are miniature, there are many of them, and in total they absorb a significant number of neutrons. Extra fuel has to be added to the reactor to compensate for this neutron loss. Hence we are developing detectors that show promise of producing an adequately strong signal but absorb fewer neutrons than existing detectors. Since successful detector designs arise from a symbiosis of calculation, experiment, and innovation in manufacturing techniques, CRNL and Reuter-Stokes Canada Ltd. collaborate closely in the development of new detectors. This results in technology transfer from the laboratories to the manufacturer who, in turn, develops the capability to offer detectors of advanced design and performance to reactor designers and to electric utilities operating CANDU generating stations. The current program to develop new detectors will probably extend over 4 years or more.

Failed Fuel Detection and Location

CANDU reactors are designed to be refuelled on power, i.e. without having to be shut down. This capability can be used to advantage if a fuel bundle is defective and should be removed from the reactor to prevent radioactive contamination of the primary coolant circuit. It should be noted here that the failure rate of CANDU fuel is very low - less than 1 in 1000 bundles [16]. In the present generation of CANDU reactors, two systems are provided to detect and locate failed fuel. The first, called the failed-fuel detection system, alerts the station operator to the presence of failed fuel [17]. This system operates continuously and detects a bulk increase in the gamma radiation in the large coolant pipes called headers. Having established that a failure has occurred, the operator must then find out which of the $\sim$5000 bundles it is. This he does by activating the failed-fuel location system [18]. Samples of coolant from each fuel channel are routed to shielded monitoring rooms where neutron counters can detect the presence of small amounts of fission-product particles. The fuel bundles from the suspect fuel channel can then be sequentially removed until the failed bundle is located.

While these systems work and have proven themselves in the field, the reactor designers and operators would like to have systems that are simpler and also require less expertise in data interpretation. R&D in support of these objectives has been in progress at CRNL for several years, as manpower permits. The Reactor Control Branch continues to collaborate with the Fuels and Materials Division in experiments aimed at obtaining an improved understanding of the release of fission products from defective fuel and their subsequent migration and deposition in coolant circuits. Over the next several years, new designs of failed fuel detection and location systems will be developed in co-operation with the AECL Engineering Company.

Boron-10 Monitors

Boron-10 is a chemical added to the reactor moderator to absorb neutrons. In a new reactor, when all the fuel is fresh, its reactivity is held down by maintaining a high concentration of boron-10. As the fuel ages and fission products accumulate, boron is slowly removed, so that the reactivity is held constant. Precise knowledge of boron-10 concentration (at the parts-per-million level) leads to the most efficient use of the fuel.

Since boron is added as a mixture of isotopes (not only boron-10) its neutron absorbing properties cannot be measured by chemical analysis. Rather, samples of the moderator must be evaporated and the residue bombarded with neutrons. Then, the concentration of boron-10 can be found by measuring alpha particle emission rates.

The apparatus to safely house the neutron source and the electronics to

- process the signals,
- detect the alpha particles, and
- calculate boron concentrations

are being assembled. The result will be a transportable facility which can be shipped to reactors as needed.

Heavy Water Monitors

Since CANDU reactors are the only commercially significant types to use water as a moderator and coolant, heavy water instrumentation has been a Canadian concern for over twenty years.

We are undoubtedly the only country with substantial experience in the design of on-line heavy water monitors. We must maintain this capability since heavy water is such an important part of the CANDU reactor. Instruments, such as those shown in Figure 6, have been invented to detect minute leaks at reactors which have prevented the loss of hundreds of thousands of dollars worth of heavy water. Others are used on reactor upgraders, heavy water plants and for monitoring heavy water vapor in air.

The development of heavy water monitors was thought to have been completed over a decade ago. Its transfer to Canadian industry met with limited success. When all heavy water monitors in every operating plant had failed several years ago, AECL directed efforts to provide more reliable monitors. A major milestone was the rehabilitation of all available existing monitors. Subsequent milestones have been the provision of wider range on-line heavy water monitors for the Glace Bay Heavy Water Plant and for R&D on tritium separation at Chalk River. The present work includes the development of rugged, plant-tolerant monitors based on current technology.

Today's on-line heavy water monitors all operate by measuring the absorption of infrared radiation as it passes through water samples [19]. The absorption is related to heavy water concentration, but is also sensitive to the sample temperature. Thus, elaborate methods to control temperature within narrow limits are required. In one development program, expensive and unreliable liquid/liquid heat exchangers are being replaced by electronically controlled thermoelectric coolers. Also, microprocessor technology is being implemented to automate calibration procedures, and provide more accurate readings.

FIGURE 6 INFRARED HEAVY-WATER MONITOR FOR LEAK DETECTION IN STEAM GENERATORS AT THE BRUCE NUCLEAR GENERATING STATION

Heavy water vapor measurements are also needed to determine losses to the atmosphere. In another development, work is proceeding on establishing means of condensing water from stack air, to provide a liquid sample. The heavy water concentration of the liquid will then be determined and combined with flow measurements to read accumulated total loss.

While the infrared heavy-water monitors give very precise readings, effort is also directed to using density or (optical) refractive index, as measures of heavy water concentration. This program seeks to assess whether lower cost heavy water monitors can be used in less demanding applications.

Special Purpose Instruments in Support of R&D Programs

This program consists of a number of relatively short-term projects (typically one year each). Recently it has included critical heat flux detectors using resistance temperature detectors, void fraction monitors, in-reactor pressure transducers and Zircaloy-clad thermocouples.

Projects underway at present include

- a less expensive and more flexible means of locating critical heat flux in test sections, using ultrasonic thermometry,
- a flow meter which can cover a very wide range of flows, for use in pump-seal leak rate tests,
- a high-temperature force transducer for experiments to measure wear rates in heat exchangers, and
- an in-reactor gauge for measuring strain in simulated reactor fuel, based on eddy current principles.

ELECTRONIC SYSTEMS R&D AT CRNL

Background Information

Canada is a pioneer in the use of computers for controlling nuclear power plants, Figure 7, and the experience to date has been excellent. However, despite the success of the dual-computer philosophy, the rapidity with which electrotechnologies advance and the need to maintain Canada's competitive advantage require that attention be given not only to the latest techniques available but also to technological trends. A long-range R&D program is underway at CRNL to ensure that the performance and safety record of the Canadian nuclear program is continually improved.

Dramatic advances in microelectronics have made available economical minicomputers and microprocessors, making it possible to design systems where equipment with processing power (commonly referred to as "local intelligence") can be distributed to locations at or very close to the applications [20]. Thus the term distributed architecture refers to an assemblage of hardware and software components tailored to appropriate tasks and linked together to satisfy the overall requirements of the job.

In the context of nuclear power plant applications, distributed architectures which encompass all station electronic systems promise a fully integrated and adaptable solution needed to guard against equipment obsolescence and to satisfy the requirements for comprehensive surveillance.

Because of the long lead time in designing and licensing nuclear power stations, the possibility of applying distributed systems in plants to be commissioned in 10 years' time must be planned for now.

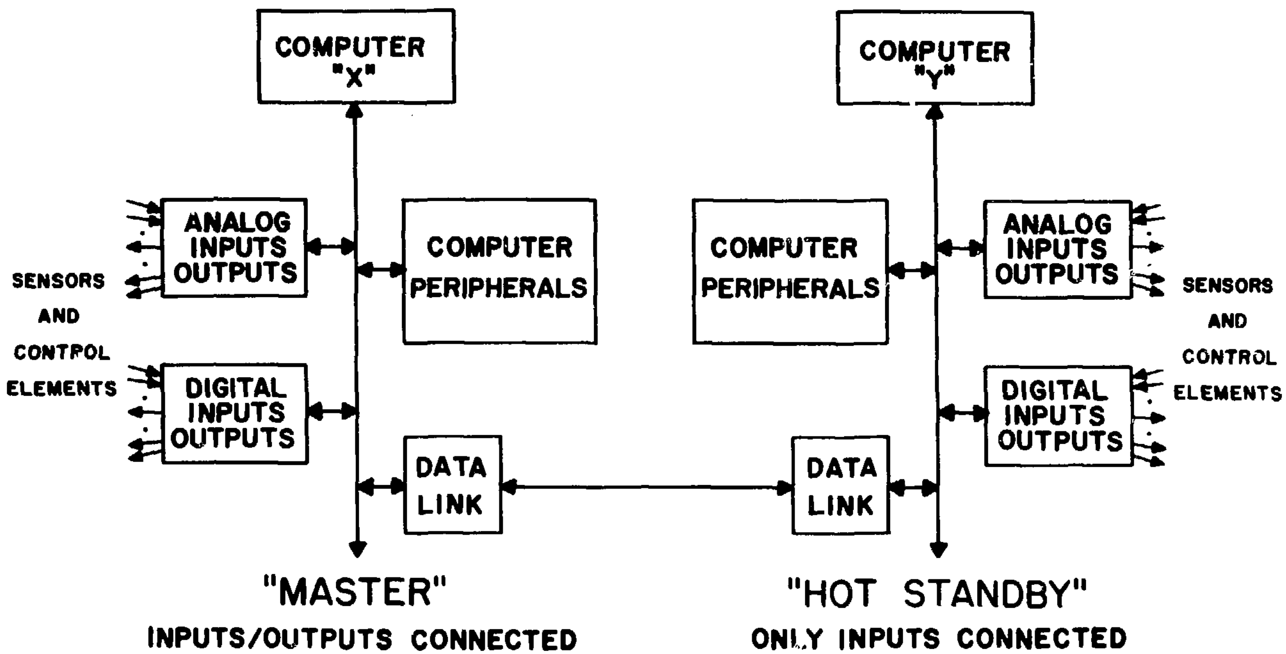

FIGURE 7 DUAL COMPUTER CONTROL OF A CANDU POWER PLANT

For these reasons, there is world-wide interest in distributed systems for nuclear plants. Specialists from many countries recently came to Chalk River for a meeting, co-sponsored by AECL and the International Atomic Energy Agency, to discuss progress on computer applications in nuclear plants.*

Future System Concept

To establish a framework upon which we can work, a reference conceptual design for a future system was developed [21]. This reference design reflects our understanding of the general requirements of a future CANDU and our projection of the technological trends. The idea is to come up with the right balance between taking advantage of novel approaches and relying on proven technologies. This balance is illustrated in Figure 8 which shows a projected broadening of the role of digital electronics and computer-related technologies.

The conceptual design was developed following these guidelines:

- The architecture should allow integration of all electronic systems in the plant;
- The architecture should be adaptable to changes in technology; and
- The architecture should be compatible with, but not restricted by, the design principles adopted by the utilities and regulatory bodies.

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*The proceedings of this conference are published as AECL-7056.

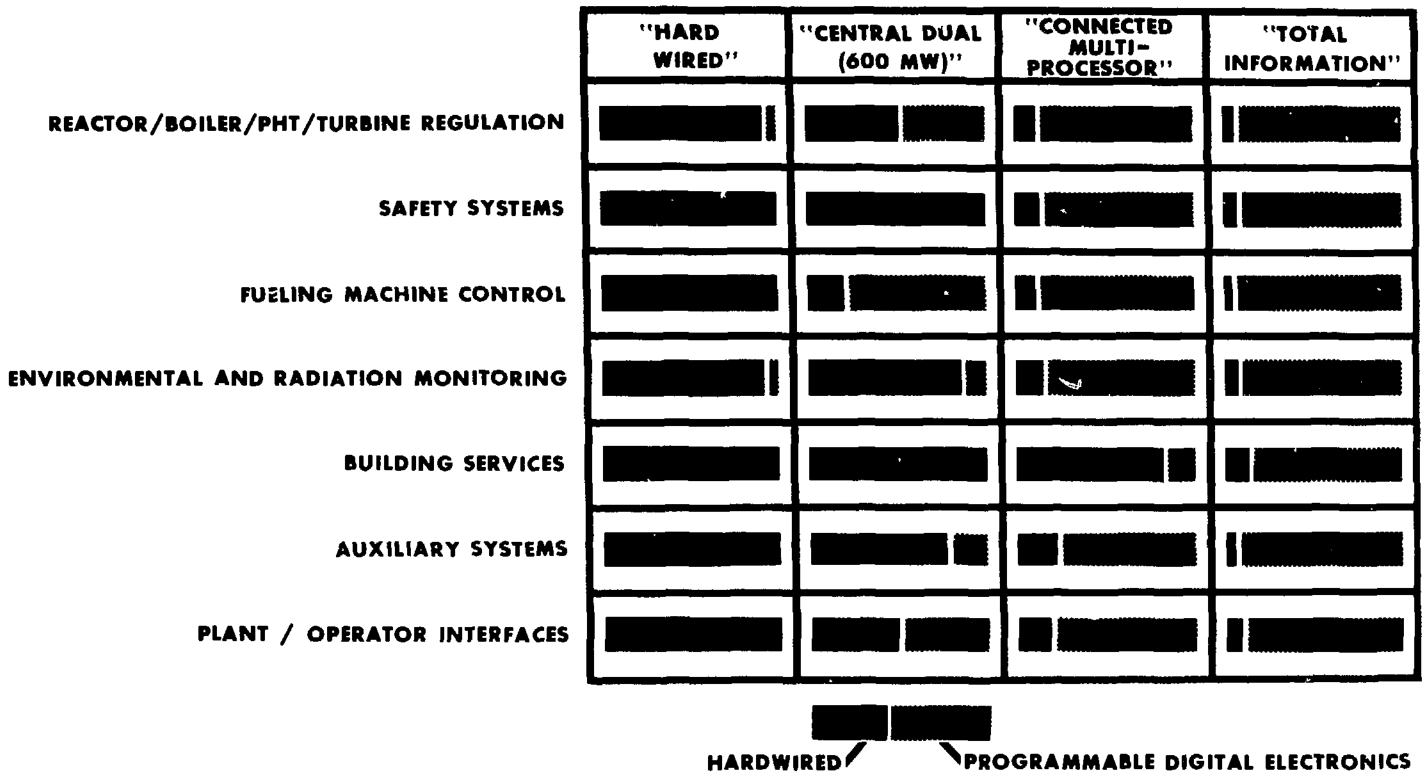

FIGURE 8 DIGITAL ELECTRONICS IMPLEMENTATION IN TOTAL CANDU PLANT

The system concept proposed as a basis for ongoing discussion is a loosely coupled, multi-level network made up of busses interconnected by interbus communicators and isolators (IBCI), Figure 9.

Each IBCI is to provide an interconnection between separate busses including the isolation needed to eliminate undesirable interactions between subsystems. Some limited functions for arbitrating the sharing of resources and diagnosis and monitoring of errors may also be performed by the IBCI.

The station computer is to concentrate on functions pertaining to the station as a whole, e.g. station environmental monitoring, building services, switchyard monitoring, burn-up calculations for all units. The station computer has access to the various unit busses.

The unit data base computers are to provide a redundant repository for all current and past history relevant to the monitoring, display and logging requirements of the unit. The actual display, annunciation and logging of such data are to be carried out by the information system, a cluster of intelligent terminals and displays.

The unit regulating system functions are to be carried out by separate dedicated processors. These functions are logical candidates for the dedicated computer approach since there is little interaction between them and what interaction there is can be effected through the regulating system busses.

To ensure their integrity and their independence from the unit and station computers, the dedicated control processors are to have their own private inputs and outputs.

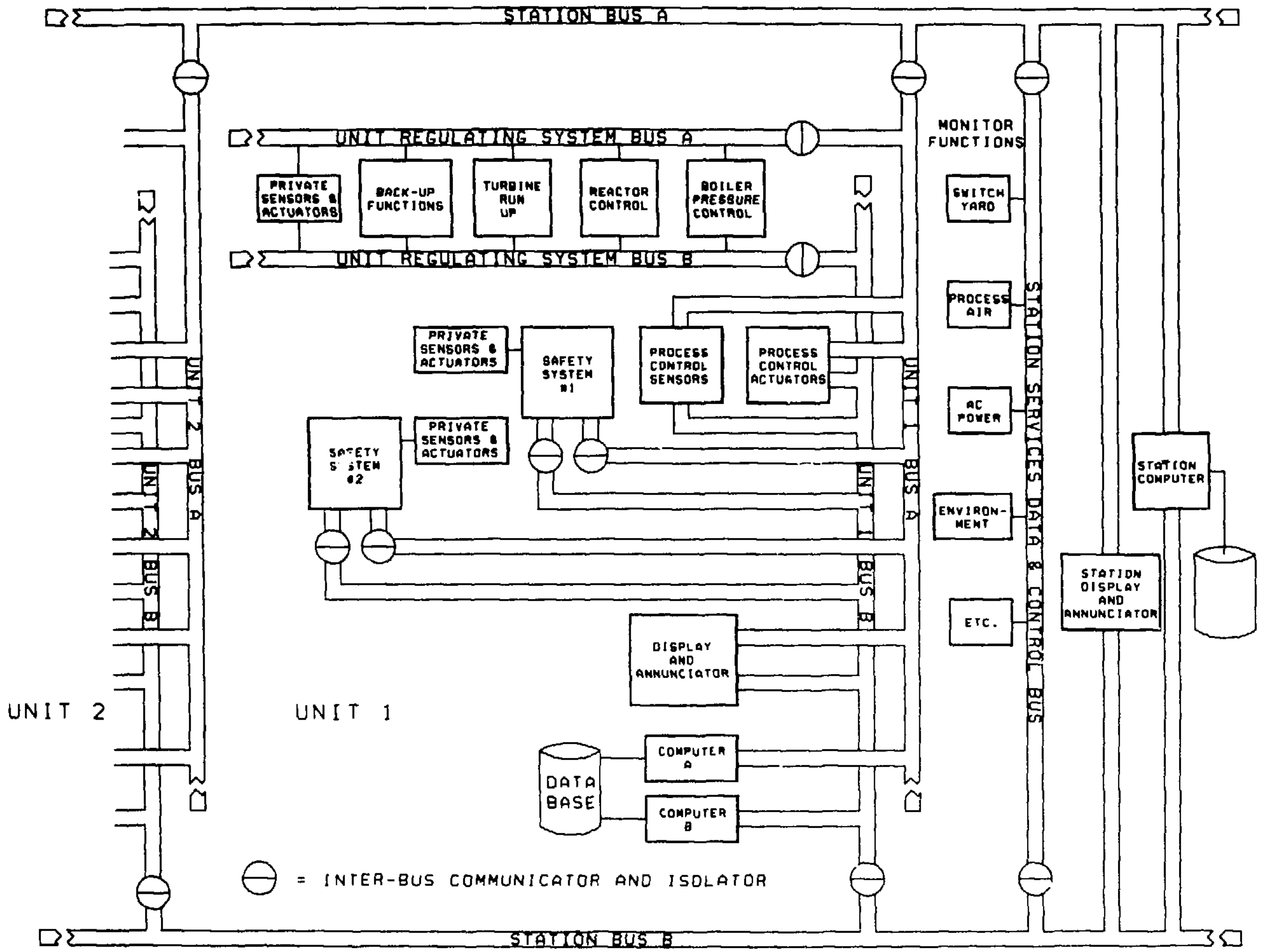

FIGURE 9 CONCEPTUAL BLOCK DIAGRAM OF A TOTAL INFORMATION NETWORK

The safety systems are to be computerized and connected to the unit busses. These systems will have their own private inputs and outputs with any access to them accepted or rejected by the safety system computers themselves.

Miscellaneous unit process control functions are to be accomplished by the broadcast of data from intelligent sensors associated with these functions and by the broadcast of control information from controllers to intelligent actuators. Depending upon the application, the sensors, controllers, and actuators may all be connected to either or both of the unit busses.

Information Transport (INTRAN)

The availability of a versatile, low-cost and reliable communications medium is a key factor contributing to the successful application of distributed systems. In a power-reactor environment, different classes of communications services are required. To simplify the design tasks, the concept of separable communications was evolved which provides a modular solution that is adaptable to specific system requirements [22].

The Information Transport (INTRAN) project is a unique Canadian development, based on world-wide advances in electronics, to translate the concept of Levels and Channels, developed at CRNL [23], into building blocks.

Each independent Level, Figure 10, is defined by a set of rules corresponding to a range of capabilities. Flexibility is assured as new Levels can be specified and added without causing disruptions, to meet evolving system requirements and to take advantage of newer technologies.

Each Level can be repeated a number of times to form independent Channels all with the properties specified by

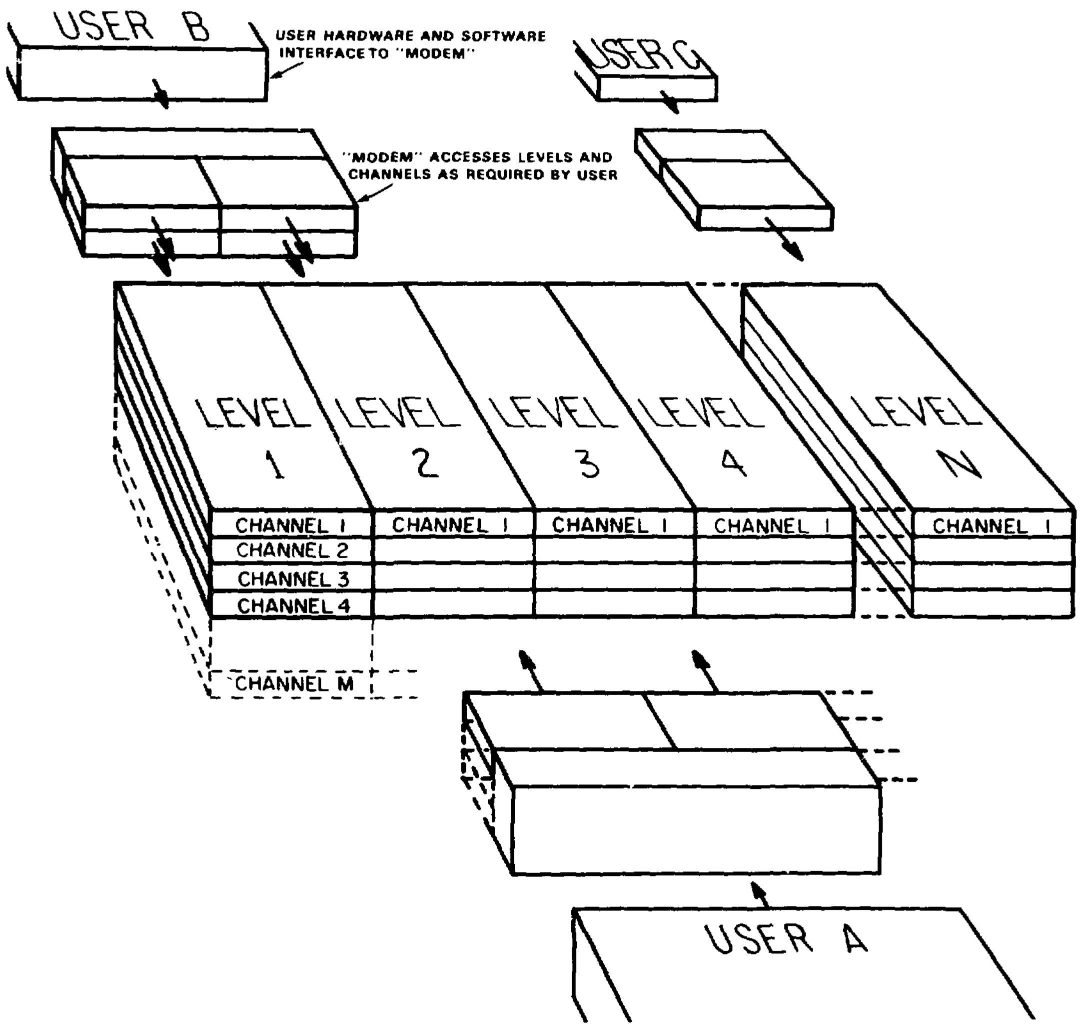

FIGURE 10 BASIC COMMUNICATIONS CONCEPT-LEVELS AND CHANNELS

the Level. Channels are used either to increase the data transmission capacity or to simplify the design by decoupling, into small parts, subsystems with similar generic requirements.

Users are connected to the communications resource in a controlled manner and the interconnection patterns may be dynamically modified to suit the changing conditions.

Currently these concepts are being implemented experimentally using equipment based on cable television (CATV) technology. The selection of this technology resulted from a study of the communications market which indicated that presently, the CATV approach showed the most promise for short-haul two-way digital communications applications suitable for industrial environments such as found in a nuclear power plant.

Reactor Data Network (REDNET)

A practical first step towards achieving the distributed systems goals is being taken in the Reactor Data Network (REDNET) project.

REDNET is being designed to upgrade the data acquisition and processing facility associated with the NRX and NRU experimental reactors and will perform the following functions:

- read the signals from a large number of transducers and sensors monitoring experiments and reactor parameters according to some sequence,
- convert these signals to digital form for storage and processing in computers, and
- sort and display information as requested to permit intervention of operators and experimenters with the data acquisition and manipulation processes.

REDNET is a network of 11 computer processors, initially being interconnected to form a three-level hierarchical system, Figure 11. Six of these processors are located in the remotely sited process I/O stations (three in each reactor) and are used for gathering and preprocessing of data and monitoring experiments. Four processors (two in each reactor) are used for final processing of data before transmission to the Computing Centre, and also for supporting a wide variety of equipment. The eleventh processor at the System Management cluster provides a performance monitoring facility and enables ongoing program development, independent of the reactor-based processors.

Implementation of REDNET is in two phases. The NRX Phase is currently in progress. Hardware equipment has been purchased and the software design is currently underway.

Ultimately, the viability of distributed systems will be demonstrated in the field by projects such as REDNET. The practical experience gained in the experimental reactor's environment will be invaluable in advancing the engineering know-how of applying electronics in the instrumentation, control and safety systems for power plants.

SUMMARY

Safe, reliable operation of nuclear power plants depends heavily on control and instrumentation systems, and the Canadian record is exemplary. The R&D program at CRNL is aimed at upgrading existing practices in CANDU plants in the light of the rapidly evolving electrotechnologies. In this manner, good ideas of the past are being replaced by better ideas of today and tomorrow.

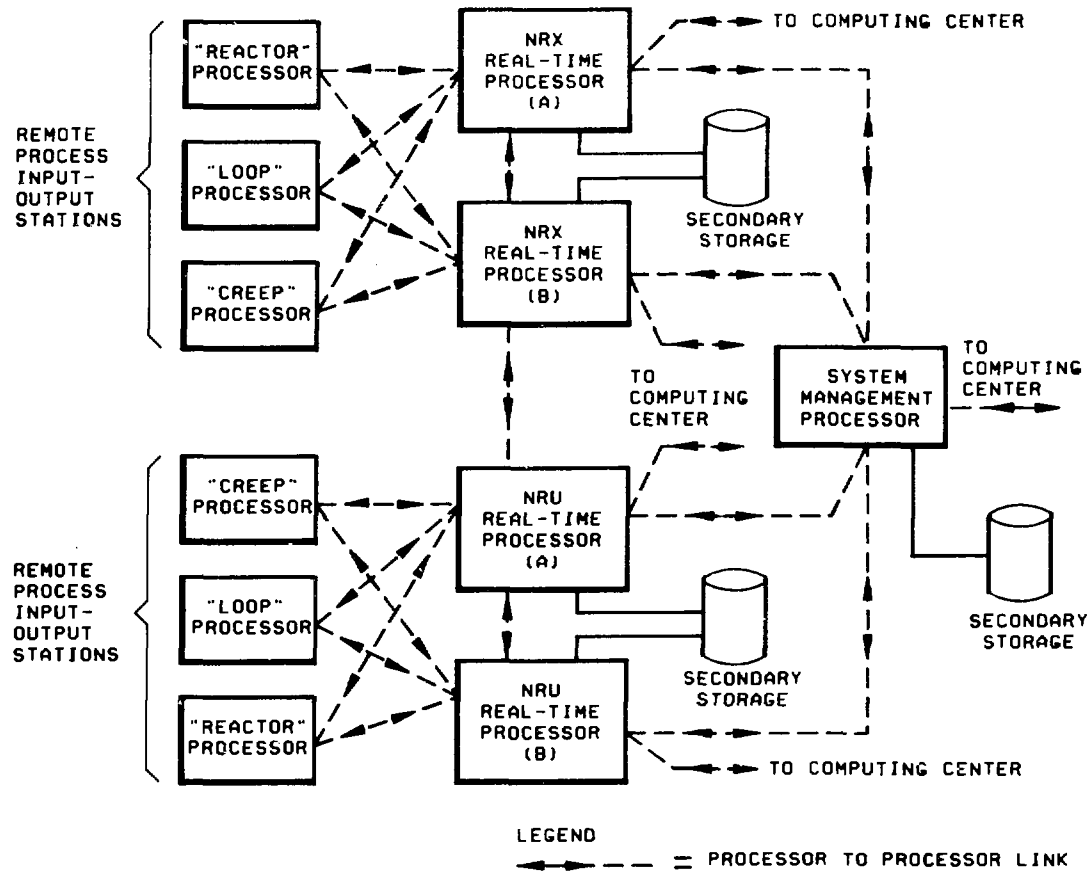

FIGURE 11 REDNET TOPOLOGY

The ongoing projects described in this report provide us with the confidence that Canada's position in the forefront of nuclear power will be maintained.

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