CNS BULLETIN SNC

Vol. 5, No. 5 September/October / septembre-octobre 1984

Society for the Preservation of Canada's Nuclear Heritage

Editorial

Faith in Interfaith

Following is the statement made by CNS President Peter Stevens-Guille on his submission of the CNS brief to the hearings of the Toronto-based Interfaith Program for Public Awareness of Nuclear Issues (IPPANI). Copies of the brief and background information on the hearings are available on request from the CNS office.

"The Canadian Nuclear Society has submitted a brief to these hearings which you have just heard. But it is with some misgivings that we are today at all. These misgivings are due to the following:

Several events, mentioned in the brief, involving ethical issues of nuclear technology, have occurred over the last few years. The interfaith group took no active part in these events and indeed have boycotted at least one of them.

At least one member church of IPPANI has a stated position on nuclear technology in Canada which is firmly anti-nuclear. Yet the stated aim of the hearings is to be "open and fair."

In its preamble on the interfaith hearings, IPPANI states that "few Canadians feel a real sense of ownership of the use of nuclear technology for peaceful purposes," a statement not encouraging one to expect open mindedness or fairness.

One of the reasons why we did decide to participate was that we perceived that you, the panel, was made up of fair-minded individuals not directly connected with IPPANI.

The Canadian Nuclear Society cannot help but wonder at the $100,000 spent on these hearings and the greater good that this money could do applied to some other endeavour. Privately I believe that the $100,000 could be much more profitably spent on outreach — either in Canada or overseas — rather than on *inreach*.

Having described our misgivings I would like to make a comment on the other briefs of this week. After reading the briefs I was surprised to see the wide range of effort in the documents submitted to you. These range from well-prepared briefs addressing the questions in Appendix A of the hearings project to emotional polemic originally articulated several years ago and served up as a "brief" with the aid of a covering letter.

In order that those who *have* attempted to address the specific questions are not penalized, may I request that the briefs which have made *no* attempt to answer *any* question raised by the IPPANI panel be placed in a separate category. This category should supply no input to you in the preparation of the summary document. They should, in effect, be placed "in limbo" as they do not meet the requirements IPPANI has laid down.

If the $100,000 spent by IPPANI bears fruit, it will be through your efforts and your (one hopes) impartial findings."

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Perspective

Microcomputers and Nuclear Safety Analysis

The following paper by D.R. Pendergast was presented at the 10th Annual Symposium on Simulation of Reactor Dynamics and Plant Control, held in Saint John, NB, April 9-10, 1984 and sponsored by the CNS. Dr. Pendergast is Manager of the Containment Analysis Branch with AECL CANDU Operations in Mississauga, Ontario.

Introduction

The nuclear industry has been one of the pioneers in the application of computers to the solution of engineering problems and simulation of physical systems. Computational models developed over the years have allowed us to simulate reactor operation and explore postulated accident scenarios which are enormously expensive or impossible to investigate experimentally.

The computer simulations, because of much lower costs than experiments, have been easy to justify and tend to proliferate in quantity and complexity. They have, in themselves, become a very significant part of the cost of nuclear safety analysis.

Perhaps help is at hand. Rapid development of computer hardware and software has taken place in the past few years. Even in the past year the cost of useful computer systems has dropped. Microcomputers have become a billion dollar[1] mass market consumer item in Canada. This proliferation of computers leads in turn to a market for software to make them useful. All of this activity should lead to a lowering of the cost of safety simulations and modelling as computer and software development and manufacturing costs are shared over a broader base of consumers.

At the moment it is difficult to identify the real significance of microcomputers in the chaotic confusion of computer cornucopia. This report represents a layman's view and evaluation of them in the context of the large "mainframe" systems and applications with which the nuclear industry developed.

A Basis for Computer System Assessment

Nuclear Safety Analysis computing requirements to date have largely been based on a need to perform a tremendous quantity of numerical calculations. Many of our programs require a large quantity of memory to store the program and variables. A useful, if simplistic comparison of computer capability can thus be derived by comparing the speed at which they can perform operations and their memory size.

The speed of a computer's central information processor can be roughly characterized by:

- the number of bits of data which are manipulated at one time in the processor's internal memory (registers)
- the number of lines which transfer data to and from memory ("data bus")
- the "clock rate" at which the processor is driven in cycles / second.

It is worth noting in this context that the status (on or off) of 8 bits of information (known as a byte) can be and is used to represent up to $2^8 = 256$ characters. Thus one byte of storage capacity is often alternatively referred to as one character of storage. A decimal number with about 7 significant digits can be represented by the status of 32 bits (or 4 bytes) of memory.

Commonly used microcomputer processors vary in register size and databus width from 8 to 32 and in clock speed from one to 25 megahertz. This suggests a range in processing capacity of about $4 \times 4 \times 25$ = a factor of 400. Other factors inherent in the computer's design may well influence its capacity (i.e. the processor may need to look after the display as well as solve your problems). Processors may vary in the number of cycles needed to complete a given application (i.e. add two 16 bit numbers). Finally, the wit and experience of programmers who design calculational algorithms, compilers, interpreters, etc., will have a strong influence on the final application.

The central processor must also keep track of the external memory in which data is stored. The amount of memory which can be accommodated is characterized by the number of "addressing" lines connecting the processor to memory and seems to be determined by 2 to the power of the number of lines. The memory addressing capacity thus typically varies from 2^{16} = 64K bytes for an Apple II with 16 addressing lines to 2^{32} or about 4 billion bytes. Table 1 summarizes the foregoing information where available, for a number of popular computers and also shows the amount of memory typically available for user programs.

The factors just discussed are by no means the only ones which determine a computer's calculating capacity. The speed at which disk drives can transfer data to and from memory can be very important. A slow printer or display system might be a critical link in a system, limiting the output of useful information. Some systems can make use of supplementary hardware arithmetic processors,[2,3] which perform complex operations such as addition, multiplication, exponentiation, division, etc. many times faster than the central processor itself. Finally the instructions provided to the processor (via high level languages such as FORTRAN, BASIC, PASCAL), through "compilers" or "interpreters" which convert the user's instructions to instructions the processor can understand can have a tremendous influence on the amount of useful calculations performed. Tables 2 and 3 compare the ability of a number of common computer systems to perform calculations on "floating point" decimal numbers of the sort which interest safety analysis. Note that neither of these "benchmark" problems involves much manipulation of data in memory nor is the ability to provide useful information to the user tested. The influence of precision (the number of digits calculated) on the speed of calculation is not tested either. The main point is that the speed of typical systems range over at least 6 orders of magnitude.

The dramatic differences in computer capacity and characteristics make a careful consideration of system and software mandatory if the intended application is to be practical. Some additional comparisons of systems on "benchmark" problems are given in references[4,5] which could be helpful in choosing a system for engineering/ scientific applications.

Appropriate Applications

Eight Bit Processor Systems: These systems are the ones which spawned the current computer craze and made the names Apple, Atari, Pet, VIC, 64, TRS80, etc., a part of our everyday language.

Business applications abound for them. Examples include spread sheet programs, graphics applications, accounting, word processing, scheduling and data base access. The 8 bit micro-computers can be applied usefully to engineering and scientific analysis. A sampling of programs we have written to solve engineering problems with them is provided in Appendix A.

The programs listed require only a fraction of the computer's user accessible memory of about 36 Kilobytes.

There are a couple of flies in the ointment. Table 2 indicates that an Apple II+ (Pascal) is 8800 times slower than a Cyber170. E. Kohn's benchmark problem (Table 3) indicates a factor of 1000 difference in computing speed. I noted a factor of 3000 difference in the running of a small program (Appendix A — FIRE).

I suspect that these "benchmarks" are favoring the micro-computers. Both programs include the calculation of many powers, logs, etc. These may well converge relatively quickly to the six to nine digits of precision typical of the micro-computers in the listing. Table 2 data is based on a repeated multiplication with the precision characteristic of the machine. The Apple calculates about 7 decimal digits (32 bit numbers). CDC calculates about 16 digits (60 bit numbers). For the sake of comparison I thus estimate that the Apple is 20,000 times slower than a Cyber170 for equal precision.

We have found that simulation of moderator circulation requires about 20 hours of Cyber170 time. This translates to about 45 years of steady calculating for an Apple II. Although they are renowned for high reliability it seems unlikely that one could be coaxed to run long enough to simulate such a problem.

Apple and other 8-bit computers can be made to calculate more quickly. A comparison (Table 2) of Apple and OSI 6502 + Hardware floating point (these computers use the same processor) indicates an improvement by a factor of about 100. The floating point processors are not very expensive. I suspect fairly sophisticated programming is needed to make them perform.

Finally the question of memory size. Computers with 8 bit processors are restricted to 30 → 64,000 bytes of user memory. It is doubtful that these computers would be able to compile and execute large programs for development and debugging purposes with this restriction on memory as the programs have been developed with many times this memory available.

In summary, micro-computers with 8 bit processors can be very useful in conducting business affairs, developing easy to use programs for engineering applications, and in new applications such as the preparation

CNS BULLETIN SNC

ISSN 0714-7074

The CNS Bulletin is the membership newsletter of the Canadian Nuclear Society; 111 Elizabeth St., 11th Floor; Toronto, Ontario; Canada; M5G 1P7. (Telephone (416) 977-6152; Telex 06-23741). Published every two months; deadline for contributions end of every odd-numbered month.

Le Bulletin SNC est l'organe d'information de la Société Nucléaire Canadienne.

CNS provides Canadians interested in nuclear energy with a forum for technical discussion. For membership information, contact the CNS office, a member of the Council, or local branch executive. Membership fee is $30.00 annually, ($5.00 to students).

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of reports and graphics, information retrieval, etc.

Eight/Sixteen, Sixteen and Sixteen/Thirty-two Bit Processor Systems: These systems are relatively new to the market (about 2 years). Their processors can address 1 or 2 orders of magnitude more memory than the 8 bit variety depending on the make.

Several of them, IBM's Personal Computer and some of its "clones," have been designed with a socket for the addition of an arithmetic processor to speed up floating point calculations. Reference (4) compares the speed of these systems with the DEC VAX 11/780 and IBM MSV370. The microcomputer seems to average only about 5 and 50 times slower, respectively, for the operations considered.

Computers in this class thus appear to be suitable, thanks to their large memory capacity, for the development of large programs. Those with arithmetic processors can also execute medium size programs quickly enough to make them practical for some of our quicker running simulations.

Some manufacturers emphasize[6] much easier use of future computer systems with innovative operating systems which use the large memory capacity to minimize the operational details a computer user must remember (or retrieve) to actually obtain useful work from the machine. Such ease of use poses the promise of the proliferation of so called "expert systems" application programs which help to make sense of a great deal of complex interrelated data. An example application, commonly quoted, is the medical diagnosis of patients by comparing user input data and symptoms to known data. Nuclear engineering seems to present a number of such possibilities as well (i.e. heat transfer, material and structure properties, post accident dose assessment, etc.).

These relatively new systems represent a great increase in computing capability over their eight bit predecessors. They don't cost much more, and with the addition of manufacturer and software company supported numeric processors can process orders of magnitude more information in a given time than their eight-bit predecessors.

Thirty-two Bit Systems: We've been reading, for the past two years, about fabulous new 32 bit micro-computers. Hewlett Parkard has begun to market one. A comparison of technical data[7,8] (Table 2) suggests that it is only an order of magnitude slower than a Cyber175. Up to 2.5×10^6 bytes of memory can be installed. This machine can sit on a desk top.

A large number of other manufacturers are also developing[9], (Table 1) thirty-two bit microprocessors and compatible numeric processors. The goal is more accessible memory and more computing speed. No computer systems are available yet, with the exception of the HP9000 mentioned above which actually make use of the processors. An array-processor chip capable of 10×10^6 floating point operations per second is said[10] to be available.

We can thus, no doubt, look forward to many interesting developments in the microcomputer art. Fortunately most of these new processors are miniaturizations of existing mainframe computers or compatible enhancements of existing sixteen bit designs. Software development should thus be minimal to make the forthcoming systems operational.

Some Nuclear Safety Analysis Applications

Differential Equation Solution: Even the cheapest available microcomputers are capable of solving a number of simultaneous differential equations.

A typical application provides an estimate of mean hydrogen concentration with time in each of two rooms comprising a reactor building. The introduction of hydrogen into one of the rooms leads to reduced density in that room which, in turn, initiates and sustains a buoyancy induced flow between the two rooms. The microcomputer solution provides computer generated plots of hydrogen concentration in the rooms as a function of several user variable parameters.

Reporting of the results provided an opportunity to explore a new kind of report, one which includes a working model of the solution in the form of a program diskette in a pocket on the back cover. It seems that this kind of extended report could lead to a greater reader appreciation and understanding of a given technical problem. The computer provides a new medium which is a useful extension of printed text and equations.

A number of discrete event and continuous (differential equation solvers) simulation languages are becoming available[11] at low cost[12] for microcomputers. These will ease the task of solving sets of equations and presenting results.

Data Processing and Display: Mainframe computers can generate a tremendous amount of numerical data. Interpretation of the data can be time consuming.

P. Hawley, of the Safety Branch, AECL, has written a program for his Commodore-64 home computer which uses data from the mainframe to provide a graphic representation of changing conditions within the reactor core. The low cost color graphics of the Commodore-64, developed for the vast video game market, are much superior to the mainframe system installed in our offices for this purpose. The formation of two phase conditions or steam in the reactor core, and its extent, is shown on the screen by changing colors in "real time" or faster.

Education Training: The Three Mile Island spawned a number of video games. They are generally stated to be educational. The message is that nuclear power plants are so complex that they are next to impossible to control and operate safely.

One of the games, "Three Mile Island"[13] alleges to put you, the players, at the controls of a pressurized water reactor. The goal is to generate power while making a profit and avoiding release of radioactive materials to the environment. The ultimate "catastrophe" is a "meltdown" of the reactor core.

The controls for the game are very complex. I invariably end up in a "meltdown" situation. The graphics of the game are commendable and suggest the utility of even rudimentary graphic systems as a training and educational tool.

Dispersion and Dose Assessment: R. Mourad of the Containment Analysis Branch, AECL, has undertaken the development of a microcomputer program to give life to the Canadian Standards Association standard on dispersion and dose. The program uses stored data for a number of nuclides along with dispersion and dose assessment relations to evaluate the consequences of postulated (or real) accidents which release a known amount of radioactive material. The code is designed for safety analysis and will have application to emergency planning and training simulations. This application of the microcomputer borders on, and could well develop into an "expert" system.

Containment LOCA Response Simulation: AECL's containment analysis program PRESCON-2 has been designed from its inception to use relatively little computer time. Its ability to complete useful simulations in a few tens of seconds of mainframe computer time make it a likely candidate for transfer to the microcomputer environment.

In the past few months software (FORTRAN compilers),[14, 15] which is compatible with PRESCON-2 and makes use of the numeric processor for the IBM Personal Computer has been made available. The increased computational speed expected from this combination suggested that the time had come to transfer PRESCON-2 to the relatively standard FORTRAN-77 used by the Personal Computer. The aim is to make the program available to a wider group of users.

The transfer has been quite straightforward. PRESCON-2 is comprised of about 3700 lines of FORTRAN source code which uses, when compiled, about 320K bytes of memory on a CDC720. It is easily accommodated, without segmentation or the use of overlays, by a 256K Personal Computer once compiled. The limited installed disk storage capacity of two 320K floppy disk drives with our particular system poses some hardship as the program must be broken down to allow for large temporary files generated by the compiler program. The program executes sufficiently quickly (about an order of magnitude slower than the CDC720) to be practical in use.

Early experience with the program reveals the inappropriate nature of the large amount

Table 1
A Sampling of Computer Central Processors

Processor	Data Lines	Register Size (Bits)	Address Lines	Typical User Memory (K Bytes)	Cycle Speed (MHz)	Typical Computers	System Cost
6502	8	8	16	35	1,2,3	Apple IIe Commodore 64	$1 - 3K $1 - 2K
Z80	8	8	16	35	4,6	Radio Shack Timex Sinclair Osborne	$2 - 3K $0 . 3K $2K
6809	8	16	16	35	1,2	Color Computer	$1 - 2K
8088	8	16	20	512	5	IBM PC/XT TI Professional HP150	$4 - 8K
8086	16	16	20	512	8,10	Similar to 8088	
68000	16	32	24	1024 +	8,10	Apple Lisa Apple MacIntosh Radio Shack 16 IBM 9000 HP3000	$5 - 10K $4K $10K ? ?
HP Focus	32	32	32	< 2500	18	HP9000	$50K +
DEC MicroVax 2	32	32	?			None ?	?
Intel; APX386	32	32	?		16	None ?	?
Motorola 68020	32	32	?			None ?	?
NS32032	32	32	?		10	None ?	?
DEC?	?	32	?	1024	?	VAX-11/780	?
CDC?	?	60	?	800	?	Cyber170	Lots

Table 2
System Computing Speeds — Microcrunch Benchmark (Taken From Reference 2)

```
10 A = 1.00013          40 X = X * A
20 X = 1                50 NEXT I
30 FOR I = 1 TO 40000   60 PRINT X
```

Computer	Language	Flops**	Reference
Radio Shack Model II (8 bit)	BASIC Interpreter	2.6×10^2	2
Timex-Sinclair ZX81	BASIC Interpreter	1.1×10^2	Test
Apple II (8 bit)	BASIC Interpreter	1.9×10^2	2
Apple II (8 bit)	Pascal Compiler	3.4×10^2	2
IBM PC	FORTRAN	7.3×10^2	Test
PDP 1103 w/Hardware Floating Point	FORTRAN	4.0×10^3	2
IBM PC + 8087	FORTRAN	9.3×10^3	Test
OSI 6502 (8 bit) + Hardware Floating Point	BASIC Compiler	1.1×10^4	2
PDP 11/34	FORTRAN	4.0×10^4	2
CDC Cyber 720	FORTRAN	5.0×10^4	Test
VAX 11/750 (DEC)	FORTRAN	4.0×10^5	2
HP 9000 (32 bit micro)	?		Advertisement
CDC 6600	?	1.0×10^6	3
CDC 7600*	?	4.6×10^6	2
CDC Cyber 170 - Model 175	FORTRAN	1.3×10^6	Test
CRAY 1	FORTRAN	6.0×10^7	2
CDC Cyber 205 Vector	?	8×10^8	Advertisement

- * 5 to 6 times faster than CDC 6600 per Ref. 2.
- ** floating point operations per second = defined here and in Reference 2 as 40000/execution time.

Table 3
E. Kohn (Safety Branch, AECL) Benchmark

```
 5 TI$ = "00000"                      40 D = A + B + C + A + B + C
 7 FOR AA = 1 TO 10                   50 IF A > B AND C > D THEN 60
10 FOR A = 1 TO 10 STEP 0.1           60 NEXT A
20 B = A * A^A * EXP(-50/A)           70 NEXT AA
30 C = SIN(A) * SQR(A)                80 PRINT TI$
```

Computer	Run time - Seconds	Language
HP 41 Calculator	3600	HP 41
Sinclair ZX81	307	BASIC
Texas Instruments Model 99	741	BASIC
Commodore Superpet (6502)	241	BASIC
IBM PC	220	APL
Apple MacIntosh (Double Precision)	210	BASIC
Radio Shack TRS 80	205	BASIC
Commodore 64	169	BASIC
Apple II +	192	FORTRAN - PCODE
Apple II +	160	BASIC
Commodore Superpet (6809)	127	BASIC
IBM - PC	125	MICROSOFT FORTRAN
IBM - PC	57	BASIC
IBM - PC (+ 8087 chip)	19.5	APL
IBM - PC (+ 8087 chip) Double Precision	3.66	MICROSOFT FORTRAN
IBM - PC (+ 8087 chip)	3.23	MICROSOFT FORTRAN
HP - 9000	1.475	BASIC Compiled
Cyber 720	0.551	FORTRAN
CDC Cyber 170 - Model 175	0.154 Adj.	FORTRAN

Appendix A
Some Micro-Computer (Apple II +) Engineering Applications

Filenames	Language	Description Comments
BREATHE BREATH2 PRESS	BASIC (Apple) Pascal (Apple) BASIC (C-69)	These programs calculate transient containment pressure changes due to leakage through the walls. The programs are intended to explore the influence of external barometric pressure fluctuations on long term containment leakage. Several days real time can be simulated in a few minutes. (See IUNUMBERS, IUDIFFSOLVE)
SSHC	BASIC	2-D steady state head conduction solution by the relaxation method. Convergence of a 25 x 25 grid requires a few hours of computer time.
H2MIX	Pascal	Program to evaluate mixing of H_2 postulated to be released following LOCA/LOECC. (See IUNUMBERS, IUDIFFSOLVE)
CALTUB 4	FORTRAN	Solves for temperatures of heated tubes cooled by radiation and convection. Also installed on CDC-720 at AECL Sheridan Park, Mississauga.
FIRE	FORTRAN	Calculates vented and unvented vessel pressure during combustion of a hydrogen air mixture. Transferred from AECL CRNL CDC Cyber 170-Model 175. Runs about 3000 times faster on CDC than on Apple.
ONE-D EXPLICIT ONE-D IMPLICIT	BASIC BASIC	Transient solution for temperature in one dimensional slab. Results are plotted. Allows comparison of two differing numerical solutions.
NOZZLE-PIPE NOZZLE-PIPE PLOT ISENTROPIC NOZZLE COMPFRIC	BASIC BASIC BASIC BASIC	Series of programs which calculate relationships between Mach Number and flow properties. NOZZLE-PIPE calculates gas flows through a nozzle connected to a pipe. Program determines whether flow is choked at the exit or not. Flow velocities, etc., calculated along the pipe. Applied to relief valve and piping in Bruce-B vacuum building.

Appendix A (Cont'd)

SLABTEMP	Pascal	A number of related one-dimensional transient solutions of heat conduction problems. Classical Fourier series solution techniques are used. Plots are generated. May be applied to gaseous diffusion as well.	IUNUMBERS	Pascal	A set of sub-routines to aid the interactive input of numbers at a computer console. (Used by BREATHE and H2MIX). Documented in Maple Orchard, Volume 2, Number 3, 1982.
GAS4	Pascal	Calculates viscosity and conductivity of a wide range of gases and gas mixtures in SI units. User supplies only temperature and mole fraction of components.	PLOTTER7 IVPLOTLIB2	Pascal Pascal	Pascal programs to interactively read computer or user generated files of data, calculate plot scales, plot data and label the plots.
GAP BETWEEN PLATES ANNULUS CONVECTION HORCYLINDER-CONVECTION	BASIC BASIC	Interactive program to calculate heat transfer coefficients. User supplies data. Program determines whether laminar or turbulent flow and returns heat transfer coefficient.	SMF100% SMF2%	BASIC (C-64)	Iterative simultaneous solution of five equations to obtain estimates of long term containment peak pressure.
IUDIFFSOLV	Pascal	A library UNIT of sub-routines used in the solution of systems of equations (See BREATHE and H2MIX).	CSITRANS	BASIC (Sinclair ZX81)	Simulates transport of water soluble fission product in the primary heat transport system and containment.

of output data displayed. The output format was designed at a time when computation of the data was very expensive. Everything was saved on paper in case it should be needed later. It is apparent that the nature of the output displayed needs to be changed (perhaps direct graphical displays) to limit it to that needed for the job at hand. The state of the computer art is getting to the point that the computations are cheaper than the paper.

Discussion and Conclusions

Skeletal material which allows the comparison of a number of computer systems on a performance basis, from low cost household microcomputers to state-of-the-art super computers has been presented. A brief outline of engineering applications (an area almost ignored by the microcomputer industry to date) of microcomputers with some examples is presented. Exciting developments in 32-bit microcomputers, array processors, low cost memory, and software make it likely that we will have current "mainframe" computer power on our desks and in our homes in a very few years. The proliferation of microcomputers has potential for a reduction in the cost of nuclear safety analysis. The savings will come from the benefits of mass production of computers and application programs.

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D.R. Pendergast

CNS Division Update

CNS Remote Handling Conference Report

The Canadian Nuclear Society's Conference on Robotics and Remote Handling in the Nuclear Industry, organized by the Mining, Manufacturing and Operations Division in Toronto, September, attracted a large number of attendees and a wide range of topics in the 40 papers presented. The title of the conference was open-ended enough — "Robotics and Remote Handling in the Nuclear Industry" — to attract a catholic array of contributions. Discussions ranged from the highly analytic — the application of uncertainty covariance matrices in the analysis of robot trajectory errors[1] — to the "nuts and bolts" of remote machining and welding at the TRIUMF (Tri-University Meson Facility) proton cyclotron[2].

Remote handling covers a range of activities and equipment, from poking things with long sticks (long handled tools operated from behind shielding), through using long articulated sticks with electric motors to do the heavy work (the master-slave manipulators, or, on a larger scale, remotely controlled cranes) to using long articulated sticks with electric motors controlled by some automatic system and monitored from a distant location (computer controlled equipment — a precursor of the "robot"). This progression sees (a) human beings removed from the immediate vicinity of a hazard (such as radiation), (b) removal of the human physical limitations of strength and stamina and (c) frees human operators from repetitive routine control tasks, leaving them free to *monitor* the process and intervene when things become non-routine.

From the perspective of an electrical utility operating nuclear power stations, all these activities and equipment must be specifically aimed at the operation, inspection and maintenance and repair of nuclear power reactors.

Remote Handling in Reactor Operations

In Canada, remote handling and computer controlled operation is inherent to the CANDU system. All commercial power reactors use dual computer control to maintain reactor power at a demanded level, accommodating fluctuations of reactivity due to fuel changing and so on. Additionally, all CANDUs use remote controlled, on-power fuelling systems with which Canada has now 22 years' experience. Fuel handling equipment must meet particularly rigorous requirements, in that the mechanical systems must be able, with high reliability, to locate and engage one of up to 480 fuel channels, match primary coolant system pressure, insert new fuel and receive irradiated fuel, seal the visited fuel channel and transport the irradiated fuel to its storage bay. Experience with fuelling equipment has been good, but problems can arise, and it is here that we see another important requirement of any remote handling system: the operator must be able to monitor the status of the equipment — in detail and rapidly — so appropriate interventions can be made when necessary. It is in this area that significant development has appeared for the Darlington station's fuel handling equipment. At the Darlington Nuclear Generating Station (a 4x850MW installation scheduled to come into service between 1988 and 1992) new monitoring and intervention systems (under development by the Canadian General Electric Co.) for the fuel handling equipment are expected to increase safety and reliability as well as reducing operator training time.[3] Menu-driven colour graphics displays will provide information on the status of all fuel handling sub-systems, backed up with textual information positioned to relate to the component in question. The displays will be animated to reflect the movement of components in the field. The use of menu-driven displays is regarded as especially significant, since it utilises the more powerful human faculty of *recognition* of a desired command rather than *recall*, restricts on-screen information to relevant data only, provides information on related components and provides information in more than one format.

Operator intervention will be via a semi-automatic control program — an important advance over earlier fuel handling control systems which involve a comprehensive manual control panel and feedback information, when provided, in the form of binary coded lights or single set-point lights — readily open to misinterpretation. The large number of individual steps required to get any machine action also increase the probability of error. The new control program, an interactive system, will, like the monitoring system, use textual and graphics displays to represent equipment positioning and set-points and limits. Commands overstepping these limits will be disallowed, a restriction which will only be circumvented by the use of documented override procedures. The control program essentially eliminates the large number of individual manual control steps required before any machine action can proceed, allowing the operator to *manage* the system rather than serving it.

Cost-Benefit for Remote Handling

There are some cases where the decision to use remote handling equipment is unequivocal. Where extreme radiological hazards exist, (such as in fuel handling) or where a clear-cut saving in time will result (such as in the piping repairs to the commercial prototype Douglas Point Nuclear Generating Station,[4] the employment of remote techniques and systems is a given. But in circumstances where radiological hazards, replacement power value or direct labour costs do not make remote handling a clear necessity, can remote handling significantly reduce costs? This question has been investigated by both Ontario Hydro[5] and Atomic Energy of Canada Ltd.,[6] a move prompted by the fact that increasingly utility operations are going to be concerned with the maintenance and repair of existing installations, rather than the construction of new ones. For inspection procedures at a "generic" CANDU, AECL has derived a "cost" of $6350 per man-rem, and, using heat transport piping weld inspection as an example, suggests the optimum expenditure on remote handling equipment would be $10,200 for each weld inspected with *zero* radiation exposure. Ontario Hydro identifies two significant cost components for work carried out in a radiation environment: the cost of supplying radiation protection services — about $2000/rem and the variable cost based on wages for maintenance staff. The first component includes protection staff salaries, protective equipment and clothing, radiation protection training and dosimetry. The second component is a function of task completion time and task complexity (i.e. training/rehearsal requirements) and these two factors are very sensitive to reductions in staff efficiency imposed by the peculiar requirements of a radiation environment. Protective clothing is a particularly good example — a full air suit can reduce a worker's efficiency by more than 50 percent. Clearly, any equipment that can speed up work, or reduce the numbers of people required to work in a radiation environment or, best of all, eliminate the requirement for any significant work time spent in that environment offers the prospect of considerable economic savings as well as following the ALARA principle (radiation exposures to be kept As Low As Reasonably Achievable).

Reactor Repair and Maintenance

One important area of reactor repair and maintenance in which practical application of "robotic" technology has made a major advance is that of steam generator inspection and repair. Steam generator tube leaks are an ongoing maintenance headache for reactor operators in the US. Tubes are subject to a number of mechanical and chemical damage mechanisms, and inspection and repair operations (in some case as radical as steam generator replacement) are costly both in downtime and personnel exposure. The situation can only get worse with time as steam generators age and radiation fields increase (Interestingly enough, this has not been the experience north of the US-Canadian border where steam generator tube leaks have only accounted for 0.3 percent of outages).

Two American NSSS vendors have developed computer controlled remote inspection and repair manipulators which promise to have significant impact on downtime and exposure costs. The Babcock & Wilcox "ROGER"[7] (Remotely Operated Generator Examination and Repair) is a three-jointed mechanical arm, computer controlled from a command centre outside reactor containment. Installing the equipment does not require entry into the steam generator channel head — an important feature for exposure considerations since fields of over 14R/hr can be experienced in these areas. The arm can carry out a full range of inspection, leak detection and repair operations, including eddy-current testing, helium leak detection, tube plugging and remote welding. Since its commercial introduction in January 1984, ROGER has carried out tube inspections and repairs on 18 steam generators (13 recirculating and 5 once-through), with an estimated personnel exposure reduction of 30-50 percent.

ROSA (Remotely Operated Service Arm), developed by Westinghouse Electric, is a somewhat more generic tool. While steam generator tube repair will undoubtedly be its most widespread application, the device's first assignment in February 1983 was measuring and plugging holes in a PWR core barrel — a job involving three days' underwater operation.[8] Westinghouse describes ROSA as a family of robotic arms, rather than a special-purpose tool. Like the B & W ROGER, the device is computer controlled and self-installing in its steam generator repair application. However its modular construction (each "joint" or actuator is a self-contained unit) means that not only can it be built up to a six degree-of-freedom unit (which the control software will support) but also that field repairs are quick and simple — a failed actuator can be readily replaced by plugging in a new one. Aside from its steam generator tube repair application, ROSA is expected to see employment at Three Mile Island-2 for core dismantling work, and Ontario Hydro is currently evaluating its capabilities for possible CANDU assignments.

In Canada the development of remote handling equipment associated with reactor repair and maintenance has been principally oriented towards inspection, adjustment and replacement of pressure tubes. Large scale pressure tube replacement, has, from the inception of the CANDU system, been envisaged as a planned refurbishing process to extend reactor lifetime. However the March 1984 decision by Hydro to commence replacement of Zircaloy-2 tubes at Pickering Units 1 and 2 has accelerated the development of remote tooling and inspection equipment to support this work. The Atomic Energy of Canada Ltd. CIGAR (Channel Inspection and Gauging Apparatus for Reactors) pressure tube inspection equipment[9] was rapidly modified following the August 1983 pressure tube failure at Pickering 2, to permit its immediate use. The modified CIGAR (known as "CIGARette") was successfuly used to locate garter spring spacers, measure the space between the pressure tube and the bottom of the calandria tube and check for hydride patches on the pressure tube OD.[10]

Spar Aerospace is currently developing a large remote manipulator system which, in association with remote work stations located on a reactor's fuelling machine bridge, will handle the cutting free and removal of pressure tubes. The system will be controlled from outside reactor containment. While it is unlikely this equipment will be ready in time to play a major role in the retubing of Pickering 1 and 2 (expected to be complete by 1987) the equipment will be ready for future retubing operations. The development trend in remote handling equipment is towards increasing use of computer control (so the operator can concentrate on *managing* the operation) of sophisticated task-specific systems. However there is a major role for comparatively simple "low tech" equipment as Ontario Hydro's experience with a Remote Mobile Investigator (RMI) unit shows.[11] In September 1982 at the Bruce Nuclear Generating Station, a fuel bundle was damaged while being transferred to the irradiated fuel bay. Fragments of two fuel elements were spilled on the fuelling machine trolley deck, and other fragments remained inside the fuelling machine snout. The fragments were highly radioactive — fields about 1 ft from the fragments were of the order of 5,000-10,000 R/h. It is significant that during a manual clean-up of fuel fragments at Bruce in 1979 following a similar kind of incident, one worker received the highest over-exposure in the history of Ontario Hydro's nuclear program, about 2.5 rem over the annual 5 rem limit. Clearly, there was a strong case for some kind of remote operation. A PEDSCO Remote Mobile Investigation Unit was purchased and, after minor modifications not only flawlessly recovered the fuel fragments, but decontaminated the area afterwards. The estimated total radiation "dose" seen by the RMI was estimated to be 10,000R.

It is interesting to note that this device is essentially an "off the shelf" machine. Designed for bomb-disposal work and hostage incidents, it's a six-wheeled articulated vehicle fitted with a manipulator arm and a TV camera. Powered by two 12 volt batteries supplying DC motors driving all six wheels, the machine is highly manoeuverable, rugged and cheap — less than $25,000. This last was a not insignificant consideration in that had the machine become seriously contaminated, it would have to have been scrapped. The RMI has seen considerable use with police and security services in Canada and abroad and has become established as a reliable and versatile piece of equipment. In the Bruce operation, the RMI was controlled via a 60 m (200 ft) umbilical cable instead of the available wireless control system. This meant that not only were possible problems with RF interference avoided, but also the on-board batteries could be recharged if necessary and the umbilical cord could be used as an emergency "manual retrieval system." Future possible applications for the RMI at Ontario Hydro include radiological survey, visual surveillance and recovery of materials and components.

Future Developments

While the term "robotics" is seeing increasing usage in discussions of remote handling technology it is clear that it will be a long time before we can expect earthbound versions of the *Star Wars* robots R2D2 and C3P0 to be carrying out reactor maintenance and repair jobs in nuclear plants (though it might be observed by *Star Wars* experts that R2D2 has one thing in common with such devices as ROSA — capability of using a wide variety of end effectors on a general purpose manipulator!).

The trend appears to be towards development of sophisticated task-specific systems. Nuclear equipment vendors certainly have an opportunity to make up for any drop-off in reactor sales by developing their repair and maintenance services, as Westinghouse and Babcock & Wilcox are. This is one area in which business can only be expected to grow, as the present generation of nuclear reactors reach middle age and newer power plants, designed with an eye to remote maintenance, come into service.

But as Ontario Hydro's experience with the RMI shows, low cost, "low tech," simple, reliable remote handling systems have a place in the sophisticated world of nuclear power generation.

Proceedings of the conference are available from the CNS office, $40.00 to CNS members, $50.00 to non-members.

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3. Keelan B.G. *System Monitoring and Operator Intervention Methods for the Darlington Fuel Handling Man-Machine Interface.*
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David Mosey

Conferences & Meetings

International ANS/ENS Topical Meeting on Probabilistic Safety Methods and Applications

Sponsored by the American Nuclear Society, co-sponsored by the Canadian Nuclear Society et al., to be held **February 24-28, 1985**, in San Francisco, California.
For information contact: **Ian B. Wall, Electric Power Research Institute, 3412 Hillview Ave., P.O. Box 10412, Palo Alto, California 94303.**

Workshop on Radioactive Waste Management

Organized by Canadian Radiation Protection Association, to be held **February 27-28 and March 1, 1985** in Toronto. For information contact: **John Tai-Pow, Ontario Ministry of Labour, Radiation Protection Laboratory, 81 Resources Rd., Weston, Ontario, M9P 3T1.**

Second National Topical Meeting on Tritium Technology in Fission, Fusion and Isotopic Applications

Sponsored by American Nuclear Society and co-sponsored by Canadian Nuclear Society, to be held **April 30 - May 2, 1985** in Dayton Ohio. For information contact: **T. Drolet, Canadian Fusion Fuels Technology Project, 2700 Lakeshore Rd. W., Mississauga, Ontario, L5J 1K3.**

25th Annual International Conference of the CNA and 6th Annual Conference of the CNS:

Co-sponsored by Canadian Nuclear Society and Canadian Nuclear Association, to be held **June 2-5, 1985** in Ottawa, Ontario. For information contact: CNS.

International Symposium on Nuclear Analytical Chemistry — Call for Papers

The objective of the symposium is to provide a forum for information exchange on recent developments in nuclear analytical chemistry, both fundamental and applied aspects. To be held **June 5-7, 1985** at Dalhousie University, Halifax. For further information contact: **Dr. A. Chatt, SLOWPOKE, Reactor Facility, Dalhousie University, Halifax, N.S., B3H 4J1.**

International Topical Meeting on Computer Applications for Nuclear Power Plant Operation and Control — Call for Papers

Sponsored by American Nuclear Society, co-sponsored by Canadian Nuclear

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Society and European Nuclear Society, to be held **September 8-12, 1985** in Pasco, Washington. Papers are solicited in a broad range of topics related to both actual and potential computer use in aiding manual and automatic control of nuclear plants. Applications may include plant control, maintenance, data acquisition and display, signal validation, management and status control, procedures, and emergency response. Related issues will be explored in special sessions and tutorials. Conference sessions will be groups as follows: 1). current uses of computerized systems in nuclear plants worldwide; 2). state-of-the-art control methods that are possible but not yet operational in existing plants; and 3). future applications and pertinent research in hardware and software. Deadline for 1000-word summary and 100-word abstract: **February 15, 1985**. Author notification: **April 15, 1985**. For detailed instructions on paper preparation, contact: **Technical Program Chairman Alan E. Waltar, P.O. Box 1970, Richland, Wash. 99352;** or **Lino Magagnia, Ontario Hydro, 700 University Ave., Torontó, Ontario, M5G 1P7.**

International Topical Meeting on High Level Nuclear Waste Disposal — Call for Papers

Sponsored by the American Nuclear Society, co-sponsored by Canadian Nuclear Society, to be held **September 24-26, 1985** in Pasco, Washington. Summaries on the subjects: site characterization and selection, repository engineering and construction, package design and testing, disposal system performance, disposal and storage system costs, disposal in overall fuel cycle context, are due **January 31, 1985**. For further information contact: **Dr. H.C. Burkholder, Battelle, Pacific Northwest Laboratory, P.O. Box 999, Richland, WA 99352.**

3rd International Conference on Nuclear Technology Transfer — Call for Papers

Sponsored by Spanish Nuclear Society, American Nuclear Society and European Nuclear Society, to be held **October 14-19, 1985** in Madrid. Summaries due **February 28, 1985**. For further information contact: **Myron Kratzer, International Energy Associates, Suite 600-600, New Hampshire Ave., Washington, DC 20037.**

The Unfashionable Side

Back to Babbage

I was lucky enough to have lunch with Dr. Dennis Molestangler shortly after his return to Canada from his 18 month sabbatical in England where he was studying alternative propulsion systems for aeroplanes. Over a few beers in the fashionable Hydride Bar at *The Star and Garter Spring* (a popular off-campus hostelry for Aphasia University faculty), Dr. Molestrangler outlined some of the conclusions he reached in the course of his project and described a dramatic new program to be launched at Aphasia University.

Due for publication in the New Year, Dr. Molestrangler's exhaustive study of propulsion systems for flying machines (both aerodynes and aerostats) will undoubtedly have a major impact on the aviation industry. Entitled *The Reciprocating Steam Engine — Cinderella of Aviation* it is expected to become required reading for design staff at Pratt & Whitney and Rolls-Royce.

Of even greater potential impact, however, is Dr. Molestrangler's revolutionary approach to computation. Computers, Dr. Molestrangle points out, have had a dramatic effect on the work of engineers or scientists. Whether a massive number-crunching mainframe or a compact "transportable," these devices place unparalleled calculational and data handling power in our hands. But, Dr. Molestrangler argues, they suffer from two major disadvantages: they are vulnerable to the vagaries of electrical supply, and they distance the operator from the computational process, taking all the fun out of it. "I can well remember one summer job I had at an engineering firm," he said, absently fingering the controls of his clockwork powered pocket abacus, "The office calculator was a magnificent piece of machinery. It looked like something somebody had pinched off the bridge of a battleship. When you turned it on the whole building shook and the street lights dimmed. And one of the junior engineers actually lost a hand while trying to extract a square root. Now *that* was what calculation was all about."

"This is all very well" I said, "But wasn't that machine equally vulnerable to an interruption in the supply of electrons?"

"Precisely," he responded, "So this is where Aphasia University's Back To Babbage Society has a part to play. This new society exists primarily to sponsor the development of a steam-engine powered Babbage-type Difference Machine. The steam engine should be a butane burning device, but also capable of using moonshine, peanut butter or old computer printouts as fuel. Modern synthetic materials and injection moulding techniques mean that the production of large numbers of gear-wheels will be quite economic and certainly cheaper than silicon chips. And for the first time in many years, we'll actually be able to watch our calculations in progress."

So far, Dr. Molestrangler informs me, the Back To Babbage Society is a fairly small group and funds are consequently limited. But a membership drive is to be launched shortly. Membership applications (including $40 fee) should be addressed to Dr. Dennis Molestrangler, Aphasia University, care of this column.

Ernest Worthing

Chuck Wood reports that Dr. Solomon Breeder has been sent up the river by the S.E.C., that Gecko Solar Laboratories, Inc. has filed under Chapter 11 and that ASLEEP has become a "missing" association. Wood has since found gainful employment as a fuel bundle at Pickering N.G.S.