CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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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 $50.00 annually, $25.00 to retirees, $15.00 to students.

La SNC procure aux Canadiens intéressés à l'énergie nucléaire un forum où ils peuvent participer à des discussions de nature technique. Pour tous renseignements concernant les inscriptions, veuillez bien entrer en contact avec le bureau de la SNC, les membres du Conseil ou les responsables locaux. La cotisation annuelle est de $50.00, $25.00 pour les retraités, et $15.00 pour les étudiants.

Guest Editorial

Con-Fusion

Tom Watson

We've come to the conclusion
That the energy of fusion
Is attainable, and wonders will accrue.
But though scientists believe it
And are trying to achieve it
It is going to be a tricky thing to do.

It's going to cost an awful lot
And it's got to be so hot
That the temperature is hotter than the sun.
The reactor they're designing
To facilitate combining
May be ready in year twenty twenty-one.

Imagine their dismay
When they learned another way
Had been found to cause deuterium to fuse!
The incomplete report
Describes a small retort
Just like the kind of thing that students use.

Oh it would be terrific
If this neat electrolytic
Method were amenable to proof,
But the numerous detractors
Say they're sticking to reactors
And their language is inclined to hit the roof.

Oh isn't it a pity
That the team in Salt Lake City
Is so hesitant to tell us what they did.
They defend a patent pending
While their images they're mending
And the scientists are checking on their bid.

Perhaps abundant power
Will be hastened into flower
And the wond'rous age of energy will dawn,
But perhaps this easy fusion
Will turn out to be illusion
And the dedicated work will still go on.

An internationally recognized corrosion specialist, Tom Watson founded the Corrosion Service Company Ltd, is past Chairman of that company's Board of Directors and is a former President of the National Association of Corrosion Engineers. As can be seen from the above he maintains a keen, ongoing interest in the development of fusion energy systems.

Fifty years on

Marking the first half century of uranium fission has been, justifiably, an occasion for some celebration by the nuclear energy community. Anyone who might raise the odd eyebrow at what might seem to be an excessive degree of self-congratulation could be quickly reminded that there is much for the nuclear energy enterprise to be self-congratulatory about. And anyway anniversaries are fun to celebrate and can occasion much pleasurable, exciting and even inspiring reminiscence.

But behind all the backslappings, enthusiastic toasts and happy recollections of the grand old days when men were men and a dollar was a dollar it's important to keep at the back of our minds a clear idea of where we've really come from, and where we may be going.

In the November/December 1988 issue of the *Bulletin* Keith Weaver drew attention to the the depth and mass of the foundations upon which our enterprise is built. While the Hahn Strassman discovery is justifiably celebrated, it is surely not mere pedantry to suggest that the theme statement for the celebration should include the qualifier "exothermic".

The Relationship

Earlier this year immediate past President Ken Talbot renewed the agreement between the CNS and the Chinese Nuclear Society. In the light of the events in China last June all CNS members should be carefully considering whether that agreement should be maintained.

There has been widespread international condemnation of the Chinese government's use of armed and armoured troops against essentially unarmed civillians and the subsequent invocation of the traditional apparatus a state brings to bear against internal threats.

What should the CNS position be? Should we even have one? The possible reactions range from an absolute repudiation of the agreement to doing absolutely nothing. Quite defensible rationales can be advanced in support of any of these possible reactions. But one thing is quite clear: the position must be considered. It may well be decided that no reaction whatsoever by the CNS is desirable – but this decision must be *made* – it cannot go by default.

Nor can this decision be made just by Council without reference to CNS members. Every member has a duty to let Council know, quite explicitly, what his or her feelings are on this matter. As noted above, compelling arguments can be advanced for maintaining and increasing contact with our collegaues in the People's Republic of China. And equally compelling ones can be made for giving notice to terminate the agreement. There's probably no "right" answer, but each member should consider the matter carefully and see that his or her view is transmitted to Council.

The Most Expensive Assumption

In his late thirties, Bruce Ames is Chairman of the Department of Biochemistry at the University of California (Berkeley) and has already attained the stature of an elder statesman in the business of research on carcinogens. In recent times he has also taken his views on the subject on the road.

Much of the 'carcinogenic hysteria' of today is the result of bad science, he claims. Fears that pesticide residues in food and trace quantities of industrial chemicals in air and water pose significant dangers to health, are almost completely groundless. Ames attacks as unsubstantiated and misleading the practice of submitting laboratory animals to doses of chemicals just below the tolerance level (i.e. in amounts just short of those that would be immediately fatal) as a means of determining whether the given chemical is carcinogenic in an absolute sense. The fallacy, he claims, is that the findings at these very high doses are not a reliable indicator of effects at very low doses. In defence of this position, he makes some interesting observations.

About one half of all the man-made chemicals tested turn out to be carcinogenic. More interestingly, however, about half of all naturally occurring chemicals (produced by plants and occurring in food, for example) also turn out to be carcinogenic. An intriguing group of chemicals which falls into this second category is the naturally occurring pesticides. Celery, cabbage, onions and many other vegetables produce their own pesticides, and these chemicals can be present in the concentration range of parts per thousand. Man-made pesticides are present in concentrations of parts per million or per billion. Both can be designated "carcinogenic". Where, then, does the risk lie, or is there any serious risk? Furthermore, if a plant, such as celery, is stressed by being under attack from a pest, the levels of its natural pesticides can increase in concentration by a factor of ten. Such stress might occur, says Ames, in the absence of man-made pesticides, for example in the case where vegetables are grown "organically". Even with the use of man-made pesticides, 99.99% of the carcinogens ingested by people with their food and water are natural. The conclusion, according to Ames, is that attempts to drive out man-made "carcinogens" from our diets is not just folly, it's dreadfully expensive folly.

Where does the problem come from? It comes from the linear hypothesis, which assumes that effects at high doses can be meaningfully extrapolated to effects at vanishingly small doses.

Take note and take heart, all ye horny-handed sons and daughters of nuclear toil.

CNS President (1989-90) Eva Rosinger

Message from the President

It is indeed a distinct pleasure and honour to be elected President of the Canadian Nuclear Society. During our annual conference in June, we looked back not only on the 50 years of nuclear fission but also at the first decade of our Society.

We can look back with pride at our accomplishments: the Society's membership stands at 600 members, we successfully organized a dozen major conferences and many smaller workshops and symposia, and we have endeavoured to upgrade our publications. We have learned a lot from our experiences and we are growing stronger. Over the years, many of you have been witness to our Society's progress as you have been actively involved in the affairs of the CNS.

But we cannot stop here. We need to acquire a stronger voice and represent nuclear science and technology to the public and to the provincial and federal governments. The technology that we have developed can further our governments' objectives of a clean environment and enhanced industrial competitiveness and can make a substantial contribution to the future of our world.

Canadian nuclear technology is one of Canada's few enduring high technology success stories, measured in terms of jobs for Canadians, a "brain trust" of technical expertise, international recognition for technical and scientific excellence, a source of safe, environmentally sound energy and contributions to fields as diverse as medicine and agriculture.

Canada's industrial competitiveness has been based in large part upon low-cost, readily available, clean electricity. Nuclear generated electricity is safe and economical, is sustainable for centuries to come, and can contribute significantly to the enhancement of Canada's competitiveness.

For the next year, you have elected a very capable and enthusiastic Council with several new members to provide fresh ideas. The members of your Council are listed elsewhere in this Bulletin.

Your president and your Council have again an ambitious programme plan for the next year. To strengthen our membership base, we must involve more people in our Society. We need the expertise and experience of academics from universities and colleges, medical doctors involved in nuclear medicine, uranium mining and processing experts, radiation application specialists, and students - the doorway to the future. We hope to strengthen the role of our branches in various parts of Canada and increase support for them. With their help, we are aiming to increase our membership by 50%. We will continue to encourage libraries and educational institutions to join the Society as institutional members.

Several major conferences have been organized: the Second International Conference on CANDU Fuel in Chalk River (October 1-5, 1989), the Third International Simulation Symposium in Montreal (April 18-20, 1990), the Steam Generators and Heat Exchangers Seminar in Toronto (April 30 -May 2, 1990), the First International Conference on Neutron Radiography System Design and Characterization in Pembroke (August 28-30, 1990) and the International Conference on Containment Design and Operation in Toronto (October 15-17, 1990).

Of special interest to CNS members will be a world conference on nuclear technology and the environment, which is being planned jointly by the CNS and CNA for October 1993 in Toronto.

Preparations have started for the 1990 CNS Annual Conference in Toronto (June 3-7) with a strong team of organizers being assembled under the chairmanship of Nabila Yousef and Ben Rouben. We plan to establish at least a five-year horizon for CNS Annual Conferences to provide better co-ordination with annual conferences of our sister organization, the American Nuclear Society. We will strengthen our co-operation with this Society to preclude or resolve conflicts in conference scheduling and sponsorship.

The technical divisions are working very hard to sponsor and co-sponsor meetings and symposia. Council will consider re-aligning the mandates of the existing four technical divisions and possibly forming new ones (fusion, nuclear technology - which would include radiation applications).

The new redesigned Bulletin has received excellent feedback from the membership and will continue to be our flagship publication. Here is an outlet and an opportunity for all members to speak out, by writing articles, technical notes, book reviews, comments and letters to the editor. Your support in this area is important for the continuance of the Bulletin so if you have a contribution, or know of someone else who might, please contact Keith Weaver (416-592 4050), Jim Weller (416-977 7620) or David Mosey (416-592 8626).

A committee of past presidents will draw on many years of CNS experience and will be working hard this year to update the CNS constitution and by-laws to reflect more accurately our Society's coming of age. The past presidents' committee will also develop a proposal for CNS awards.

Your president and Council members hope to visit many of the local branches in conjunction with Council meetings. The CNS Council Secretary, Dennis Bredahl, has been contacting the branch executives to establish a schedule for the year. We hope to start at least one new branch, in Saskatchewan, to round up the total number of branches to ten.

I am honoured to lead such an active organization of individuals involved in nuclear science and technology. I am very optimistic about the bright future for the CNS. I look forward to the important challenge of promoting nuclear science and technology as a means of protecting and sustaining our environment while furthering Canadian science, and fostering the development of our technology.

* * *

Être élué Présidente de la Société Nucléaire Canadienne est pour moi vraiment un plaisir et un honneur. Durant notre conférence annuelle en juin dernier, nous avons effectué une retrospective non seulement des 50 années de l'ère de la fission nucléaire, mais aussi de la première décennie de notre Société.

C'est avec fierté que nous pouvons contempler nos réalisations: notre Société compte présentement 600 membres, nous avons organise avec succès une douzaine de conférences majeurs et un grand nombre d'ateliers et de symposia d'envergure plus modeste, et nous avons même tente d'implanter une revue technique de première classe. Nous avons appris énormement de nos expériences, ce qui permet à la Société de s'affermir davantage. Au cours des années, plusieurs parmi vous ont été temoins des progrès de notre Société par votre implication active aux activités de la SNC.

Cependant, nous ne pouvons pas nous permettre do nous arrêter ici. Nous devons affirmer notre voix afin de représenter la science et la technologie nucléaires au public en général et aux gouvernements fédéral et provinciaux en particulier. La technologie que nous representons peur contribuer efficacement aux objectifs gouvernmentaux d'une environnement propre et d'une competitivité industrielle accrue, assurant de ce fait un évanir positif pour le monde.

L'électricité produite par la fission de l'atome est une source d'énergie sure, faible et benigne pour l'environnement. Elle ne génère pas d'emissions qui contribuent aux pluies acides et à l'effet de serre.

La technologie nucléaire canadienne est l'une de réussites du Canada en haute technologie. Ce succès se mesure en termes de milliers d'emplois pour les Canadiens, d'expertise technique, d'excéllence technique et scientifique reconnue internationalement, et de contributions importantes dans des domaines aussi divers que la médecine et l'agriculture.

La competitivité de l'industrie canadienne est basée en grande partie sur la disponibilité d'électricité abondante, propre et peu couteuse. L'électricité d'origine nucléaire est sure et economique, assez abondante pour les besoins des siècles à venir, et peut contribuer de façon significative à réhausser la position concurrentielle du Canada.

Pour l'année qui commence, vous avez élu un Conseil très compétent et enthousiaste, comprenant plusieurs nouveaux membres qui apporteront des idées fraiches. La liste des membres du Conseil apparaît ailleurs dans ce *Bulletin*.

Votre Presidente et votre Conseil vous proposent encore un ambitieux programme pour cette année.

Afin de renforcer la base de l'adhésion à la Société, nous devons y impliquer plus de personnes. Nous avons besoin de l'expertise et de l'expérience des gens du milieu academique oeuvrant dans les universités et collèges, des médecins actifs en médecine nucléaire, des spécialistes des mines d'uranium et de son traitement, des experts des applications de la radiation, et, bien sûr, des étudiants que représentent notre futur. Nous espérons renforcer le rôle et le support des sections locales dans les différentes régions du Canada, et, avec leur aide, augmenter de 50 pourcent le nombre de nos membres. Nous allons continuer d'encourager l'adhésion des établissements d'enseignement et des bibliotheques.

Plusieurs conférences majeures sont au programme: La Seconde Conférence Internationale sur le Combustible CANDU à Chalk River (1-5 octobre, 1989), la Troisième Conférence Internationale de Simulation à Montréal (18-20 avril 1990), le Séminaire sur les Générateurs de Vapeur et les Échangeurs de Chaleur à Toronto (30 avril - 2 mai, 1990) et la Conférence Internationale sur la Conception et l'Exploitation des Encientes de Réacteurs à Toronto (15 - 17 octobre, 1990).

Les membres de la SNC seront particulièrement intéressés à la conférence mondiale sur la technologie et l'environnement, que la SNC et l'Association Nucléaire Canadienne sont à planifier ensemble pour octobre 1993 à Toronto.

Les préparatifs sont déja en cours pour la Conference Annuelle de la SNC à Toronto (3 -7 juin, 1990). Les coprésidents Nabila Yousef et Ben Rouben ont commencé a reassembler une forte équipe d'organisateurs. De plus, on cherche à établier un horizon de cinq ans au moins pour les Conférences Annuelles de la SNC (et de l'ANC), pour une meilleure coordination avec les conférences annuelles de notre société-soeur, l'American Nuclear Society.

Les Divisions Techniques de la SNC travaillent d'arrache-pied pour organiser et commanditer des réunions et des symposia. Le conseil soigne a une redefinition des mandats des Divisions Techniques et a en créer de nouvelles (fusion, technologie nucléaire qui incluérait les applications de la radiation).

Les commentaires des membres sur la nouvelle présentation du *Bulletin* ont été nombreux et très favorables; celui-ci continuera d'être le porte-étendard de la Société. Il est une précieuse opportunité pour tous nos membres de contribuer à la Société en écrivant des articles, des lettres ouvertes, des notes techniques, des revues de livres, ou encore en apportant leur concours a sa réalisation. Le *Bulletin* est le fruit des efforts d'un très petit groupe de personnes dévouées et enthousiastes qui ont grand besoin de votre aide. Donnez un coup de fil à Keith Weaver (416-592 6771) ou à David Mosey (416-592 8626) si vous pouvez aider ou si vous connaissez quelqu'un qui le peut.

Sur la scène internationale, nous allons renforcer nos liens avec l'American Nuclear Society et essayer de resoudre les conflits entre nos conférences. Un comité des anciens présidents va puiser dans l'expérience et la sagesse accumulées depuis bien années afin de travailler fort à la réécriture de la Constitution de la SNC et a ses règlements pour mieux réflèter de notre Société. Ce Comité des anciens présidents va aussi proposer un programme de prix et recompenses de la SNC.

Votre Présidente et les membres du Conseil esperent visiter plusieurs des sections locales a l'occasion des réunions du Conseil. Le Sécretaire de la SNC, Dennis Bredahl, se mettra en contact avec les membres de l'éxecutif des sections afin d'établir un calendrier de ces visites. Nous esperons créer au moins une nouvelle Section cette année – à Saskatoon-pour porter à dix le nombre de sections locales de la Société.

Je me sens honorée de présider a une telle organisation dynamique de personnes impliquées dans la science et la technologie nucléaires. Je suis très optimiste pour un avenir brillant pour la SNC, alors que nous allons jouer un rôle primordial de promotion de la science et de la technologie nucléaires comme protectrices de notre environnement tout en favorisant le developpement de la science, de la technologie et de l'industrie canadiennes.

Annual Conference Report

CNS Technical Sessions Reports(*)

Compiled by Paul Fehrenbach

Session 2: Small Reactor Development I

The Small Pressurized Light Water Reactor: An Appropriate Marine Propulsion Source, F. N. Macdonnell *et al.*

The AMPS-1000: An Advanced Reactor Design for Marine Propulsion A.F. Oliva.

The Nuclear Battery Programme: Progress and Future Possibilities K.S. Kozier *et al.*

Recent Initiatives at the IAEA and Within Canada to Develop Small Reactor Safety Criteria P.M. French *et al.*

SPORTS-M Prediction of Transient Behaviour in a MAPLE Heat Transfer Test Facility P.J. Mills *et al.*

The five papers were presented to audiences numbering between 25 and 40. Although the papers were well prepared all five speakers had far too much material for a twenty minute presentation. As a result there was little time for questions and, generally speaking, the answers were too long and detailed.

The first paper was an excellent review of pressurized water reactors for marine propulsion. It was followed by ECS Power Systems' paper on their proposed 1000 kWe nuclear generator for battery charging on conventional (diesel-electric) submarines. The third paper described AECL's small high-temperature reactor, proposed for electricity production in far northern communities.

After a short coffee break all three speakers were invited to address the question of licensing within present Canadian guidelines. With only five minutes' prepartion all responded bravely, but many questions remained, and it was very evident that safety criteria for small reactors are urgently needed.

The next paper, on safety criteria for small reactors, summarized past work by the IAEA and current work by a Canadian working group formed in 1988. The scope and structure of the safety criteria have been developed and a safety philosophy formulated. A draft document for peer review will be available later this year.

The final paper described the SPORTS-M thermalhydraulic computer model for the proposed MAPLE research reactor. It is a one-dimensional, two-phase model suitable for the analysis of slow transients in a large volume coolant circuit. SPORTS-M was validated by comparing predictions with measurements on a laboratory test facility.

J. W. Hilborn

Session #3: CANDU Performance and Improvements

Oxygen Addition to the Annulus Gas Systems of Pickering NGS A, Units 3 and 4 J.M. Kenchington *et al.*

Some Aspects of Darlington Status, Schedule and Complexity V. Austman.

CANDID – Integrated Design System T.H. Prescott *et al.*

New Approaches to Alarm Annunciation for CANDU Power Plants R. Olmstead *et al.*

CANDU 3 – Single-Ended Refuelling R.K Nakagawa *et al.*

Circumferential Cracking of the End Cap Welds – Case Analysis R. Sejnoha *et al.*

This session presented six papers on CANDU performance and improvements ranging from in-service experience with changes to Annulus Gas Systems and analysis and results of fuel performance to construction and commissioning experience on Darlington GS. Enhancements in design and the design process for future reactors which are currently being applied were the topics of half of the papers.

These topics were of considerable interest to conference delegates judging from the attendance at the presentations. The Alberta Room had standing room only as the presentations got underway, until more chairs were brought in. At one point 55 people crowded the room and there were up to 30 people in attendance for all of the papers in the session.

The topic which drew the largest audience was the review of the status of the Darlington generating station presented by Austman. This overview of the vast amount of new technology and the phsical resources and plant was supported by excellent slides and a video of the vacuum building dousing spray tests. Another Ontario Hydro paper presented by Kenchington (co-authors Mg and Meranda) reported on experience with oxygen addition to the gas annulus system of Pickering Units 3 and 4, a development made particularly to decontaminate these units of C-14 for the retubing programme and to achieve long term oxide renewal on the pressure tube outer surface. The results to date drew several expressions of interest in the improved resistance to hydride embrittlement for the pressure tubes and the potential for application to other other stations.

The presentation on CANDID illustrated, in an excellent series of slides, the enchanced capabilities to create designs and control the vast documentation in a large design project using computer drafting, modelling and a general purpose computer ring for analysis and documentation. The displays of the designs in 3D were a preview of the CANDU 3 station after only two years of application and were remarkably similar to physical station slides shown in the Austman presentation. CANDU 3 also featured in a joint AECL/Hydro Quebec paper (Olmstead, Pauksens and Goddyn) which highlighted the advances that have been made in computer monitoring and control technology that are now being designed into

* *Ed. Note* – Reports on sessions 1, 5, 12, 14, 17 were unavailable.

CANDU. The experience of station operators in handling large amounts of information has been used to identify where automation can assist the operator and have the system do much more such as sorting of nuisance alarms and to identify required operator actions. The resulting simplifications and enhancements to the control centre and the man-machine interface were illustrated in the presentation.

The Buchan, Mansfield and Nakagawa paper illustrated the application of proven, successful CANDU operating experience with on-power refuelling to achieve simplification, reduced equipment quantities and cost, including reactor building size reduction in the new generation CANDU 3. The discussion which followed focussed on the unidirectional core flow, the modularized, replaceable single ended fuel channel design and the differences in refuelling operations with the use of a single fuelling machine. The paper which followed reported on joint development work for COG and introduced new results in analysis which correlate with operating experience and testing of fuel. The discussion focussed interest on the ability that was being developed and demonstrated to predict fuel performance and define defect threshold parameters. The work was clearly of interest to CANDU station operators, offering the prospect of limiting fuel defects even further and maximising fuel performance.

The quality of the papers in the session was excellent and the topic was an important one and of great interest to many of the delegates to the conference. The session drew attendance from representatives of all CANDU user utilities, domestic and abroad. It appears that topics on performance experience, improvements, engineering and directions in new design could be expanded next year and would generate the interest to warrant two sessions.

D.W. Bredahl

Session 4: Fuel Channel Design Performance and Monitoring

Irradiation Induced Deformation in CANDU Fuel Channels R. Dutton.

Pickering NGS: Assessment of Calandria Tube Integrity Following Sudden Pressure Tube Failure P.S. Kundurpi *et al.*

Design Features of the Fuel Channel to be used in the Retubing of Pickering 3 and 4 R. DeGregorio and J.L. Wills.

The Evolution of Pressure Tube Sampling Tools for Life Assessment R. Joynes and C.A. Kittmer.

Remotely Operated Inspection Equipment for the CANDU Fuel Channels K.S. Mahil *et al.*

Comparison of Measured and Calculated Dose Rates and Activities During Pressure Tube Replacement in Pickering Units 1 and 2 K.M. Aydogdu *et al.*

The papers presented in this well-attended session (audience numbers ranged from 20 to 40) covered a wide range of topics associated with fuel channels, from work to understand the effects of radiation damage to the crystal structure of the metal (zirconium) to the practical and realistic changes which can be incorporated into a retubed reactor.

Dutton and Woo have long been associated with deformation of fuel channels caused by irradiation. Their present work on the isotropic migration of vacancies and interstitials will lead to much better predictions of fuel channel deformation during service. A "layman's guide" to this topic, written by R. Dutton, is soon to be published by the CANDU Owners Group.

Kundurpi, Muzumdar and Tran concluded in their paper that in the event of a pressure tube rupture at full power in Pickering "A" there is a margin in the strength of the calandria tube which will prevent its rupture. This work is part of a continuing programme to assess calandria tube integrity following pressure tube rupture.

Fuel channel design modifications to be incorporated into the Pickering Units 3 and 4 retubing were the subject of a paper by DeGregorio and Wills. Improvements are limited to those that correct for initial deficiencies (ie garter springs) and improve the installability of the channel whilst not compromising the 23 month retubing schedule. The process will follow the evolution of steady improvements to fuel channel designs.

A related paper by Aydogdu, Boss and McKean compared calculated and measured dose rates during the Pickering Units 1 and 2 retubing and found good agreement in most instances. Poor agreement was found in the case of the transfer flasks and the reason for this discrepancy is currently under investigation.

Fuel channel inspection is becoming more critical and more extensive. Papers by Mahil, Larvis and Donnelly of Ontario Hydro and Joynes and Kittmer of AECL-CRNL included the tools CIGAR (which has so far completed about 270 full-length inspections PIPE and BLIP as well as new devices to take "scrape" samples for deuterium analysis – a sort of destructive NDE method. Discussion of these papers also covered the possibilities of on-line inspection in the future. An on-line device to monitor garter spring positions is currently under development and is scheduled to receive its first trial in February 1991.

George Field

Session 6: Thermalhydraulics I

Verification of the TUF Code Against Selected RD-14 Experiments J, Pascoe *et al.*

Verifaction of CHAN II (OD6) Against Experiments, M. Bayoumi *et al.*

FIDAS: A Three-Fluid Subchannel Code for Dryout Predictions in Rod Bundles Takaaki Saki *et al.*

Status of Physical and Numerical Modelling of CANDU Moderator Circulation R.G. Huget *et al.*

Determination of Blowdown Heat Transfer Based on Experimental Investigation of RD-14 Experiments. Analysis with the Code SLLOH J-C. Amrouni *et al.*

CATHENA Simulation of Thermosyphoning in a Multiple Channel Pressurized Water Test Facility J.P. Mallory and P.J. Ingham.

Simulation of "Standing Start" Behaviour by the CATHENA Thermalhydraulics Code B.C. Hanna and J.P. Mallory.

An audience of up to 40 attended the seven papers in this session. Not only was the general quality of the papers good, but each generated lively discussion.

The central theme of the session was the progress made in the area of thermalhydraulic code verification. The codes discussed included TUF, CHAN II, FIDAS, MODTURC, SSLOH and CATHENA. Validations against the results of selected experiments conducted in RD-14, RD-14M and the CHAN verification facility (AECL-WNRE CWIT and the moderator test facility (Stern Laboratories, Hamilton) and the Heat Transfer Loop (Japan) were used for validation. All the experimental programmes are designed to lead to a better understanding of the flow and heat transfer characteristics of reactor cooling systems.

From the papers presented in the session, it appears that in general good progress has been made in the area of thermalhydraulic model development and validation in support of CANDU safety. With some models development is still ongoing and validation has just begun. A large body of data already exists, on various aspects of CANDU reactor cooling system behaviour under upset conditions, and more continues to be generated. It is essential that refinement and validation of all thermalhydraulic models keep pace with the experiments.

V.S. Krishna

Session 7: CANDU Operating Experience I

Repair of Endshield of Pressurized Heavy Water Reactor A. Krishnan.

Remote Inspection and Repair of CANDU Reactor Vault Components A.B. Powell.

Turbine Trip Due to Inadvertant Operation of ECI Injection Vavlves During Routine Testing at Pickering NGS B N.G. Blair-Johns.

Operating Experience with Mercury Relays at Ontario Hydro's Nuclear Generating Stations P.V. Castaldo.

Ten Year Performance of Bruce NGS A On-Power Fuelling System S. Jayabarathan.

Full Scope Power Plant Simulator C. Drouin.

Reactor Physics Recommissioning of Pickering NGS Units 1 and 2 J. Jucah.

Co-sponsored by the CANDU Owners Group, this session provided a forum for the technical staff of all COG member stations and CANDU designers to exchange operating experience on a formal basis. Operators of CANDU stations are able to learn not only from each others' mistakes but also their successes.

Of the seven papers in this session, all but one were presented by their authors, the exception being that of Mr A. Krishnan of the Nuclear Power Corporation of India. Because of a last minute change of plan he was unable to attend and his paper was read by George Field.

Henry Chan

Session 8: Reactor Physics Simulation

A Synthetic Model for Slow Neutron-Molecule Interaction. Generation of Neutron Group Constants and Thermalization Parameters for Common Moderators J.R. Granada *et al.* (Not presented)

Coupled Neutronics-Thermalhydraulics Simulations of Fast Transients in CANDU B. Rouben and P. Soedijono.

TRAWA-FEE Simulation of Reactivity Transients in PWR Cores D. Pevec and D. Grgic.

Evaluation of Neutron Resonance Data and Analysis Techniques for CANDU Type Fuel Bundles F. Leszczynski. (Not presented)

The Sudbury Neutrino Observatory (SNO) E.D. Earle *et al.*

On Factors Contributing to Quality of Nuclear Reactor Control Computer Software S. Rannem and E. Hung.

As noted above, two papers in this session were not presented since their authors (both from Argentina) were unable to attend the conference.

This session would have benefitted from a more appropriate title since none of the papers in it could accurately be described as on the topic of "Reactor Physics Simulation". The last three papers had no connection with reactor physics *or* simulation, the two papers on simulation dealt with the coupling of reactor physics and thermalhydraulics, hence would have been of interest to a wider audience than the session title implied, and the two Argentinian papers dealt with reactor physics but had no simulation elements.

The two papers addressing simulation covered CANDU fast transient simulations (Rouben) and PWR transients (Pevec).

The project to construct a heavy-water neutrino detector (the Sudbury Neutrino Observatory) in a deep mine shaft was described by H.C. Evans, and S. Rannem presented a paper on software quality assurance for the Darlington reactor regulating system computers. The session concluded with a presentation on Hydro Quebec's computerized fuel accounting, tracking and scheduling system by D. Aubin.

As was noted earlier, the title of this session was quite misleading – a more appropriate one might have been "Miscellaneous Topics of Wide Interest".

Al Wight

Session 9: Reactor Safety I

Emissivity of Zircaloy-4 Sheath at High Temperatures in Argon and Steam Atmospheres P.M. Mathew and M.H. Schankula.

The Experimental Measurement of Circumferential Temperature Distributions Developed on Pressure Tubes Under Stratified Two Phase Flow Conditions: Test 1 to 5 P.S. Yuen, *et al.*

Experiments to Determine the Thermal Mechanical Response When Molten Zircaloy-4 Flows onto a Ballooned Pressure Tube D.B. Sanderson *et al.*

Overpressures and Timescales Associated with Hydrogen Combustion G.W. Koroll *et al.*

We are making significant progress in better understanding the behaviour of fuel and pressure tubes under accident conditions. The results of Mathew and Schankula confirm the expected behaviour of fuel sheath emissivity under oxidising conditions. And from Yuen *et al* and Sanderson *et al* it appears that early fears that that the pressure/calandria tube would fail either from molten Zircaloy dropping onto it or from excessively sharp temperature gradients have been greatly exaggerated. A better understanding of post-dryout and rewet behaviour of the calandria tube shows that failure is unlikely. Stratified flow conditions within a channel can lead to high temperature differentials around the tube, but the temperature gradients are not sharp enough to lead to channel failure.

Koroll *et al* presented a summary of experimental hydrogen results showing the effects of, and interrelationships between, burning rate, turbulence and venting on peak pressure achieved during combustion. Again, the database, modelling and understanding of these parameters has improved significantly over the last few years and licensing calculations based on the vent code are now well supported. Further work is needed to better define the conditions which can lead to transition from deflagration to detonation. While it seems to be very difficult to create conditions for detonation further experiments are necessary to put the issue to rest. The Canadian nuclear programme is currently at the forefront in understanding this very difficult problem of post-accident hydrogen control, and mitigation provisions are among the best in the world.

R.A. Brown

Session 10: Small Reactor Development

The AMPS Reactor Cooling System: The Key to Flexibility in Passive Safety Design J.S. Hewitt.

MAPLE-MNR: Preliminary Thermalhydraulic Studies P.C.Ernst.

CATHENA Studies of Flap Valve Performance in the MAPLE Research Reactor S.Y. Shim.

Experimental Design Verification of the Hydrodynamic Ports for the AMPS Reactor J.C. Atkinson.

The first paper (Hewitt) described the safety philosophy underlying the conceptual design of the AMPS reactor family, with particular reference to the passive operation of all safety-related equipment. Also addressed were the design constraints imposed by maritime applications, specifically those of weight, volume and system response to translational and rotational accelerations.

The thermalhydraulic calculations performed to asses the viability of adapting the existing McMaster University research reactor primary heat transport system to a modified MAPLE core were described by Ernst. It was reported that safety studies have been completed on the basis of a 5 MW limit and that these will now be extended to cover operation at up to 12 MW.

Some thermalhydraulic considerations raised by the possibility of adapting the existing McMaster Universty reactor to incorporate a modified MAPLE core were addressed by Shim. Calculations using the CATHENA code were performed to demonstrate that a flap valve is not required in the MAPLE-X10 reactor pool to ensure coolant flow following a loss of pumped circulation.

In the AMPS reactor design passive hydrodynamic ports are used to permit either pumped flow direct to the reactor core or natural circulation through a reserve coolant tank. The experimental programme to verify the performance of these ports was described by Atkinson, and it was shown that evaluation of the ports under simulated operating conditions indicated that design targets had been met, with less than one percent flow bypass when coolant was pumped through the port.

H.A. Robitaille

Session 11: Reactor Decommissioning and Waste Management

Cost Estimate for Decommissioning a CANDU 620 Mk1 Nuclear Generating Station G. Pratapagiri *et al.*

A Demonstrative Impact Analysis of the Concrete Integrated Container H.P.J. Lee.

Public Opinion on Nuclear Fuel Waste Management Programme in Canada M.A. Greber.

Public Consultation in the Canadian Nuclear Fuel Waste Management Programme E.R. Frech and M.A. Greber.

The Proposed Spent Fuel Dry Storage Facilities at Point Lepreau Nuclear Generating Station J.C. Dunlop.

This session covered a broad range of topics in five papers. Two papers dealt with concrete canisters for dry storage of used fuel, two papers covered public consultation and public opinion on waste management and one paper examined decommissioning costs for a CANDU-6. As noted above, the paper on very long-term storage of low level radioactive waste was withdrawn. The wide range of topics attracted a large audience (ranging from 25 to 45) and stimulated lively discussion.

Methods of estimating decommissioning costs for the CANDU-6 were outlined by Pratapagiri and illustratively applied to the Point Lepreau and Gentilly-2 nuclear generating stations.

An approach to the stress analysis of a concrete integrated container for used fuel was presented by Lee. Using a finite element based technique, the response of various parts of the container at progressive stages in its impact onto a rigid surface can be determined. Dry storage canister facilities are planned for the Point Lepreau station. The paper by Dunlop provided an overview of the engineering work carried out in preparation for the construction of these facilities and a description of some of the specific equipment to be used in their construction.

Public awareness of AECL's waste management programme is lower than expected after 10 years of R & D, according to the results of a December 1988 survey presented by Greber, with the highest self-assessed knowledge level of 50 percent in Ontario. Ontario support for the concept had fallen significantly, from 53 percent in 1986 to 38 percent in 1988, it was reported, and it was further noted that 43 percent of all respondents demanded an absolute safety guarantee before the waste management concept would be regarded as acceptable. However 51 percent believed that such an assurance is not possible and that the experts should be trusted. There is generally a level of public support for the deep geological disposal concept but it remains weak and it was concluded that while some strengthening in support would result from the independent ERP review a substantial proportion of the public will remain sceptical until disposal is actually demonstrated. A second paper by Frech and Greber described AECL's public consultation programme on waste disposal. The programme has been running for five years and is designed to identify issues of public concern related to the disposal of nuclear fuel waste. Input from a large number of external groups has been sought and has identified a number of important issues including monitoring and retrievability, alternative disposal options and the credibility and fairness of the review process.

This session clearly demonstrated that the range of topics related to radioactive waste management is wide enough that a single session can only sample a few. It was unfortunate that relevant papers from Session 5 (Public Information Needs for Waste Management) and the CNA presentation by Connelly (*Environmental Assessment Review of the Concept of Disposal of Nuclear Fuel Waste in Canada*) were not presented together with the two papers on related topics from Session 11 to provide a wider base for discussion. Equally unfortunate was the fact that the schedule was such that the Connelley presentation coincided with the panel session.

Waste management will undoubtedly remain a major issue for some time to come and in future it might be most appropriate to separate the technical and the public affairs aspects of this topics into two sessions.

E. Rossinger

Session 13: Fusion and Physics

International Thermonuclear Experimental Reactor: A Canadian Involvement J. Blevins.

Fusion Blanket – Fabrication Development and Irradiation Testing I.J. Hastings *et al.*

Hydrogen Erosion of First Wall Materials for Fusion Applications J.W. Davis and A.A. Haasz.

Diffusion and Retention of Tritium in Graphite I.S. Youle *et al.*

Application of Risk Assessment Techniques to the Joint European Torus Active Gas Handling System C. Gordon *et al.*

The MCNT Code, A Heterogeneous Monte Carlo Neutron Transport Code for Fission and Fusion Reactor Designs and Neutron Shielding Calculations J.C. Campeau and Jen-Shih Chang.

RF Current Drive and Heating on the Tokamak de Varennes Y. Demers *et al.*

This session comprised seven very good papers, however the small audience (a maximum of eight) was a disappointment. While limited interest may have been a factor in this, it seems probable that timing (last afternoon of the conference) and location (a back room, hard to locate) helped to reduce attendance to a low level.

J. Blevins presented an overview description of the objectives and current design parameters of the International Thermonuclear Experimental Reactor (ITER) with especial emphasis upon the Canadian contributions to the tritium systems, remote handling, equipment layout and the aqueous salt lithium blanket concept.

The Canadian Fusion Fuels Technology Project/Atomic Energy of Canada Ltd fusion blanket programme was reviewed by Hastings. Fabrication development is concentrated on producing lithium aluminate and lithium zirconate spheres with diameters of 1-3 mm. The recently completed CRITIC experiment was discussed in detail.

The UTIAS work on hydrogen erosion was put in context by Davis' review of the important mechanisms in plasma-wall interactions. In particular chemical sputtering – erosion due to chemical reactions with carbon – was shown to be a significant factor in graphite erosion in certain temperature regimes.

First results from the UTIAS tritium laboratory were reported by Youle. Diffusion coefficients have been measured for tritium in graphite using a tritium imaging system.

The JET active gas handling system was reviewed by Gordon. The design targets of this system are based on UK safety criteria and related regulations. The design safety review phase is now nearly complete and a full safety report will be issued soon.

A Monte Carlo neutron transport code developed at McMaster University to examine the neutronics of blanket designs was described by Campeau, who also reported some recent results. A new neutron facility to be installed at McMaster was reviewed and the application of the code to the safety analysis of this facility was presented.

A new RF current drive upgrade to the Varennes Tokamak will permit long pulse operation by driving a plasma current of 200 kA for 30 seconds. The upgrade was described, and the rationale for the choices made in the conceptual design presented, by Demers.

D.P. Jackson

Session 15: Reactor Safety II

Radiation-Induced Air/Water Partitioning and Gas Phase Speciation of Iodine from Irradiated Iodide Solution, S.M Mirbod and R.E. Jervis.

Some Implications of Assumed Tellurium Behaviour in Containment in the Long Term Following a LOCA, K.R. Weaver.

Fission Product Grain Boundary Inventory, F.C. Iglesias *et al).*

Examination of TMI-2 Core Samples in Canada, D.S. Cox *et al.*

Interaction of Zircaloy with Uranium Dioxide and Steam at Temperatures Between 1000 and 1700C. Verification of HITO Code, L.A. Denis and E.A. Garcia

In their discussion of the results of experiments on the partitioning and speciation of radioiodine, Mirbod and Jervis noted that the partitioning coefficient has been found to be strongly dependent upon pH, CsI concentration, total dose and dose rate. Radiation decreases the partition coefficient, this effect being more important at high concentrations and lower pH. A lower limit for the partition coefficient of a CsI concentration of 1×10^{-5} is 10^{4}. In the presence of 10^{-3} M hydrazine partition coefficients were increased even in strong radiation fields.

Reviewing the current assumptions used in predicting Te resuspensions in containment, Weaver concluded that these were overly conservative. For example, since Te resuspension occurs via the formation of water aerosols, a 1 percent resuspension of Te implies that 1 percent of the water and iodine in containment would have to be resuspended. This, it was argued, is unreasonable. A more realistic picture of Te resuspension would be one related to the actual aerosol densities observed in experiments.

Measurements of Xe and I grain boundary inventories in irradiated fuel were described by Iglesias. It was noted that in the centre of the fuel, where grain growth occurs, the grain boundary inventories were found to be higher than nearer the surface of the fuel. Although the grain boundary inventories for Xe and I were similar nearer the surface of the fuel (9 percent of inventory) the grain boundary inventory of I (21 percent) was higher than Xe in the centre region. This may be attributable to the reaction of iodine with surfaces on other fission products which prevents diffusion out of the central region during the short period that a pathway is open.

The key findings of the analysis of fuel rod segments and molten core samples from the TMI-2 reactor core were summarized by Cox. This work is providing a large quantity of valuable information on fuel behaviour during severe accidents, including fission product behaviour, melt compositions, hydriding, oxidation, relocation phenomena, materials interactions and temperatures. For example, measurements on samples from the upper crust revealed that most of the volatile fission products had been released as expected. However similar measurements on a sample from the lower crust region revealed that much of the Cs had been retained, a result at odds with the conventional view that Cs would be released before core slumping. Since the sample revealed considerable oxidation (some U3O8 was formed) it is possible that the Cs was retained as a stable caesium oxy-anionic species. The results from the TMI fuel measurements will continue to be analyzed in cooperation with the other participants in an international programme to characterize samples from the damaged core.

L.A. Denis described the HITO code which has been developed to model the external (due to steam) and internal (due to UO2) oxidation of Zircaloy fuel cladding during severe accidents. Although the processes involved are many and complex, it was found that oxidation rate could be described in terms of the oxygen diffusion rate, the interface velocity rate and lattice displacement. Good agreement with experimental data was reported.

The in-reactor blowdown test facility (BTF) at the NRU reactor has been designed to provide data on the thermal mechanical behaviour of fuel and the release and transport of fission products from fuel under accident conditions. The design of the facility, its commissioning schedule and the experimental programme were described by Walsworth. The out-of-reactor commissioning tests on the BTF re-entry tube sliding seal have been completed and the seal has been demonstrated to have negligible leakage. Non-nuclear, in-reactor commissioning tests have begaun with a 30 minute blowdown test in which pressure tube and shroud temperatures were as expected and sliding seal performance was good. A brief description of the SFD tests, scheduled to begin in late 1989, was presented.

The SEATFB system, which enables the continued on-line estimation of BTF fuel temperatures after failure of the thermocouples, was described by Sills. The system is based on the measured temperatures in the lower-temperature regions and/or a model providing a description of the fuel elements during the tests. The system provides a real-time colour graphics display of the thermal behaviour of the fuel, including circumferential and axial temperature distributions. As well, a colour coding system is used to indicate the confidence level associated with the temperature determinations. The system can be used for pre-test analyses as an aid in the definition of test conditions.

D.F. Torgerson

Session 16: Operating Experience

Primary Heat Transport System Bleed Valve Erosion and repairs at Bruce NGS "B", S. Abercrombie.

Heavy Water Leak due to Fretting of DN Tube, Jong-Won Park.

Improving Reliability of the Uninterruptible Power Supply (UPS) Inverters at the Point Lepreau Generating Station, G. Greenlaw and J. Shaw.

Operating and Commissioning Experience with the Darlington Tritium Removal Experiment, R.B. Davidson *et al.*

Reactor Safety Considerations During Major Safety System Retrofits on a Fuelled Pickering Unit, U.A. Schwabe.

The Impact of Fission Products on Radiation Fields in Ontario Hydro CANDU Reactors, M.R. Floyd and J.R. Lamarre.

Deaerator Transient at Bruce NGS "B" Unit 8, H. Braul and G. Paquin

The seven papers in this session covered a good cross section of topics ranging from serious equipment problems to the execution of a complex generating unit outage. All the Ontario commercial reactor sites were represented as were the 600 MW installations in New Brunswick (Point Lepreau) and Korea (Wolsung).

Attendance was not commensurate with the quaility of the papers, with a maximum of 16 tailing off to only five at the end of the afternoon. This was almost certainly a reflection of the fact that this session was the last one on the last day of the conference and many (perhaps most) people had left for home. This meagre attendance is very disappointing for those presenting papers and while it is true that all the papers will receive wide circulation (through the *Proceedings*) this is little compensation for the lack of the stimulating discussion which can be generated by a substantial audience at an oral presentation.

A change in the conference structure is needed to preclude this kind of problem – some possibilities might include changing the banquet to the third evening, eliminating the last afternoon (though this might simply tranfer the problem to the later morning sessions) or holding a CNS dinner (rather than lunch) on the last day. Of course another approach might be to hold only one session on the last afternoon dealing with particularly popular subjects.

H.L. Austman

Letters to the Editor

"Safety Culture": a needed term.

Dear Sirs:

Keith Weaver's article "Treading Warily with Safety Culture" in the March/April 1989 issue contains a useful critique of this new buzz-word. He carefully and systematically beats "safety culture" to a pulp, mostly by pointing out that the term is fuzzy, poorly defined and unnecessary. It must be a very dangerous phrase to warrant such rough handling.

It is patently obvious that "safety culture" cannot stand up on its own. In this way it is similar to terms such as "defence in depth" (well defined only in the tactical military context), "quality assurance" (is the desired quality high or low?) and "human factors" (anthropomorphous algebra?). Each term must be expanded into a set of clear directives, each defined carefully within the limited domain where it is to be used. Given clear directives we could do without any or all of these "fuzzy" terms, yet each appears to have its place as a heading for part of the nuclear safety management system. As it was originally applied to the nuclear industry in 1986, the term "safety culture" was intended to be a heading for those problems which are evident in analysis of most plant accidents and which are primarily human, or management, problems. Mr. B. Edmondson introduced the terms to the IAEA safety group with some trepidation that it might become what Mr. Weaver now properly fears – another vague concept like the many under which we already suffer. The explanation which follows each Principle in the IAEA report is intended only as an indication of what the authors mean in establishing the principle, not as a full and precise definition of a directive ready for use. Mr. Weaver is exactly correct in rewriting and extending the IAEA explanation in his own words, but he still includes only an incomplete outline of the items which would be needed in practice.

Do we need such a term as "safety culture" in the nuclear industry? I suggest only that *something* is needed to emphasise the human dimension of safety; Mr. Weaver seems to agree. We do tend to put a lot of faith in the hardware installed in the plants. It concerns me that we may lose people's dedication and enthusiasm by concentrating exclusively on mandatory procedures and strictly defined analysis; in effect, by denying individual initiative. We tend to ignore the fact that the safety hardware is worthless unless the people, including senior management, are both able and willing to make it work. Mr. Weaver does a good job addressing the hardware and knowledge side. Discipline is essential. But is it not also essential for managers to foster an "esprit de sureté" among their staff? Herein another fuzzy term for Mr. Weaver to address.

The IAEA report INSAG-3, of which I was a co-author, laid only the foundations of what we considered to be both necessary and universally acceptable. Detailed definitions were deliberately left out because of strong objections from some members (including myself) to wording which appeared to tell national safety authorities how to do their business. Each nation should have available well directives founded on principles similar to those in the INSAG report, but accounting for different technical and sociological factors within their own system. The intent of the report was to indicate areas in which various nations should establish safety principles and practices. It was unanimously agreed that the human dimension of safety is one area where most nations need to improve. Name it whatever you wish.

The process of INSAG-3 revision following comments is now under way. Mr. Weaver may wish to submit comments on the safety culture topic to IAEA through Mr Z. Domaratzki, the INSAG member closest to home.

One small detail: protection of the plant from damaging accidents is an immediate concern of its owners who happen to be, in almost all cases, senior management of the operating company. This downside risk of plant damage can be a powerful motivation for them to support in-plant safety vigilance and thereby to assist the cause of public safety (see Starr and Whipple, *Nuclear Safety* 23, No. 1, 1982).

D.A. Meneley,
Professor of Nuclear Engineering,
University of New Brunswick

Professor Meneley's comments encourage me to think that we are in quite close agreement on the nature of the reality which the term "safety culture" is trying to represent. Several of his statements, however, invite some response.

If I left the impression that "safety culture", or some equivalent term, is unnecessary, as Professor Meneley seems to interpret, then I stand accused of the very vagueness and imprecision it was my purpose to attack. Some such term quite clearly is necessary, because it provides the needed label (try thinking about something that has no name) for an entity whose characteristics we now have to articulate. Given that the term "safety culture" is probably here to stay, we should make the best use of it, and this includes guarding against its misuse or its ritual, almost catechetical invocation. My subjective observation is that both these undesirable tendencies are alive and thriving and this was the motivation for the article.

My critique of safety culture was intended to be thorough, but the statements that I have "carefully and systematically beaten "safety culture" to a pulp", and that it must be a dangerous character, are a bit extreme. They also conjure up an image about which I am somewhat ambivalent. Perhaps I ought to be flattered at being seen as a sort of technical "rocker", but the intention was not to stage a dust-up and then leave "safety culture" for dead. If the corporal metaphor must be retained, then a preferable and less passionate variant would be to say that I had turned an admittedly harsh light upon "safety culture" and invited it sternly to assist me in my inquiries.

To try to clarify any remaining confusions I may have generated, let me attempt to restate the problem briefly. The choice of a term to designate a phenomenon may be good or not so good since the term itself, by its nature, may help or hinder understanding. But the inherent propensity of a term for being fuzzy, or the fact of its actually being fuzzy, does not necessarily constitute the whole problem, nor even the main problem. It is in the nature of language and words to be fuzzy, and any expectation that one can ever achieve fully exact, completely unambiguous meanings is a pipe dream. What is required is to establish the context of a term such that its ambiguity is reduced to a level which is judged appropriate. As Professor Meneley points out, the terms "defence in depth", "quality assurance" and "human factors" consist of ordinary household words and the terms themselves, if interpreted in an everyday face value sense, can be made to yield a wide range of irrelevant and useless "definitions". It is in their restricted technical contexts that these terms have specific, commonly understood, reproducible and applicable meanings.

Among the terms Professor Meneley lists, "safety culture" stands out in this respect. At its present stage of development, the term "safety culture", in my view, has not yet acquired such a specific, commonly understood, reproducible and applicable meaning, and (once again in my view) the effort to establish an adequate context for the term is a weak one. In spite of all this, and in spite of the importance of the phenomena which can be included under "safety culture", it is not uncommon to find the term being used freely as though it actually had such a meaning. This kind of self-delusion has its dangers. In the extreme case, the King's Cross fire and other accidents (for example, the Hinton railway collision) give clear and urgent warning of the consequences that such an approach can help bring about.

This, as concisely as I can phrase it, is my concern.

Keith Weaver

Simulation Symposium Report

15th Annual Nuclear Simulation Symposium

Organized by the Nuclear Science and Engineering Division of the Canadian Nuclear Society, the 15th Annual Nuclear Simulation Symposium was held April 30 - May 2 at the Sheridan Park Conference Center in Mississauga, Ontario. It was hosted by Atomic Energy of Canada Limited, CANDU Operations.

The Simulation Symposium is a forum for informal discussion and exchange of ideas. Presentations emphasize on-going work, work with partial results, and work with uncertain conclusions are welcomed. Papers on any topic related to simulations in the field of nuclear science are appropriate.

This year's symposium was very well attended, with 98 registrants representing the whole range of organizations in the nuclear field in Canada: designers, the research labs, utilities, regulators, private industry, and universities.

There were 13 students, and most of them gave presentations.

Following a wine and cheese reception on the Sunday evening and a welcoming address from Don Lawson (President of Atomic Energy of Canada Ltd., CANDU Operations) on the Monday morning, the work started in earnest.

The Technical Programme was very busy, and occupied two full days with 52 papers presented in ten technical sessions. In fact, the number of papers meant that parallel sessions were required on Monday afternoon.

Session topics encompassed Thermohydraulics, Physics, Small Reactors, Modelling and Methods, and Fuel and Thermohydraulics. Among the many topics covered in the papers were thermohydraulics simulations and comparisons between codes, loop experiments, benchmark problems, the MAPLE and SLOWPOKE reactors, marine-propulsion reactors, the nuclear battery, space-time simulations, reactivity transients, fuel-management simulations, thermal and mechanical analyses of fuel, fission-gas release in fuel, and critical-heat-flux studies. In addition there was a session on miscellaneous subjects outside the usual topics, with papers on such topics as a Monte-Carlo code for the development of flux detectors, a simulation of a containment standard problem, the assessment of facilities for tritium-breeder material tests, risk assessment, and the simulation of electrical distribution systems. The papers were generally very well received, and engendered lively discussion and exchange of views.

In the afternoon of the second day (Tuesday), about twenty symposium attendees took the opportunity to tour Ontario Hydro's Darlington Nuclear Generating Station, the first reactor of which is due to start up this September.

In the context of the 50th anniversary of the discovery of uranium fission, the guest speaker at the Monday night banquet was Dr. Leo Yaffe, Professor Emeritus of Chemistry at McGill University. Professor Yaffe spoke on "Canada's Early Participation in Atomic Energy". His fascinating talk spanned the years from the very beginnings of atomic physics research in Canada, with the work of Rutherford and Soddy at McGill, to the Montreal Laboratory during the Second World War, the establishment of Chalk River, and the building of the first Canadian research reactors, ZEEP and NRX. Prof. Yaffe presented his personal recollections of the early Chalk River days and enlivened his talk with numerous anecdotes about those times and the personalities who helped shape Canada's nuclear future with the heavy-water reactor.

To commemorate the 50th anniversary of uranium fission, a coffee mug bearing the 15th Annual Nuclear Symposium's logo was presented to each of the registrants. The Organizing Committee trusts that all attendees found the Symposium both interesting and informative, and that everyone is making plans to attend and contribute to the Third International Conference on Simulation Methods in Nuclear Engineering, to be held in Montreal next April.

B. Rouben, Chairman, Organizing Committee,
15th Annual Nuclear Simulation Symposium

What is what is?

Keith Weaver

Contradictions are hard to handle. Everyone is familiar with the algebraic tricks incorporating a contradiction which allow one to prove anything while apparently not violating any obvious rules. (The violations are not obvious because they occur in the form of symbol manipulations, and one is encouraged as part of the game to forget just what the symbols represent.)

Contradictions should be avoided, we are told, because they lead to the spurious ability to prove anything. Inconsistencies, which can have the force of contradictions in algebra and logic, are also unspeakable ogres, to be hunted down and seen off at the earliest opportunity. And yet discussions by and about real ordinary people and how they view real ordinary (or not so ordinary) situations, brings to light the numerous apparent contradictions which populate the world views of these individuals. With these contradictions and inconsistencies bristling at every turn, it makes you wonder how folks manage to put any kind of order into their lives at all.

Of the several sessions on public acceptance at the CNA/CNS annual meeting held in Ottawa in June, perhaps the most interesting and revealing was that sponsored by the CNS, and entitled "Heeding the Need for Public Information". Five very competent panelists presented views from widely different perspectives, all connected by the putative common thread of "public acceptance". Some excellent points were made. Some good questions were asked. Not unexpectedly, some hazy concepts floated by, rudderless in the (alas) all-embracing mist.

These ghost ships were unidentifiable with the available semantic radar. They hovered just off the screen. Incomplete snatches of them hove into view now and then: "... public education ...", "... information ...", "... knowledge ...", "... confidence ...". These were some of the glimpses through the fog.

It was just this semantic haze which was most interesting. Because of this haze, because the panelists presented very different or opposing views on almost every theme, there seemed to be no main message. Looked at in one light, it would be tempting to say that the presentations themselves were riddled with inconsistencies. Statements were made that information was needed, but other statements affirmed that plenty of information was available and anybody wanting it only had to look. The desirability (even necessity) of "educating the public" and the impossibility of doing so were simultaneously put forward, but were then left deadlocked and floating helplessly. The concepts of "information" and "knowledge" were deemed important enough to label, but any further distinction was left to the listener and the point was ultimately abandoned, as real but as amorphous and incomprehensible as a ball of hibernating snakes.

But from another angle, it might seem that the problem is more one of definitions and of clear objectives. Of what are we trying to convince the public? Is it useful or meaningful to talk about educating the public? Are we trying to impart knowledge or information? Is there any distinction? If there is, how important is it? Given that the public is restive when it comes to things nuclear, does public acceptance imply an effort to supply information, facts, data which can be assimilated, leading to a higher level of awareness, the rational analysis of the situation and thence the evaporation of irrational fears and concerns? Or does public acceptance imply the operation of what is basically a hypnotic process whereby irrational fears are merely allayed, swept out of the field of consciousness, by some non-rational interaction (advertising, charismatic personal contact, etc.) with reason not entering into the picture? In other words, is public acceptance an active process involving the conscious mastery of concerns, or is it the attainment of a passive state in which there is an absence of non-acceptance? Should the public acceptance standard bearer be Descartes (or is he too rational to understand) or Ouspensky (or is he too visceral to accept)?

Public opinion polls seem to reveal the presence, within the bosom of the unwashed masses, of any number of implicit inconsistencies and contradictions, and yet the SS Joe Public still seems to maintain a satisfactory heading somehow. But is it actually satisfactory in today's world? And is being "just satisfactory" good enough? Should those inconsistencies and contradictions be weeded out as part of some general ongoing improvement of the human condition, something driven by an internal impulse and done just for its own sake? Or is the whole introspective, carping, agitated debate on "public information" being driven by a set of newly arisen outside forces which act on people and which actually derive from the demands imposed by our emerging and developing technologies? Does the rational and materialistic approach, apparently so successful when applied to simple situations such as power reactors and space craft, become irrelevant or hopelessly mired when faced with more complex social questions?

Are considerations such as these perhaps at the root of the problem of why risk and its perception seems to be so intractable? Among risks, those which people feel are imposed (involuntary risks) are said to be least acceptable for some reason (because the risk is too high?), and yet an involuntary risk of low objective concern can be found sharing the same sandbox with a voluntary risk of shuddering fright value. Should this situation be considered normal and acceptable and if so does the algebraic ogre of contradictions not really exist in everyday life?

Someday there will be an interesting panel discussion. It will be about panel discussions. Do panel discussions on public acceptance actually result in ground being won? Does this form of continuing unstructured assault on uncertainties, puzzles, vaguenesses eventually help to dispel the mist and point the way toward some resolution? Or is it all just a sideshow, a diverting but meaningless intellectual pastime that takes our minds off the confusing, contradictory and incomprehensible real world for a while?

And about the real world . . . .

Technical Note

Minimizing the risks of human performance

H. E. Gould and I. Walker

Introduction

Ontario Hydro has sixteen CANDU reactors in operation, of which four comprise the Bruce NGS 'A' Station. Each unit at Bruce has a gross rating of 904 MW(e) and the station's net capacity factor since it entered service twelve years ago is 79.6 percent.

Bruce NGS 'A' has a long-established safety management programme of which INPO's Human Performance Evaluation System (HPES) has been a part since 1985. The programme has matured and expanded in the past four years of operation, resulting in various changes. The factors causing human error have also changed.

This Note reviews key improvements made to the Bruce NGS 'A' HPES programme, discusses some of the results derived from using the programme and presents a representative case study. A strategy for future error reduction is also discussed.

Key improvements

The effectiveness of our HPES programme has been significantly enhanced by three modifications in the following areas:

- the evaluation process
- communication of results
- handling of actions

A striking improvement in the programme resulted from the decision to use selected senior production and operating staff as HPES evaluators. Their experience in shift and process operation gives them excellent background and credibility. In addition those they interview speak freely knowing that they deal with "one of their own".

Bruce 'A' now uses two evaluators to analyse HPES problems, either two production evaluators or one production and one management evaluator. This team appraoch has worked well and resulted in an improvement of the quality of the evaluations and the skills of the evaluators.

The second improvement is in communication of results. It is important to give HPES information to management, regulatory agencies and INPO. It is essential to give feedback to station staff. We use HPES on events where people make mistakes. People need to know why mistakes happen and how to prevent them happening again. Education has become an essential part of every HPES solution.

The third improvement is in the handling of corrective actions. To make sure that HPES results are acted upon at all levels, especially over the long term, periodic review is needed. Trending of data initiates action before major problems develop. Followup after actions are completed determines their effectiveness and demonstrates the worth of the programme. In the past we believe that this part of the programme received less attention than it deserved.

HPES programme results

Since 1985 we have analysed 47 events using HPES. The average annual number of events is 130, of which about 40 involve human error, thus we have examined about a third of the human error related events in this period. Figure 1 summarizes the main contributors to personnel failures. These data are comparable with the international experience reported by INPO.

In Figure 1:

- *written communications* includes permanent and temporary procedures, work requests, memos, logs and all other information on paper;
- *work practices* are methods workers use to enhance safety and efficiency, including error detection, document use, equipment and material use and work preparation;
- *verbal communications*, the clarity and accuracy of which frequently bear on performance, can be made in person or by telephone, intercom or radio headset;
- *managerial/supervisory* factors contribute to the quality of work and involve defining expectations and standards, giving clear direction, using each worker's skills and acknowledging high quality work;
- *environmental conditions* are the characteristics of the workplace that cause physiological or mental stress which can influence performance.

As Figure 1 shows, the percentage of events caused by environmental and managerial/supervisory factors dropped sharply after 1986. We attribute this to

- improved control over such actions as call-ups and jumpers
- a greater emphasis on the quality of supervisory practices
- efforts to improve station housekeeping and material conditions.

Problems remain, however, with communications and work practices. Two programmes designed to address these areas over the next two years are

- a Division-wide programme to upgrade both the content and presentation of Operating Procedures
- a training programme for workers that will focus on teamwork, communications and people skills.

Of the more than forty events analysed since 1985, only one type was repeated. This event occurred during unit cooldown activities when not enough heat transport feed inventory was maintained to compensate for shrinkage as the system was cooled. The result was a main pump trip on two occasions in 1985 and once in 1988.

Prompt completion of corrective actions could have prevented this repetition, specifically the installation of a separate alarm to warn of low tank storage inventory.

Also our earlier HPES analyses were of poorer quality, resulting in failure to recognize unsuitable work practices and procedure deficiencies. Including production evaluators in the analysis teams and reducing the number of events analysed each year helped remedy these deficiencies.

The HPES programme has led to a number of changes:

1. Training enhancement occurred with the introduction of a communications module to the Supervisory Development Programme.
2. A one-day training seminar improved the analytical skills of production supervisory staff.
3. A work protection refresher training programme is under development.
4. Panel operators now have timing devices for use in Safety System tests.
5. Motor control centres and important circuit breakers are now accurately labelled.
6. Production staff now review outage logic diagrams before issue.
7. Our planning unit has adopted internal verification procedures.

Case study

In July 1988 there was a shutdown to clean plugged piping in the primary heat transport upgrader system. Installation of some new instrumentation was a late addition to the outage. The work permit prepared for this job warned that the piping contained primary heat transport heavy water and that there was an associated tritium hazard. In preparation for installing the new instrumentation the piping was cut and tritiated heavy-water spilled out.

The production/management team analysing this event used HPES techniques. Listed below are the causes of this event.

Unclear verbal communications prevented anticipation of the problem. Violation of work protection procedures occurred when:

1. Work authorization requests were submitted late and not checked independently by two operators.
2. Forms were incorrectly completed. There was a discrepancy between the *request* for isolation and the isolation *permit*. The first asked for drained piping, and the second provided piping full of tritiated water.
3. Work protection procedures did not include satellite work control area.
4. Contrary to the work plan, no senior operator was on the day shift during the shutdown to control work.
5. There had been no work protection refresher training for several years.

The following corrective actions were taken in response to this event:

1. Revision of work protection procedures.
2. Expedited development of work protection refresher course.
3. For future upgrader outages use senior operating staff for work control or, alternatively, have work protection overseen by control room or work control area staff.
4. Emphasized the importance of submitting work authorization requests well in advavnce of the work date.

The HPES analysis resulted in a thorough understanding of the event and generation of effective corrective actions. In addition, good communications increased interest in HPES at the worker level.

The future

HPES is not a complete answer, but it is an important part of any error reduction programme. It contributes to the reactive error reduction portion of the programme along with equipment failure analysis techniques. However a proactive risk reduction strategy is also necessary to complete the programme. Risk is the product of error frequency and error consequences. Risk reduction therefore requires an improvement in at least one of these two quantities. Figure 2 shows the elements of a complete error reduction process.

Some precedents do exist for a proactive error reduction strategy. One approach employs task analysis and probabilistic risk assessment[1]. Another similar approach is the Reliability Centred Maintenance method[2], used by airlines, the military and electric utilities.

The corporate strategy of the future combines human performance failure analysis with risk reduction. It is an ambitious goal to which we must all contribute ideas, experience and effort.

References

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Mr. Walker is the Maintenance Superintendant at Ontario Hydro's Bruce 'A' nuclear generating station. Ms. Gould is the Acting Technical Superintendent in Quality Assurance at the same station.

Eyepiece

The road to CANDU

Don Hurst

An adaptation of material presented by Don Hurst to the Ottawa Branch of the Canadian Nuclear Society in March and the Nuclear Safety Department of Ontario Hydro in May

The national policy and large scale aspects of this topic have been comprehensively dealt with in such works as Eggleston's *Canada's Nuclear Story* or Bothwell's *Nucleus.* And Bertrand Goldschmidt has told the story of the heavy water that had a Cook's tour of Europe before it finished up in Montreal in *Pioneers de l'Atome.* I should like to present things from a rather more personal perspective – a sort of worm's eye view – but I should explain that such a course is not without its dangers. Some twenty-five or thirty years ago an author who was writing a book on uranium mining visited Chalk River to get information for a chapter on nuclear matters and was sent to see me. After chatting for a few minutes about the problems he faced in his task, he remarked that in his experience a company would always pass him on to some old fogey who had forgotten or confused past events. He then turned to me and said: "You've been here for quite a while. What can you tell me?". Since then I've built up a further twenty-five years or so of experience with which to confuse you.

Uranium fission – early days

Late in 1938 it was realized that fission had been occurring in the course of experiments carried out with uranium. Groups working in both Paris and Berlin had come to the realization that the uranium nucleus was behaving in an odd fashion when hit with neutrons – instead of being "chipped" it was splitting and transmuting to substances considerably removed on the periodic table – and in a different direction. The Paris group (which included Halban, Kowarski and Joliot) were quick to follow up the possibility of a chain reaction.

In March 1939 Halban and Kowarski showed that on average more than one neutron is emitted per fission – a primary requirement for a chain reaction. They realized the need to slow neutrons down and knew that light elements would do this. Experiments with water ruled out ordinary hydrogen but Halban had shown, some years earlier in Copenhagen, that heavy water was not a strong neiurton absorber and was therefore an attractive candidate material. The problem was the scarcity of this material. It was available in small quantities, at a cost of about a dollar a millilitre, and was being used for isotopic studies and in accelerators. For example, we were using deuterium to bombard bismuth in the Cambridge cyclotron.

Other materials than heavy water were being considered elsewhere, for example at about this time George Laurence was just beginning his pioneering work at NRC's Sussex Drive laboratories attempting a carbon black (graphite)/uranium assembly.

The world's stock of heavy water, about 160 litres, was held by its manufacturer (Norsk Hydro) in Norway and late in 1939 Joliot approached the French Minister of Munitions and obtained permission to acquire this stock. The man sent to make these arrangements, a financier and engineer (Allier) who had arranged French financing for the Norsk Hydro plant, found to his surprise and pleasure that Norsk Hydro was only too pleased to make their heavy water available to the French on a loan basis – they had earlier turned down requests from the Germans. Allier took the precaution of dividing the heavy water into two consignments. He made arrangements for a flight to France via Amsterdam but instead, with half the heavy water, took a flight to Scotland. His prescience was rewarded, for German fighters intercepted the Amsterdam flight, forced it to land at Hamburg and searched the aircraft. Allier went from Scotland to France, and the remaining heavy water followed by the same route two days later.

Before Halban and Kowarski could complete any experiments with the heavy water the Germans were through the Maginot line and advancing on Paris. Halban and Kowarski left Paris and, with the heavy water, made their way to England. There, working at Cambridge, they were able to determine that a fission chain reaction was possible with heavy water and uranium.

The Montreal laboratory

Long and involved negotiations between Britain and the United States eventually resulted in the establishment of the Montreal laboratory. Britain, stretched to the limit, could not adequately support the work of the Cambridge group, and besides the Cavendish was a possible (and reachable) target for German bombers. At the same time the Americans were unwilling to incorporate all of the cosmopolitan group from Cambridge into their own project. The upshot was a compromise Canada-US-UK agreement which established the Montreal laboratory under the leadership of Halban.

A mix of scientists from Cambridge, Canada and the US formed the Montreal group – but not all the Cambridge group crossed the Atlantic at that time. Personal differences between Halban and Kowarski resulted in the latter remaining in Britain together with some Cambridge colleagues. Halban was a bright scientist but he was not a good, or happy, laboratory administrator. This, together with the effects of the ups and downs of UK-US co-operation, resulted in poor morale and bad personal relationships in Montreal.

Despite this, and despite the lack of a clearly defined goal, the Montreal staff kept busy. Measurements and calculations were done on mixtures of uranium with heavy water or graphite, including a homogeneous concept using uranium oxide slurry called mayonnaise. Later a group under B.W. Sargent was to undertake the decisive lattice measurements for the NRX reactor. The engineers worked on the design of hypothetical reactors and the physicists built a kicksorte – the ancestor of the poulse height analyser. Some U-233 was available and was used in experiments, however one morning it was discovered that half of it was missing. A thorough search failed to locate it and it was not until years later that examination of Igor Gouzenko's papers revealed that Alan Nunn May had provided the Russians with 162 microgrammes of U-233.

It was not until the Quebec Conference of 194- that the Canadian project received its clear direction – the pursuit of the heavy water reactor. At Quebec Churchill and Roosevelt agreed on closer nuclear co-operation, however there was considerable dissatisfaction with Halban and the Americans insisted that he should no longer lead the project. John Cockcroft was appointed as new director of the Montreal laboratories and arrived in April 1944. However no-one had informed Halban of this, with the result that Halban introduced Cockcroft as his assistant at a staff meeting, leaving Cockcroft with the unenviable task of explaining that in fact *he* was the new Director, and he was making Halban Head of physics. Soon afterwards Halban was essentially banned from the laboratory, although he was provided equipment and an assistant to continue research in his Westmount basement.

My own involvement began in June 1944 when I received a one sentence, two-line letter from Cockcroft suggesting that I join the laboratory. Upon my arrival I was briefed on the project by May who began by saying "Well, it works". It was at about this time that the Chalk River site was chosen and construction of the Chalk River Laboartories and staff accommodation at Deep River began.

With Halban out of the picture, Kowarski was brought out from Britain and Cockcroft asked him to take charge of the design and construction of a very low power reactor that was to become ZEEP. Kowarski and I arrived at about the same time and there was a suggestion that I might work with him. In our interview he explained that he knew how to mix heavy water and uranium and he wanted someone who knew how to mix ordinary water and concrete. I was assigned to George Laurence's section.

The NRX reactor

The NRX reactor was to be heavy-water moderated, river water cooled and fuelled with uranium metal. It comprised a vertically oriented aluminium calandria threaded by 198 vertical 2.5 in tubes containing the fuel, shutoff and control rods as well as provision for irradiation of specimens. A larger diameter central thimble was reserved for special irradiations. The reactor was originally designed operate at 10 MWth with a maximum power of 20 MWth.

The original purpose of NRX was to develop heavy water reactor technology and produce U-233 by irradiating thorium. However in anticipation of peacetime use elaborate mechanisms for isotope production were built into the graphite reflector and neutron beam channels through the shielding were provided.

To restrict the spread of plutonium and its technology, the Americans decreed that all irradiated fuel was to be returned to the US without chemical processing. This upset the British and the French who were keen to learn about plutonium and, after some vigorous protesting by the British, General Groves agreed to supply the Montreal laboratory with a few irradiated slugs from the Oak Ridge reactor. Using material from these slugs Glodschmidt, Cook and Hardwick in Montreal tested more than 200 solvents to arrive at the trigly plutonium extraction process used in the plutonium extraction plant that was built, together with a U-233 plant, at Chalk River. To my knowledge not one of those irradiated slugs was returned to the US.

The NRX design was the responsibility of the engineering section in Montreal with supporting services provided by another engineering group at the downtown offices of Defence Industries Ltd (DIL), the company that was to arrange for the construction of the Chalk River laboratories and the Deep River residential site. My recollection is that the engineering staff (headed by R. Newell) totalled seven or eight, all but one on secondment from Imperial Chemical Industries (ICI).

When I arrived in Montreal the overall design of the reactor was well advanced. As a newcomer I was not caught up in the various personal antagonisms that had developed during the Halban period and I was able to move freely among the sections. However I did see many examples of the problems such antagonisms could create. There were several engineers in Laurence's group, some of them nominally with me, who were there only because they would not work in the engineering section. One of these was a young engineer who was involved with the design of the shutoff rods, in close collaboration with a design engineer. On the agenda of an engineering meeting Cockroft allocated forty-five minutes to the shutoff rod topic, naming me and the design engineer as the speakers. The design engineer arranged to speak first and filled up all the allocated time himself, thus precluding any presentatiom from Laurence's Technical Physics Division. I was pretty relieved, in fact, because I didn't have much to say. Actually the design engineer seemed to be in the same position because he used most of the time to give his views on the differences between engineers and physicists!

I cooperated with the chief engineer, Ginns, on a number of areas including control, shutdown and cooling. He was very able but very overworked and in January 1945 he fell ill and left the project. That meant that Newell had responsibility for design, but was without Ginns to carry it out. The responsibility was quickly transferred to the DIL engineers downtown who assumed it very ably. Such was the urgency at that time that construction sometimes anticipated design and draughtsmen had to be sent to the site to prepare their drawings from the as-built machine. Even so construction seemed to lag a long way behind what I had considered a very unrealistic schedule.

I worked with Pontecorvo on shielding calculations. The main shielding was already decided but many details required study and refinement. The original design, with cooling water channels running through the upper and lower concrete shields and an elaborate system of stepped diameters, involved permanent casting *in situ*. I did not like this and was able to show that a simpler arrangement was adequate and that the upper shields could be made removeable. This turned out to be a useful feature when the reactor had to be dismantled.

We learned about the phenomenon of xenon poisoning in March of 1945. Concern was followed by great relief when the theoreticians concluded that the contingency allowance on the size of the NRX core was adequate to cope with the phenomenon. Xenon poisoning would have made the American plutonium production reactors at Hanford almost useless had a Dupont manager not increased the original specified core size by about 30 percent, explaining his decision on the grounds that scientists never get things right!

John Cockcroft's replacement, W. B. Lewis, arrived in September 1946, just at the time when it was found that the aluminium fuel sheaths for NRX were found to have become badly corroded because a colloidal graphite lubricant had been used during assembly (graphite and aluminium form a corrosive couple in water). Virtually the first decision Lewis had to make was to authorise resheathing of all the fuel rods.

By late spring 1947 construction was complete and the reactor seemed ready for start-up, but there was a residual inleakage of light water which was eventually traced back to the large blowers used to circulate the helium moderator cover gas through recombiners. When the blowers were opened it was found that the working surface looked like sponges with water oozing through from cooling channels. Electrolux vacuum cleaner blowers were installed as a temporary measure – to become permanent when it was discovered that the rate of radiolytic decomposition of the heavy water was much less than anticipated. The rate was low in comparison with American experience because the heavy water was kept pure. There was some initial worry that the gas might accumulate in the heavy water and boil off suddenly as an explosive mixture, but this proved to be groundless.

With the water leakage eliminated hopes were high for start-up – but then further testing detected the presence of light water vapour. After much searching some water was found trapped in a U bend in a previously unidentified pipe. The water was removed, and preparations were made for start-up.

At the time of the start-up the only people in the control room were the operating staff plus B.W. Sargent and myself (for general consultation) and Pontecorvo and Kirkwood who had provided low power instrumentation. Criticality was achieved in the early hours of 22 July 1947.

Over the next few months the power was raised to the intended 10 MWth operating level, and then to the original design limit of 20 MWth. Later this limit was raised to 30 MWth, which was as high as one could go without raising the possibility of thermal buckling of the upper and lower inner shields. In the course of rebuilding after the 1952 accident thinner water-cooled shields were installed, which would allow operation at power levels up to 40 MWth. However before operation at such power levels could be countenanced Art Johnson and I had to review fuel heat transfer to confirm that existing fuel cooling provisions were adequate. We found that, subject to minor conditions, adequate cooling would be provided at 40 MWth, and this was adopted as the new upper power limit in April 1954.

Research

NRX had a uniquely high flux and for many years was the world's most powerful research reactor. The design incorporated numerous beam tubes and isotope irradiation positions and there was ready access to high flux positions in the core. The simple core geometry and the accuracy in setting and monitoring the heavy water moderator level enabled reactivity measurements of high precision to be carried out.

Early physics research included measurements by Kinsey, Bartholemew, Elliott and Bell of gamma rays resulting from neutron capture in various elements. Robson measured the lifetime of the neutron. Tunnicliffe and I set up a neutron spectrometer which was the forerunner of research, particularly that of B.N. Brockhouse and his group, which still continues. Tunnicliffe used the energy resolved beams to measure fission cross-sections as functions of energy.

Chemistry research included transuranic chemistry, extraction processes, radiation chemistry and study of fission products. Precision mass spectrometry of uranium and transuranics was developed to a high degree. Isotope sales began in 1949 and included iodine-131, phosphorous-32, carbon-14, cobalt-60, caesium, americium and plutonium. Two years later the newly formed Commercial Products Division took over this work.

NRX was itself used as an instrument to measure reactor physics parameters. As the power programme emerged it became increasingly important to measure the effect of irradiation on the reactivity of fuel and to unravel this into its many components, for example depletion of U-235, production and fission of Pu-239 and other transuranic isotopes, neutron absorption by fission products and surface effects due to resonance absorption.

A major programme was developed around one highly irradiated fuel rod and included reactivity measurements at Chalk River and Argonne using foot-long slugs and measurements of the radial distributions of relevant isotopes in thin sections of the rod. Many groups were involved in this, with Art Ward as the central figure.

Fuel

To begin discussing fuel we have to step back to Autumn 1944, when we were evolving the specifications for the uranium metal fuel for NRX. George Laurence, the American liaison officer and I met to decide details – actually I was there because Laurence was letting me use a desk in his office until space was found elsewhere. A fuel rod diameter of 1.36 in was chosen. While the Americans were using fuel in the form of foot long slugs we decided to try full-length rods – about 10 feet long. We differed from American practice too in that we decided not to bond the aluminium sheath to the uranium metal.

This *ad hoc* approach was very successful. Soon after NRX started up we were warned by the Americans to expect mechanical problems with the fuel, such as warping and pimpling, when it reached a burn-up of about 300 MWd/ton. However we went well past this figure without encountering any problems and it was not until October 1949 that examination of a rod, which had required unusual force to withdraw it from the reactor, revealed a compression-type wrinkle around the outer sheath. Two weeks later another rod was found to be jammed in place. Subsequent testing revealed that six more rods were either firmly jammed or moveable for only a short distance. The uranium in the rods had shortened, forcing the aluminium sheathing to wrinkle. After considerable testing and development the rods were successfully removed.

It was discovered that the offending rods were all from a second batch – the first batch had not suffered this deterioration. This provided the metallurgists with something of a challenge since the rolling conditions for the first batch had not been documented and they had to work from scratch to discover rolling conditions which would reproduce this good behaviour – a task in which they were successful. However we can say that this incident is another example of the good fortune with which the Canadian programme has been favoured, since had the initial batch of fuel misbehaved the project might well have been jeopardized.

During the 1950s attention became focussed on oxide fuel and this kind of fuel was to oust uranium metal for commercial power reactors. The development and specification of uranium oxide fuel is a long and fascinating history in itself – Archie Robertson's paper *Fuel for Thought* (published in the proceedings of the nuclear sessions of the 1987 Engineering Centennial Conference) gives a comprehensive overview of this vital programme. Although little was left to chance in the oxide fuel programme there was one decision reminiscent of the NRX case. Lewis wanted the fuel sheaths to be 10 mils thick – others wanted 25 mils. After much debate a compromise decision was made and a thickness of 15 mils was specified. I have learned recently that following favourable test results a 10 mil sheath thickness may be used in the future.

NRU

The useful lifetime for NRX was originally predicted to be about five years, after which, it was felt, corrosion would make further operation impossible. In 1948 a committee to consider an NRX replacement was set up. Individual committee members were given specific reactor types to study – I was assigned a beryllium moderated concept. I fear I may not have done the concept justice, since I was a confirmed heavy water supporter!

As a result of this committee the NRU concept emerged. There is a widespread misconception that the expansion of NRU was "National Research Universal", however my recollection is that in order to facilitate discussion, George Laurence made a list of the reactor concepts under study, giving them designations in alphabetical order, eg NRS, NRT, NRU, NRV etc. NRU, the heavy water reactor, was his assignment. It took a few meetings to determine that heavy water was to be the concept of choice. But then we had another, and more formidable, hurdle to surmount: cost. Funding looked remote until at one meeting Lewis (in the chair) mentioned to C.J. Mackenzie, who was present as an observer, the possibility of selling plutonium to America. This was turning point. Funded largely on the prospect plutonium sales, NRU, one of the world's best research and engineering test reactors, came into being.

The NRX Accident

In December 1952 the NRX reactor was severely damaged by a power transient in the course of an experiment to measure the reactivity of irradiated fuel rods. In the Montreal days the control and shutdown systems and the water cooling arrangements were designed with what was called the "boiling disease" in mind. It was recognised that coolant boiling in the fuel channels would result in a reactivity increase, giving a positive feedback power increase mechanism. This phenomenon was a crucial factor in the NRX accident (indeed calculations suggest that had boiling not taken place the reactor power rise would have levelled off at an acceptable level).

The NRX accident was a costly interruption in the work at CRNL, but it happened at the least undesirable stage in the programme. Had it occurred a few years earlier it could have brought the Canadian project to an end. A few years later, and important fuel tests would have been disrupted.

After the accident C.J. Mackenzie told the press that there had been a "pinhole leak". When a large group of Americans visited Chalk River to discuss the accident one of them prefaced his remarks by noting that the Canadians must have measured pinholes they way they did gallons, since this certainly appeared to be an imperial pinhole!

Mackenzie also said that they accident might be a blessing in disguise – a remark which many of us felt was singularly inapt. But he did have a point because designers and operators learned some very important lessons which stood them in good stead as they went on to become prominent in the nuclear power work at Ontario Hydro and Power Projects. There had been a tendancy to ignore such matters as limit switches failing. Just as in the case of Chernobyl, the accident prompted a strengthening in concern for safety.

Power

During the late 1940s there was, in parallel with the NRX replacement committee, a committee to consider electric power production. Some of the ideas discussed were pretty far out, but were consistent with a widely held belief that the total amount of economically available uranium was very limited. In view of this concepts such as breeders and thorium/U-233 burners were given priority. This belief lasted for many years in some quarters and prompted Lewis, in one of his papers at the 1955 Geneva conference, to note that the Ottawa River flowing past the NPD site carried more uranium than would be consumed in the NPD reactor. His objective was to counter criticism that uranium was too scarce to be fissioned wastefully in such a machine as NPD.

The planning for electric power production remained highly academic until, in 1950, Lewis presented the following combination of facts:

1. NRX fuel had survived burnups of 3000 MWd/ton and had retained much of its reactivity.
2. Using in-reactor loops, uranium was being cooled by heavy water at temperatures and pressures comparable to those in thermal power plants. Under these conditions zirconium was a possible cladding material.
3. Fuel changing without interrupting reactor operation was planned for NRU.

On the basis of a simple reactor concept, Lewis calculated the cost of commercial-scale nuclear power. His figures aroused interest both generally throughout the engineering community and, specifically within Ontario Hydro, which was having to turn its attention to thermal energy for future generation. When AECL was established in 1952 its Board of Directors included utility representatives, that from Ontario Hydro being Richard Hearn, the utility's Chief Engineer. With contact at this level, it was not surprising that by mid-1953 an understanding between Ontario Hydro and AECL had been reached by which the two organisations would cooperate in the development of a nuclear power project. As a result of this agreement a Nuclear Power Group, staffed by engineers from electric utilities and industry, was established at Chalk River under the leadership of Harold Smith from Ontario Hydro and charged with responsibility for developing a preliminary design for a reactor to demonstrate the feasibility of nuclear power.

In early 1955 AECL, Ontario Hydro and Canadian General Electric formed a partnership to design and build NPD (Nuclear Power Demonstration), the Nuclear Power Group's first proposal. The concept was a heavy-water moderated uranium metal fuelled reactor with a power output of 10 MWe (later 20 MWe). The reactor core was to be contained in a pressure vessel. The NPD design team was located at CGE Peterborough under the leadership of John Foster and included some members from the Nuclear Power Group as well as some AECL engineers, while remaining members of the Nuclear Power Group continued their work at Chalk River to scope out a full scale nuclear power plant.

As a result of developments in zirconium alloys a horizontal pressure tube concept was proposed and adopted. By this time the NPD pressure vessel was being manufactured, site excavation was almost complete and other components were on order. Nevertheless, in 1957 construction was halted to allow for redesign of NPD as a pressure tube reactor. This was a wise decision. Not only would there have been great difficulty scaling up the pressure vessel to the sizes necessary for higher reactor powers, but the whole thing would probably have been a dead end street when you remember that megawatt for megawatt a heavy-water reactor is a much larger machine than an LWR and to get reactor powers in the 500 to 800 megawatt range very large pressure vessels indeed would be required.

Another reason which made adoption of pressure tubes more desirable was the fact that the original design called for the pressure vessel head to be bolted to a ring which was loosely fitted round the vessel. Failure of this ring would have resulted in a catastrophic accident. Whether or not this consideration weighed in the decision I do not know, but I do know there were quite a few sighs of relief when the pressure vessel concept was abandoned.

While NPD-2 may be said to be the CANDU prototype, the design of the next stage – the Douglas Point reactor – was well advanced before NPD went into operation. Douglas Point is nowadays called a prototype but when it was being designed 200 MWe was regarded as full commercial scale.

After the basic design of Douglas was developed by the Nuclear Power Group at Chalk River the group was disbanded and the staff, with others from AECL, moved to Toronto to become the nucleus of Power Projects, which undertook the final design. My main connection with the project was in association with Bill Henderson. We decided to learn something about programming the Datatron computer and chose to do this by studying the effect of reflectors on heavy water reactors. We started with the simple core of the early Douglas Point design and estimated power costs for a wide variety of configurations of the fuel and core. Gene Critolph and others supplied the basic reactor physics and engineering data and we soon had professional programming. The result was that the final Douglas Point Core had a heavy water reflector and operated with two levels of irradiation in order to produce a flattened radial power distribution.

Douglas Point went critical in 1966. It was not an ideal example of CANDU. It leaked heavy water and had other problems. However it operated moderately well and the lessons learned were applied in the Pickering four-unit station which was already underway. Pickering became one of the world's best performers. Canada had arrived at a mature CANDU.

The Unfashionable Side

The case of the computer and the Caledonian

I was in the pigeon loft attaching miniature radar transponders to the birds when the telephone warbled at me. I decided to let it ring a while to test the persistency of the caller (creditors usually hang up after six rings – *urgent* creditors are rarely satisfied by fewer than 10). The thirteenth warble began, and I picked up the beastly machine. Obviously this was a creditor of more than usual persistence, or perhaps some kind of psychopathic-telephonic compulsive. It was neither. It was Giovanni Romano from the Nuclear Safety Department of Ontario Hydro. Giovanni wanted to see me. Urgently. Today. Within the next twenty minutes. "But Giovanni, what's the panic?" I murmured, "let us at least delay meeting until Opening Time, when we can discuss things in a civilized manner over a few pints. *Festina lente*, old chap, *festina lente*". The only response was a sound reminiscent of an exploding expresso machine, and a neapolitan click as the telephone was hung up. The chap obviously had something on his mind.

I had a few minutes before his arrival to tidy up the office a bit. I tactfully slid the Minox into my pocket, straightened the photograph of Laventri Beria and checked that the two Ferrograph decks in the broom cupboard had full tape spools.

Giovanni entered my office displaying what I felt to be a totally uncalled for degree of caution which showed his lack of understanding of the fundamentals of structural engineering and a profound degree of unfounded scepticism about the properties of knotted string. It's been at least six weeks since the bookcase collapsed, and then nobody was injured – permanently. "Sit down, old chap", I said reassuringly, "in what way may I be of assistance?"

Giovanni's patrician features were clouded, and he seemed unusually ill at ease. In fact he looked rather as Coriolanus might have appeared after an unusually protracted and tedious session with the plebians. "This is a very confidential matter" he mumbled, "no person must ever know of this conversation". Unobtrusively I flicked the ON switch to the Ferrographs with my knee and leaned forward. "You should remember better than most," I said in somewhat reproving tones, "that I never reveal details of my cases – to anyone".

Romano flushed with embarrassment (doubtless recalling the Case of the H P Sauce Term, in which I was of some trifling assistance to him) and began his story. "Just recently our department has purchased a brand new Cyclops computer," he began. "Jolly good" I said encouragingly, "just the thing to keep the old nuc safe biznai up to snuff, eh what?" He twitched slightly then, recovering his composure, continued. "You are quite right – or at least it *would* be if . . . if . . ." His discourse broke off into choked sobs. "Pray calm yourself, my dear fellow", I said "and continue your most interesting narrative". He took a grip on himself and continued. "Well, our manager . . ."

"You mean Rob Roy?" I interjected, trying to hurry things along.

"Yes, I thought I could take anything from him. I could stand the noise of his bagpipes. I got used to the smell of the take-out haggis. I could even live with the odd bellow of 'scots wa hae!' or 'hoots the noo!' But this we can't take. All our work has ground to a halt". Romano handed me a large bundle of computer printout. At first sight it appeared ordinary – columns of inscrutable digits marching with teutonic inevitability up each page. Then I saw it – tucked away in one column a "wee sleekit cowrin'" and, nearby, a "fair fa' yer honest sonsie face". As I examined the pages more carefully I saw that they were peppered with such caledonianisms. "Do you mean to tell me", I asked with a certain amount of incredulity, "that this renegade caledonian has loaded your new computer with Rabbie Burns text files?"

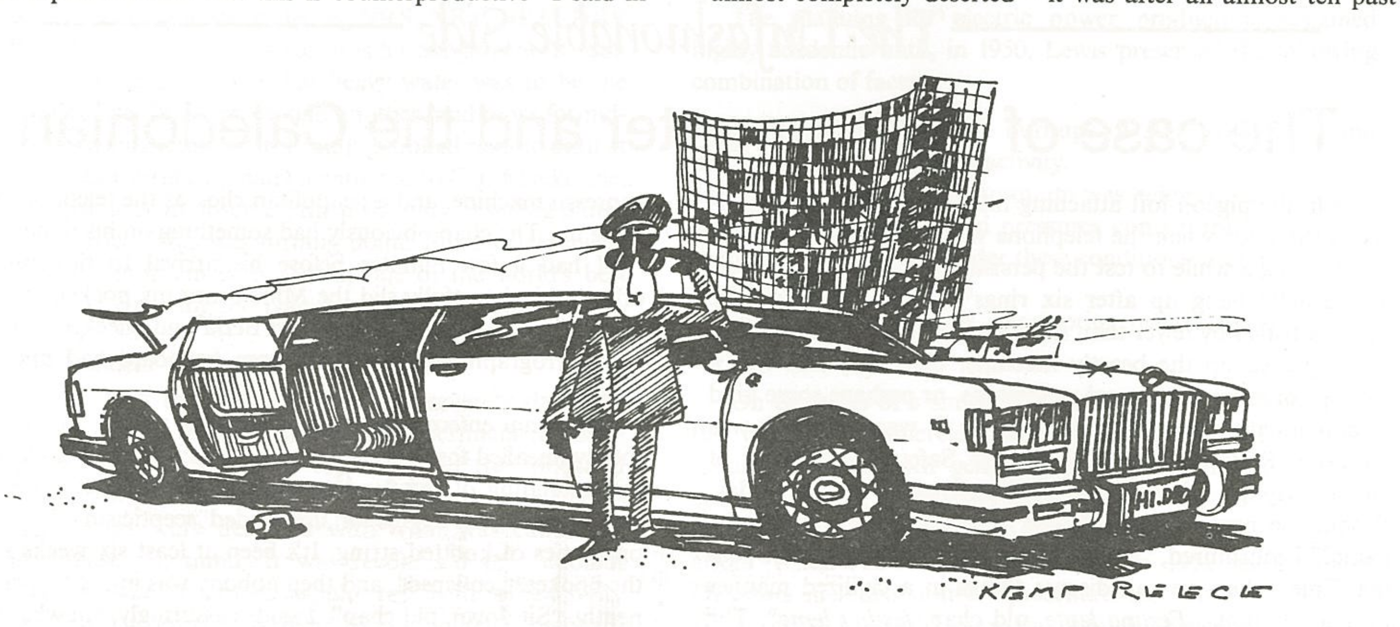
"Yes!" Romano admitted in an hysterical yelp. "Then you must explain to him that this is counterproductive" I said in reasoned tones. Romano jumped as though he'd been stung. "But we can't" he shouted, "he just won't listen. The last report we gave him on this he shredded with his claymore. And as of last week he's ordered that all programming instructions are to be written in gaelic! You've got do do something, Worthing!".

I leaned back in my chair and scanned the bookshelves for inspiration. "This seems to be a fairly straightforward problem", I said (I hadn't the foggiest), "how about moths in his sporran . . . or helium in his bagpipes . . ." My voice trailed off as my eye ran over the volumes facing me . . . *Prosser on Torts* . . . *The English Auden* . . . Underhill's *Advances in Naval Architecture (1790-1870)* . . . *Bauer on Alewives* . . . F R Leavis . . . Wilson Knight . . . Granville Barker . . . . There seemed to be little here of direct application to the problem at hand. And then, next to Macaulay's *Lays of Ancient Rome* I saw the answer in the form of a slim octavo volume bound in a lurid tartan. "Giovanni, I believe I've got it!" I shouted, leaping to my feet, "if you will stand at my right hand and keep the bridge with me, I think we can sort things out this very day".

Romano was peculiarly insistent on the fact that I should not drive to Toronto but rather ride with him in what he called the "corporate limousine". While he ran off to roust out the chauffeur from whatever gin-palace he'd found I picked up the slim volume and tossed it, together with the brandy bottle and the gasogene, into the Dominion shopping bag I keep for such purposes. In fifteen minutes we were on our way.

The "corporate limousine" turned out to be a disproportionate saloon car which could only have been the result of a perverse mating between a Lincoln and a rather large dachshund, perhaps instigated by a deranged antipodean, since what looked like a boomerang had been impaled to the boot lid. Luckily it was provided with a drinks cabinet. Unfortunately some joker had filled all the beer bottles with some form of carbonated industrial effluent so I had little to occupy my mind on the trip but bending moments and my next article for *National Enquirer* ("Giant Chickens Battle UFOs at Kiev").

When we arrived at the Toronto mirror glass palace it was almost completely deserted – it was after all almost ten past



. . . a disproportionate saloon car which could only have been the result of a perverse mating between a Lincoln and a rather large dachshund . . .

four in the afternoon – and we were quickly whisked up to the eleventh floor where the nuclear safety Cabal has its headquarters. From the south-east corner of the building came the low whine of a *pibroch* running on fast idle. Romano paled slightly, then ushered me into the acoustically antiseptic computer room where the Cyclops lived.

The printer was spitting out sheets of paper but a few clouts from my flying boots soon put a stop to that. I sat down before the console, took out the book and arranged the brandy bottle and gasogene with military precision on a nearby disc drive housing. "Now Giovanni" I said, "first you must show me the instructions for accessing text files". Romano complied, and I prudently noted them down for future reference. "Very good" (I was all laconic confidence), "I require three further things: a styrofoam cup, a bag of ice cubes . . .". Romano, all eagerness, was heading for the door so I stopped him with an upraised hand ". . . and complete privacy."

He was as good as my word, and I was able to work uninterrupted. I am only a two-finger typist (though reasonably fast) but I worked steadily entering text from the little tartan bound book. Every now and again odd pieces of mechanism inside the computer clicked and whirred to let me know it was absorbing the material. Predictably, perhaps, the printer remained silent.

It was about two in the morning when I rose stiffly from my seat, tossed the empty brandy bottle into the "Recycle Material Only" bin and rang for Romano to escort me out. On the principle that you never know when it might come in handy, I worked the room over pretty thoroughly with the Minox before I left (luckily the light levels were high enough to accommodate the fine grain film). My ride back to Aphasia was uneventful, save for the appalling quality of the scotch, and I was able to tumble into my pit just before dawn.

Romano's phone call came through a couple of days later, just as I was finishing up a very late breakfast. Now he sounded like Anthony after the Battle of Phillippi. "It's worked!" he shouted, "whatever you did, Worthing, it's worked. Rob Roy has the Cyclops people in this morning, they're wiping the memory, and a general order has been issued to the effect that textual caledonianisms are to be totally eliminated from all safety documentation!" I smiled to myself. It appeared my approach had been the right one. But Giovanni was still chattering away ". . . and, Worthing, he's put his bagpipes up for sale! How on earth did you do it?". I murmured a few pleasantries, wished him a nice day and put the telephone earpiece into the marmalade pot.

"But how *did* you do it, Worthing?". The question came from George Bauer as we sat over our pints in the faculty club bar that afternoon. "Well, Bauer, it was merely a matter of identifying the problem – one of selective cultural recall, SCR that is – and then the solution became self evident". Bauer made a rude noise into his almost empty glass. I waved to the waiter for refills, and continued, "Rob Roy suffered from SCR with respect to his caledonian heritage. It's a not uncommon syndrome, best analogized by the tendency to remember the sunny days from one's holidays, rather than the mosquitoes, poison ivy and so on". I lit a cigarette in a didactic manner. "Rob Roy had to be reminded of the downside of the caledonian culture". Bauer looked at me with an air of dawning enlightenment. I passed him the tartan-bound volume I had been carrying with me since my return from Toronto. He read the title aloud, "*The Poetical Gems of William McGonnagal, Poet and Tragedian* – you mean . . ."

"Yes" I said. "I input approximately twenty percent of McGonnagal's not inconsiderable body of work into the Cyclops. In a way" I continued reflectively, "McGonnagal is rather like Chernobyl." Bauer's eyebrows rose questioningly, and I added, "he may not have been the worst possible poet, but he's certainly the worst so far".

"A brilliant case!" said Bauer, with his characteristic generosity, "but I believe there's one item you've overlooked". I gazed at him with some puzzlement. "Your fee," he said, handing me an envelope emblazoned with the Ontario Hydro symbol. "I picked it up from Dr Romano this morning". I opened the envelope and withdrew a crisp, decorative cheque with an entirely satisfactory number of digits to the left of the decimal point. "Bauer", I said quietly, "what would I do without you. Let's go and spend it at once".

Ernest Worthing

Predictably, perhaps, the printer remained silent.