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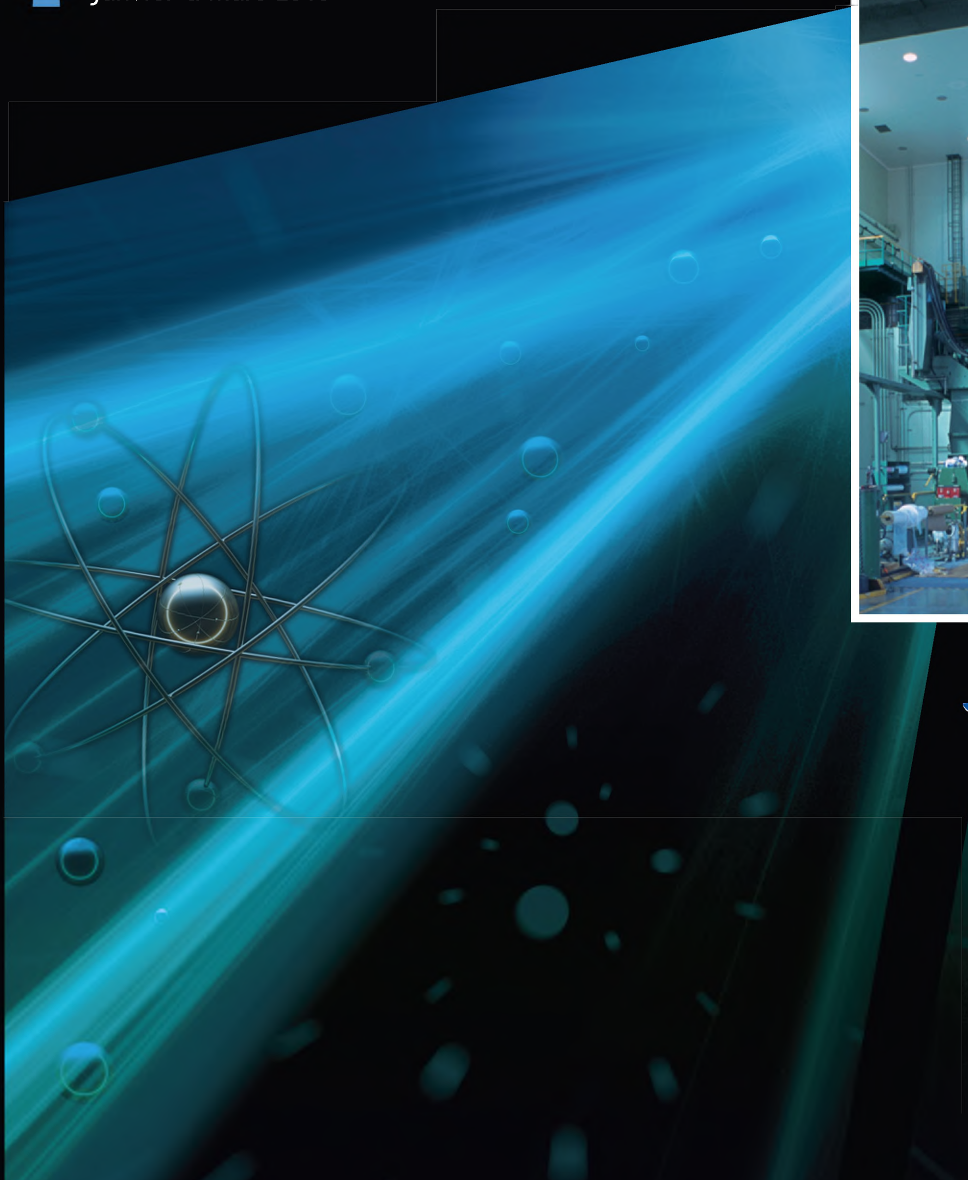

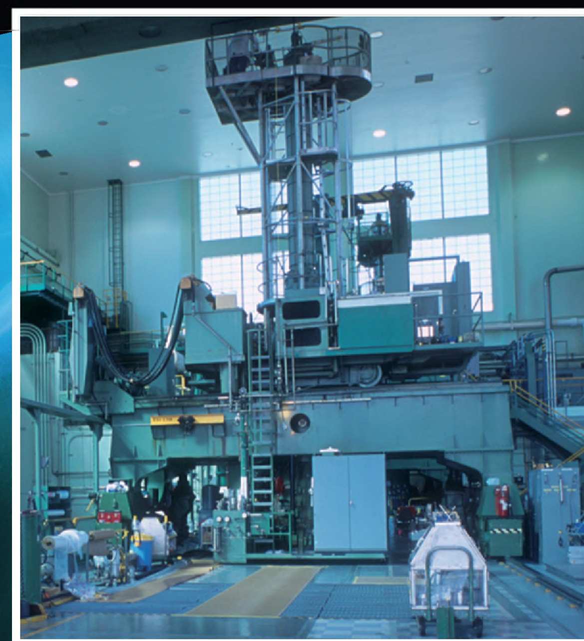

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THE MEDICAL ISOTOPE CRISIS
and the Broader Implications for Research

LA CRISE D'ISOTOPES MÉDICAUX
et ses implications profondes sur la recherche

Canadian Association of Physicists /
Association canadienne des physiciens et physiciennes

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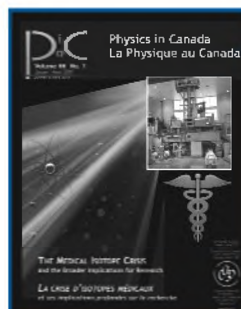

Cover / *Couverture* :

A montage illustrating the main theme of the issue. The photograph represents the National Research Universal (NRU) reactor located near Chalk River, Ontario, which is at the center of the medical isotope crisis. Photo courtesy of Atomic Energy of Canada Limited. Atom background provided courtesy of the NRC Canadian Neutron Beam Centre.

Un montage illustrant le thème central du numéro. La photo représente le réacteur National Research Universal (NRU) situé près de Chalk River en Ontario. Ce réacteur est au coeur de la crise des isotopes médicaux. Photo courtoisie de l’Énergie atomique du Canada, limitée. L’arrière plan avec l’atome courtoisie du Centre canadien de faisceaux de neutrons du CNRC.

Education Corner
Espace Éducatif

Departments / *Départements*

Canadian Association of Physicists (CAP)
Association canadienne des physiciens et physiciennes (ACP)

The Canadian Association of Physicists was founded in 1945 as a non-profit association representing the interests of Canadian physicists. The CAP is a broadly-based national network of physicists in working in Canadian educational, industrial, and research settings. We are a strong and effective advocacy group for support of, and excellence in, physics research and education. We represent the voice of Canadian physicists to government, granting agencies, and many international scientific societies. We are an enthusiastic sponsor of events and activities promoting Canadian physics and physicists, including the CAP's annual congress and national physics journal. We are proud to offer and continually enhance our web site as a key resource for individuals pursuing careers in physics and physics education. Details of the many activities of the Association can be found at http://www.cap.ca . Membership application forms are also available in the membership section of that website.

L'Association canadienne des physiciens et physiciennes a été fondée en 1946 comme une association à but non-lucratif représentant les intérêts des physicien(ne)s canadien(ne)s. L'ACP est un vaste regroupement de physiciens oeuvrant dans les milieux canadiens de l'éducation, de l'industrie et de la recherche. Nous constituons un groupe de pression solide et efficace, ayant pour objectif le soutien de la recherche et de l'éducation en physique, et leur excellence. Nous sommes le porte-parole des physiciens canadiens face au gouvernement, aux organismes subventionnaires et à plusieurs sociétés scientifiques internationales. Nous nous faisons le promoteur enthousiaste d'événements et d'activités mettant à l'avant-scène la physique et les physiciens canadiens, en particulier le congrès annuel et la revue de l'Association. Nous sommes fiers d'offrir et de développer continuellement notre site Web pour en faire une ressource-clé pour ceux qui poursuivent leur carrière en physique et dans l'enseignement de la physique. Vous pouvez trouver les renseignements concernant les nombreuses activités de l'ACP à http://www.cap.ca. Les formulaires d'adhésion sont aussi disponibles dans la rubrique "Adhésion" sur ce site.

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THE SAGA OF NRU, THE SUPPLY OF MEDICAL ISOTOPES, AND THE FUTURE OF NEUTRON SCATTERING IN CANADA

It took a medical isotope crisis to expose to the Canadian public and to the whole world the troubles of a venerable aging nuclear reactor. Built in 1956, the National Research Universal (NRU) has been a valuable research reactor for decades for the development of the CANDU power plants, but its real source of fame was the pioneering work on neutron scattering which lead to Dr. Bertram Brockhouse's Nobel Physics prize in 1994, and the production of a significant fraction of the world supply of medical isotopes for cancer diagnosis and treatment.

The fragility of this supply became clear when the head of the Canadian Nuclear Safety Commission Linda Keen shut down the reactor in November 2007. The government's response was to fire the regulator and force the restart of the reactor with an act of parliament. This was short lived. In May 2009, the reactor closed because of a water leak, and it is still closed at the time of writing this editorial. Weekly updates on the status of its repairs are posted on AECL's website (www.nrucanada.ca).

As NRU aged there were no plans to replace it. The political and social climates were hostile to anything nuclear. In the mid 90's a replacement plan emerged which eventually evolved into the ill-fated MAPLE 1 and 2 reactor project whose sole aim was to guarantee the future supply of medical isotopes. It is notable that the other functions of NRU were not included in the plans. The MAPLE reactors were granted an operational license in 1999, and soon after went critical, but problems surfaced, in particular a positive coefficient of reactivity (PCR). Although this should not have been a safety issue, it became one because the design predicted a negative PCR, i.e. a negative feedback effect when the neutron flux is increased. The discrepancy between design and reality created sufficient doubt about the project that the regulators requested more research. In May 2008, the MAPLE project already eight years behind schedule, with significant costs overrun, was cancelled.

The feeling among scientists and stakeholders, in particular the isotope distribution company MDS Nordion, is that the government acted prematurely in shutting down the MAPLEs. No alternate solution was proposed except to extend NRU's license to 2016.

When, a year later in May 2009, NRU had to shut down because of a water leak, the medical isotope situation became a crisis — a wake-up call that was heard around the world. An expert panel was set up in June 2009 to advise the government "on the most viable options for securing a predictable and reliable supply of the key medical isotope technetium-99m in the medium and long term" [1]. The panel submitted its report in November 2009.

This issue contains the executive summary of the expert report and a series of articles by physicists describing possible solutions using either accelerators [2-4] or a new reactor [5,6]. As a non-expert I will not enter the debate about the merit of the proposals.

When this issue will be read, the government will have announced its plan, which will likely not address the larger issues of the aging NRU. The government's main concern is the "health" of Canadians; i.e. ensuring the supply of medical isotopes. But, as several authors in this issue argue, research reactors such as the NRU have benefits that go far beyond providing medical isotopes [1,5,6]. They supply neutrons for research and a platform for developing nuclear power technologies.

Little is heard in the press about these other functions of NRU. As Peter Calamai comments in this issue "neutron scattering simply isn't on the media radar ."[8] Scientists often write that the demise of NRU is depriving the Canadian research community of a valuable tool. But over the years AECL has had other concerns than replacing NRU in a climate hostile to nuclear energy. If we want Canada to be a leader in materials science and a number of leading-edge sciences, including the medical sciences, the scientific community has to build a case for a new nuclear reactor that involves strong support from segments of society other than the physical scientists. We need to find allies. If neutron scattering is so important to industry, one should be able to find support in that sector.

The future of neutron scattering need not rely solely on demonstrating that nuclear reactors are the best source of the currently-used medical isotopes. It is likely that NRU will be back on-line in the spring. It will rise again like a phoenix to extend its remarkable longevity. This will give

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everyone involved breathing room to plan ahead. The medical isotope crisis is providing increased visibility to nuclear physics that should be capitalized on, as Normand Mousseau argues in his Science Policy column [9].

Living in a more favourable global climate towards the use of nuclear reactors for electricity production, new research reactors are again being built around the world, and this is the time to act in Canada.

B. Joós, P.Phys.
Editor, *Physics in Canada*

1. Executive summary of the Report by the "Expert Panel on Medical Isotope Production", this issue, p. 25-28.
2. Thomas Ruth, "A Short Term Solution to the Medical Isotope Crisis via Direct Production of Tc-99m at Low Energy: A Piece of the Puzzle", this issue, p. 15-16.
3. Randy Kobes et al., "Medical Isotope Production Using Commerically-Available Accelerator and Processing Technologies", this issue, p. 17-18.
4. Carl Ross et al., "Using the ^{100}Mo Photoneutron Reaction to meet Canada's Requirement for ^{99m}TC", this issue, p. 19-24.
5. Dominic Ryan, "Medical Isotopes and the Future of Neutron Scattering in Canada", this issue, p. 5-9.
6. Richard Florizone and Dean Chapman, "The Canadian Neutron Source: Strengthening Canada's Isotope Supply and R&D Capacity", this issue, p.11-14.
7. Zin Tun, "Creating the Future of Chalk River", this issue, p. 29-30.
8. Peter Calamai, "Getting Inside Hearts and Minds of Journalists will help Scientists make Better use of the Media", this issue, p. 31-33
9. Normand Mousseau, Science Policy Corner, this issue, p. 34.

Comments of readers on this editorial are more than welcome.

La saga du NRU, l'approvisionnement en isotopes médicaux et l'avenir de la diffusion des neutrons au Canada

Il aura fallu une crise des isotopes médicaux pour révéler à la population canadienne et au monde entier les difficultés d'un vénérable réacteur nucléaire vieillissant. Depuis des décennies, le réacteur national de recherche universel (NRU), construit en 1956, est précieux pour mettre au point des centrales nucléaires CANDU, mais il doit vraiment sa notoriété aux travaux d'avant-garde sur la diffusion des neutrons, qui a valu le prix Nobel de physique à Bertram Brockhouse en 1994, et à la production d'une part importante de l'approvisionnement mondial en isotopes médicaux pour diagnostiquer et traiter le cancer.

La précarité de cet approvisionnement est apparue clairement lorsque la Présidente de la Commission canadienne de la sureté nucléaire Lisa Reitt a fermé le réacteur en novembre 2007. La réaction du gouvernement a été de licencier la Présidente et de légiférer la remise en marche du réacteur. Ce fut de courte durée. En mai 2009, à cause d'une fuite d'eau, le réacteur a été fermé de nouveau et l'était encore au moment de la rédaction de cet éditorial. Énergie atomique du Canada limitée (EACL) publie sur son site Web (www.nrucanada.ca) un bulletin hebdomadaire décrivant où en sont les réparations.

Au fil du vieillissement du NRU, on ne prévoyait pas le remplacer. Les climats politique et social étaient hostiles à tout ce qui était nucléaire. Au milieu des années 90, un plan de remplacement a vu le jour, suscitant le projet des réacteurs MAPLE 1 et 2, voué à l'échec qui visait seulement à garantir l'approvisionnement futur en isotopes médicaux. Il est notoire que le plan n'incluait pas les autres fonctions du NRU. Les réacteurs ont obtenu un permis d'exploitation en 1999 et atteint le stade critique peu après. Des problèmes se sont posés, dont un coefficient de réactivité (CR) positif. Même si cela n'aurait pas dû mettre en danger la sûreté, ce fut le cas, car on avait prévu un CR négatif, soit une contre-réaction négative à une augmentation du flux de neutrons. L'écart entre la conception et la réalité a semé tant de doutes au sujet du projet que les responsables de la réglementation ont exigé davantage de recherche. En mai 2008, on a annulé le projet MAPLE qui accusait déjà huit ans de retard et dépassait largement les coûts prévus.

Les scientifiques et les parties intéressées, notamment la compagnie de distribution des isotopes médicaux, MDS Nordion, estiment que le gouvernement est intervenu prématurément en fermant MAPLE. On n'a proposé aucune autre solution que prolonger le permis du NRU jusqu'en 2016.

Un an après, lorsqu'il a fallu fermer le NRU à cause d'une fuite d'eau en mai 2009, la situation des isotopes médicaux a déclenché une crise et un avertissement au monde entier. Un groupe d'experts a été créé en juin 2009 afin de conseiller le gouvernement « sur les options les plus viables pour assurer un approvisionnement prévisible et fiable de technétium-99m destiné au système de soins de santé pour le moyen et le long termes [1] ». Il a présenté son rapport en novembre 2009.

Le présent numéro contient un résumé et une série d'articles dans lesquels des physiciens proposent des solutions comprenant des accélérateurs ou un nouveau réacteur. N'étant pas expert, je ne participerai pas au débat sur le bien-fondé des propositions.

Lorsque vous lirez ce numéro, le gouvernement aura annoncé son plan qui ne visera probablement pas les problèmes plus vastes du vieillissement du NRU. Sa principale préoccupation est la « santé » des Canadiens, et donc d'assurer l'approvisionnement en isotopes médicaux. Mais comme l'affirment les auteurs de plusieurs articles du présent numéro, les réacteurs de recherche tels le NRU offrent des avantages bien au-delà de la production d'isotopes médicaux [1-4]. Ils fournissent des neutrons pour la recherche et une plateforme permettant d'élaborer les technologies de l'énergie nucléaire.

La presse est peu loquace au sujet de ces autres fonctions du NRU. Comme l'affirme Peter Calamai dans le présent numéro, « la diffusion des neutrons n'est simplement pas sur l'écran radar des médias » [5]. Beaucoup de scientifiques déclarent que la fin du NRU privera la collectivité de la recherche canadienne d'un outil précieux. Mais au fil des ans, EACL s'est souciée d'autres choses que de remplacer le NRU dans un climat hostile au nucléaire. Si nous voulons que le Canada soit un chef de file en science des matériaux et dans diverses sciences de pointe, dont les sciences médicales, la collectivité scientifique doit démontrer l'utilité d'un nouveau réacteur nucléaire en recrutant de puissants appuis d'autres segments de la société que les spécialistes des sciences physiques. Nous devons trouver des alliés. Si la diffusion des neutrons est si importante pour l'industrie, on devrait pouvoir trouver des appuis dans ce secteur.

L'avenir de la diffusion des neutrons ne doit pas uniquement reposer sur la démonstration du fait que les réacteurs nucléaires sont la meilleure source des isotopes médicaux. Il est probable que l'exploitation du NRU reprendra au printemps. Comme un phénix, il renaîtra et prolongera sa remarquable longévité. Cela donnera une marge de manoeuvre pour planifier l'avenir. La crise des isotopes médicaux confère à la physique nucléaire une visibilité accrue dont nous devrions tirer parti, comme l'affirme Normand Mousseau dans sa chronique de Politique scientifique [6].

Nous vivons dans un climat mondial plus favorable à l'énergie nucléaire et de nouveaux réacteurs de recherche sont construits de par le monde, donc voici le temps d'agir au Canada.

B. Joós, phys.
Rédacteur en chef, *La Physique au Canada*

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9. Normand Mousseau, Coin de la politique scientifique, ce numéro, p. 35.

Les commentaires de nos lecteurs au sujet de cet éditorial sont bienvenus. NOTE: Le genre masculin n'a été utilisé que pour alléger le texte.

NOTE ADDED IN PROOF: FROM BUDGET 2010 (DELIVERED MARCH 4TH):

Diversifying the Supply of Medical Isotopes:

Provinces and Canadian health researchers are exploring new avenues for the production and use of medical isotopes. The Government of Canada is taking action to help support these efforts. Budget 2010 provides $35 million over two years to Natural Resources Canada to support research and development of new technologies for the production of isotopes. An additional $10 million over two years will be provided to the Canadian Institutes of Health Research for a clinical trials network to help move research on isotopes and imaging technologies into clinical practice, and $3 million over two years will be provided to Health Canada to work with stakeholders to optimize the use of medical isotopes in the health system.

NOTE AJOUTÉE À L'ÉPREUVE: DU BUDGET FÉDÉRAL 2010 (PRÉSENTÉ LE 4 MARS):

Diversification de l'approvisionnement en isotopes médicaux

Les provinces et les chercheurs canadiens du secteur de la santé étudient de nouvelles options pour la production et l'utilisation des isotopes médicaux. Dans le budget de 2010, le gouvernement du Canada prend des mesures à l'appui de ces efforts en accordant 35 millions de dollars sur deux ans à Ressources naturelles Canada pour financer des travaux de recherche-développement portant sur de nouvelles technologies de production d'isotopes. Un montant supplémentaire de 10 millions sur deux ans sera versé aux Instituts de recherche en santé du Canada pour l'établissement d'un réseau d'essais cliniques qui permettra de mettre en application les recherches sur les isotopes et les technologies d'imagerie dans la pratique clinique. En outre, une somme de 3 millions sur deux ans sera accordée à Santé Canada pour travailler avec les intervenants à optimiser l'utilisation des isotopes médicaux dans le système de soins de santé.

CAP Members Become New Fellows of the Royal Society of Canada

BAO, XIAOYI
Department of Physics, University of Ottawa

Dr. Xiaoyi Bao has made exceptional contributions in distributed Brillouin sensors and their applications to civil structures as well as dynamic impairment emulator for evaluation and design of high speed communications systems. Her pioneering efforts on diagnosing the health of structures connects measured physical parameters with the status of the civil structures, which is instrumental in preventing the collapse of steel and concrete structures. She is making outstanding contributions not only to the development of the sensing technology but also to the discipline of physics in general.

ORR, ROBERT
Department of Physics, University of Toronto

Robert Orr is one of Canada's leading experimental particle physicists, having made crucial contributions to discoveries in elementary particles. Through the development and exploitation of new experimental techniques, he has made seminal contributions to the study of the electroweak interaction, proton structure and heavy quark physics. Through his leadership, a team of 100 Canadian scientists is playing a significant role in the ATLAS experiment at the CERN Large Hadron Collider, a project designed to uncover the fundamental mechanism for mass and search for phenomena that would allow us to understand the properties of the basic forces.

CAP Members Become New Fellows of the American Physical Society

PAGE, SHELLEY A.
University of Manitoba

Citation: For her leading role in a series of sequential hadronic parity violation experiments designed to elucidate the interplay of the weak and strong interactions in hadronic systems.
Nominated by: Nuclear Physics (DNP)

BAARTMAN, RICHARD A.
TRIUMF

Citation: For significant contributions to the theory and elucidation of collective instabilities and higher order aberrations in particle accelerators and beamlines.
Nominated by: Physics of Beams (DPB)

BECHHOEFER, JOHN L.
Simon Fraser University

Citation: For seminal experimental and theoretical contributions to nonlinear dynamics, pattern formation, phase transitions, solidification and biological physics as well as important advances of scientific instrumentation.
Nominated by: Statistical & Nonlinear Physics (GSNP)

LUKE, MICHAEL
University of Toronto

Citation: For seminal contributions to the phenomenological understanding of heavy quark decays, providing experimentalists with the tools needed to make precision measurements of several fundamental parameters in the Standard Model.
Nominated by: Particles and Fields (DPF)

SLATER, GARY W.
University of Ottawa

Citation: For groundbreaking contributions to our understanding of electrophoretic sieving and entropic separations of macromolecules in gels, solutions, and microfluidic devices.
Nominated by: Polymer Physics (DPOLY)

SPRUNG, DONALD W.L.
McMaster University

Citation: For his many important contributions to the understanding of nuclear dynamics, including the development of the first realistic soft-core two-nucleon interaction and the identification of the role of long-range interactions in the deuteron.
Nominated by: Few-Body Systems & Multiparticle Dynamics (GFB)

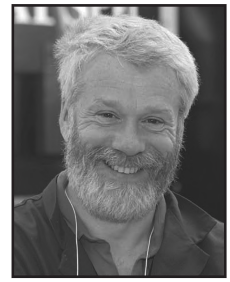
MEDICAL ISOTOPES AND THE FUTURE OF NEUTRON SCATTERING IN CANADA

BY DOMINIC RYAN

SUMMARY

Last May, a thunderstorm caused a power trip at Chalk River Laboratories in Ontario and during the re-start inspection, a heavy water leak was discovered in the reactor vessel. The National Research Universal (NRU) reactor has been down ever since. Canadian neutron scatterers have been without a home base for ten months and tens of thousands of patients around the world have gone without critical diagnostic procedures and essential treatments. *Finally* the issue of a replacement for our 52 year old research reactor is in the news and at the centre of government.

John Katsaras and Ron Rogge of the Canadian Neutron Beam Centre (CNBC) working at the N5 triple-axis spectrometer



Dominic Ryan, (P.Phys.), <dhryan@physics.mcgill.ca>, Professor of Physics, McGill University, President, Canadian Institute for Neutron Scattering

NRU has been at the centre of Canadian research for fifty years. It has supported fundamental research in materials, engineering, physics, chemistry and biology. The NRC's Canadian Neutron Beam Centre (CNBC) has also established Canada as the world-wide leader in providing access to industry from key sectors: nuclear, aerospace, automotive and manufacturing. The unique knowledge obtained using neutron beams helps companies to develop more competitive products that are safer, more reliable and less expensive to manufacture. Neutron scattering at NRU has enabled engineering studies of production technologies, corrosion, stress cracking and welding techniques. In-core work at NRU has supported Canada's nuclear power industry and contributed to the orderly stewardship of our fleet of CANDU reactors. NRU enabled the creation of a medical isotope business that saw us supplying 40 % of the world's needs for ^{99}Mo (for several extended periods NRU was actually supplying as much as *80 %* of the total market) and essentially all of the high specific activity ^{60}Co used for cancer treatments. Almost every person in Canada knows at least one person who has *benefited directly* from radioisotopes produced in NRU.

Despite the remarkable impact of NRU and the quality research carried out by the many people who worked at or visited the facility, NRU has been allowed to decline and age, with no succession plan in place. Over a decade of lobbying and reports from organisations such as NSERC, NRC, CAP and CINS (my own organisation, the Canadian Institute for Neutron Scattering) has produced no tangible results. Since the 1980s, funding cuts at AECL led to the death of Chalk River Laboratories as a National Laboratory, and its place as a key component of Canada's infrastructure for science and industry was diminished. TASCC was closed, the neutron scattering group was abandoned (only intense lobbying by CAP members saved them from termination), commercial in-core activities were ended and the ill-conceived, and ultimately doomed, MAPLE program was created to hive off the medical isotope business. Even in this crippled state, NRU continued to support research in nuclear technology; neutron beams continued to be available (thanks to substantial funding from NRC and NSERC) and were used extensively for basic and applied research in support of academic and industrial users; critical radioisotopes were produced and exported around the world; and NRU just got older.

With no formal vision for the future, benign neglect became the operating principle: NRU could not be closed because there was no other source of the essential medical isotopes that it produced, but renewal was kept to the minimum required to satisfy the regulators, and no coherent plan for a replacement was developed. Successive governments became distracted by “the future of AECL” and saw NRU as simply part of the “AECL problem”. The Canadian Nuclear Safety Commission (CNSC)-driven shut-down of NRU in the winter of 2007 precipitated an immediate isotope crisis and led to direct government intervention to re-start the reactor. Even after this clear warning, no real action was taken, no succession plans were developed. With NRU shut down again, and not expected to return to service until April of 2010, the government is still working on privatising AECL and now appears to view NRU simply as an “isotope issue”.

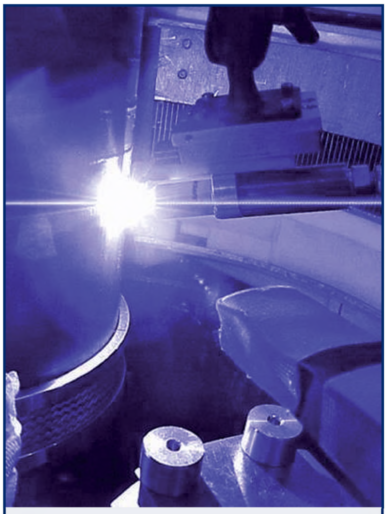
Students learning to use neutron beams at Chalk River.

NRU is not, and never has been, just an isotope reactor. Nor is it just a development platform for AECL. NRU was designed and built as a major piece of *research* infrastructure that has supported Canadian science and industry for over fifty years. It is long overdue for replacement, and only a flexible, multi-purpose research reactor can properly fulfil the many missions that NRU currently supports. Indeed, flexibility may be the most important feature needed in the new facility, since none of the key missions currently carried out by NRU really existed when the reactor went critical. Nuclear power reactors were just starting to appear, Brockhouse was just beginning his Nobel Prize winning research, radiation therapy for cancer was in its infancy and nobody was thinking of using radioisotopes for medical imaging.

While we welcome the attention that the current shortage of medical isotopes has focused on the aging NRU reactor, and do not want to be seen as in any way minimising the seriousness of the situation, we do need to remember that medical isotope production is just one of the missions fulfilled by NRU, and there is a real danger that by fixating on a single-mission solution, we will be distracted from the bigger picture and miss this golden opportunity to re-invest in Canada's future. The ill-fated MAPLE project is one example of a failed single-mission solution (they were intended solely to produce ^{99}Mo for MDS-Nordion and had no other mission or capabilities). The current crop of opportunistic “accelerator options” being touted as “solutions” to the medical isotope problem is another dangerous distraction from the bigger picture with little prospect for success. Such limited single-mission “solutions” could irrevocably damage our prospects of developing a coherent strategy for building a new research reactor facility for Canada that will support Canadian science, Canadian industry, Canadian research and Canadian health. As with the failed MAPLEs before them, accelerator projects are being presented as cheap, single-mission solutions with no regard for the wider implications. Furthermore, since these accelerator facilities would be single-mission installations — ^{99}Mo production only — their construction would represent a massive government subsidy for a commercial activity that exports most of its output to the US.

The central role of proton cyclotrons in the production of a wide variety of essential proton-rich medical isotopes for PET imaging etc. is undeniable. However, ^{99}Mo is a neutron-rich isotope that is produced at very high efficiency through fission of ^{235}U by thermal neutrons (approximately 6 % of all fission reactions create a ^{99}Mo nucleus [1]). The cross sections for all other production reactions for ^{99}Mo are four to five orders of magnitude smaller — including *all* of the accelerator-based reactions [1]. Reactor-based production of ^{99}Mo is a commercially demonstrated technology backed by decades of experience. Several countries, most notably Australia whose ^{99}Mo is licenced for use in Canada, have now moved to using low-enrichment uranium in their process, eliminating proliferation issues associated with the use of highly-enriched uranium.

Small-scale accelerator-based production routes are unattractive for several reasons: (i) They carry a significant risk as they rely on unproven techniques and have not been demonstrated on a commercial scale. These are research projects, not production technologies; (ii) By aiming to supply only the Canadian market they do nothing to enhance the security of the *global* isotope supply. We would no longer contribute to the rest of the world, but would remain dependent on external supplies in the event that our system failed; (iii) As a single-purpose facility, they would serve only to supply a single medical isotope, with very limited additional benefits. They would be either government-run or government-subsidised factories; (iv) Most importantly, they would be completely unable to support the rich diversity of fundamental and applied research activities that a multi-purpose research reactor could, and NRU currently does. By failing to replace NRU with a modern multi-purpose facility, we would be walking away from over fifty years of leadership and expertise.



In-situ studies of welding on C2, the powder diffractometer.

WHAT SHOULD BE DONE?

The panel of experts that was assembled by the Minister of Natural Resources to investigate and report on solutions to the isotope supply problem recognised that a single-purpose facility could not be justified on economic grounds. They further recognised that the various accelerator production routes were largely unproven and would demand a significant R&D effort before their viability could be determined, making them a high risk path. As a result, their primary recommendation was: [2]

> "The lowest-risk path to new Mo-99/Tc-99m production capacity is to build a new multi-purpose research reactor. The research reactor also promises the most associated benefits to Canadians based on its multiple purposes."

The role of government is to provide infrastructure for science and industry that will enable Canadians to carry out research and develop their businesses. As far back as 1994, the Bacon report (commissioned by NSERC) recommended that "Canada should make an immediate commitment to develop a new fully equipped reactor-based national source for neutron beam research". The need for neutron facilities has certainly not diminished. In 2008, we at the Canadian Institute for Neutron Scattering proposed in our report "Planning to 2050" [3] that Canada should build the Canadian Neutron Centre, a new multi-purpose research reactor that will serve Canadians as a key piece of infrastructure for science and industry. While last November, the isotope panel stated: [2]

> "We recommend that the government expeditiously engage in the replacement of the NRU reactor as we believe a multi-purpose research reactor represents the best primary option to create a sustainable source of Mo-99, recognizing that the reactor's other missions would also play a role in justifying the costs. With the National Research Universal (NRU) reactor approaching the end of its life cycle, a decision on a new research reactor is needed quickly to minimize any gap between the start-up of a new reactor and the permanent shutdown of the NRU."

The multi-purpose research reactor concept builds on the successes of NRU and is aimed at drawing together all of the current stakeholders while maintaining the flexibility to serve new and emerging needs. By combining in-core research facilities for nuclear engineering, with high-flux irradiation ports for isotope production and world-class neutron beam instruments, the Canadian Neutron Centre would support a wide range of industrial and research activities. Industrial users would be able to build their businesses around the facilities offered, obtaining services on a realistic, full cost-recovery basis, so that revenue from these activities could be used to offset the operating costs of the facility.

A new world-class facility would be a magnet for talented engineers and scientists in Canada. It would become the heart of a renewed National Laboratory at Chalk River. Our continued leadership in nuclear engineering and neutron based research, both fundamental and applied, would be assured. A stable, reliable source of medical and industrial isotopes would be put in place.

HOW SHOULD WE PROCEED?

To make this project a reality, we must establish a formal engineering design, in collaboration with all of the stakeholders, and develop an accurate costing estimate for the project so that the construction can be undertaken in a transparent and responsible manner. A suitable Federal Agency should be identified that can undertake such a project. It should be given both the mandate and the appropriate funding to coordinate a multi-departmental working group and bring forward a properly costed design proposal as soon as possible. Canada will then be properly prepared to consider an investment in a future Canadian Neutron Centre as a world-class resource for science and industry for the next 50 years.

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MEDICAL ISOTOPES - SIDEBAR

Diagnostic imaging using radioisotopes is well-established and widely used around the world. It relies on some basic chemistry that is keyed to simple biological processes, and some relatively straightforward radiation detection, however its impact on healthcare has been profound. ^{131}I (produced either as a fission product of ^{235}U or through neutron capture by ^{130}Te) is probably the simplest isotope to understand. Iodine is selectively taken up by the thyroid, so small (few mCi) doses injected or ingested by the patient can be used to determine thyroid function by simply measuring the absorbed activity and, by using a gamma-imaging camera, the size of the thyroid gland can be determined. The uniformity of the uptake can be used to identify abnormalities. A few tens of mCi can be used to correct an over-active thyroid, and hundred-plus mCi doses are used to kill thyroid tumours.

However, the most widely used and versatile medical isotope by far, is ^{99m}Tc derived from ^{99}Mo. It is used in 60%–70% of all diagnostic medical procedures in the US [1]. This popularity is the result of several accidents of fate:

- efficient production by fission of uranium makes it widely available;
- the relatively convenient 67-hour half-life makes it possible to extract and distribute the ^{99}Mo with acceptable decay losses;
- the 6-hour half-life of ^{99m}Tc (the daughter isotope that is actually used) means that high specific activity, but short-lived radiopharmaceuticals can be delivered to a patient;
- the very different chemistries of Mo and Tc mean that the ^{99m}Tc daughter can be recovered from the ^{99}Mo as it forms using simple chemistry.
- the 140 keV decay gamma from ^{99m}Tc is well suited for efficient detection by scintillation instruments such as gamma cameras.

Medical use of cyclotron-produced isotopes generally requires a dedicated on-site (or close by) cyclotron facility and a specialised radiopharmaceutical laboratory, whereas hospitals using ^{99}Mo simply take delivery of a new Tc-generator (that is about the size of a jug of milk) every week or so. The generator is flushed with a small amount of saline solution to extract the ^{99m}Tc as needed, and chemical kits are used to convert the extract into a targeted dose for the patient. The wide availability and ease of use of Tc-generators have led to a rich variety of delivery forms being developed. Some target liver and bone marrow function and can be used to detect cancers; others bind to calcium deposits that form following a heart attack and enable doctors to confirm the occurrence (or not) of a heart attack with greater speed and reliability than electrocardiograms (ECG); still others concentrate in areas of high metabolic activity and can be used to measure heart function to investigate the need for, or effectiveness of, by-pass surgery.

The extreme popularity of these nuclear medicine techniques arises from several key features:

- they can be carried out with essentially no lead time or patient preparation;
- they are totally non-invasive making them an ideal first-choice test;
- they can target specific organs or processes in the body;
- they yield highly specific key diagnostic data quickly;
- they carry no significant risk to the patient.

Easy, quick, effective, safe.

Unfortunately for the tens of thousands of patients who need these tests every month, ^{99}Mo is now in extremely short supply. In some cases, alternative radioisotopes produced in cyclotrons can be substituted, but they are not the first choice, and their use diverts resources that were already in heavy demand for other tests.

Current commercial production relies almost entirely on highly enriched uranium (HEU) targets which raises proliferation concerns as 40–50 kg of "weapons grade" uranium is needed annually to supply world demand [1]. This comes primarily from US stockpiles, and it would be hard to imagine a better use for it. However, Argentina, South Africa and Australia have all switched to low-enrichment uranium (LEU) targets so the proliferation problem has effectively been solved.

In a typical production process used at the new Australian reactor facility (OPAL), an aluminium-clad plate of uranium aluminide about the size and shape of a 12" steel ruler is loaded into the reactor for about six days. The target is

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then removed, transferred to a hot cell (the activity at this stage is many thousands of Curies, so some care is required) where it is dissolved in sodium hydroxide, filtered to eliminate the solid waste and the solution is purified by ion exchange and then passed through an alumina column that selectively adsorbs the molybdate (MoO_4^{2-}) ion. The ^{99}Mo is then washed from the column and recovered as a highly pure product. ^{99}Mo recovery yields at OPAL are currently about 60%, with 80–90% expected as the process is further refined. Production levels are about 500 6-day Curies/week [2] – enough to satisfy their domestic market and allow export to South Africa, Japan and South-East Asia. For comparison, US demand in 2006 was about 6,000 6-day Curies/week [1], so a much larger facility would be needed to supply North American needs.

A few Curies of the extracted ^{99}Mo are re-adsorbed onto a pencil-sized alumina column, loaded into a shielded case and shipped to a hospital as a "technetium generator". The shortlived ^{99m}Tc builds up in the generator as the ^{99}Mo decays, and is washed out as needed using a saline solution. The extract is processed using a pre-constituted kit to create the specific radiopharmaceutical required for the test to be run. The product is delivered to the patient and the organ(s) of interest are imaged [1]. The lifetime of the generator is limited not only by the decay of the ^{99}Mo, but also by "breakthrough": increasing amounts of molybdenum appear in the extract as the generator ages and eventually (after about a week), it can no longer be used for work involving human subjects. The initial isotopic purity of the ^{99}Mo therefore plays a major role in extending the working life of technetium generators. Clearly, stockpiling ^{99}Mo is not an option, so a secure stable source is essential.

The capital costs of a reactor to produce ^{99}Mo would run to many hundreds of millions of dollars, so a single-purpose facility is not an economic option [3]. An equivalent capacity accelerator-based production facility would be at least as expensive to build, and would cost far more to run. Neither approach makes economic sense. We at the Canadian Institute for Neutron Scattering (CINS) have therefore proposed the construction of a multi-purpose research reactor that will both serve all of the stakeholders currently using NRU and also provide a stable source of ^{99}Mo for the next fifty years [4].

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THE CANADIAN NEUTRON SOURCE: STRENGTHENING CANADA'S ISOTOPE SUPPLY AND R&D CAPACITY

BY RICHARD FLORIZONE AND DEAN CHAPMAN

Shutdowns of Canada's National Research Universal (NRU) reactor in 2007 and in 2009-10 have created a crisis in the global supply of medical isotopes. While this shortage of isotopes is a critical issue, Canada stands to lose much more if the NRU is permanently closed — as is planned for 2016.

Research reactors like the NRU are a key component of global research and development infrastructure. In addition to providing the medical isotopes currently in demand, they

- enable the research and development of new applications for isotopes and advance the frontiers of nuclear medicine;
- supply neutrons for research across a broad spectrum of disciplines — from material and basic sciences to industrial applications and medicine; and
- provide a platform for training and for research and development on fuels and components for nuclear power technologies.

Indeed, nations such as Australia, the Netherlands, Germany, Egypt and Jordan have recognized these benefits and invested in their own new research reactors.

Canada needs a new, multi-purpose research reactor to replace the NRU — a reactor that will secure the country's supply of medical isotopes and build on its historic strengths in neutron science and nuclear medicine.

The authors and the University of Saskatchewan are partners in a consortium to establish just such a facility — the Canadian Neutron Source (CNS) — based on Australia's recently commissioned OPAL reactor. Potentially located near Canada's only synchrotron (the Canadian Light Source) in Saskatoon, Saskatchewan, the CNS could synergize neutron and photon science in Canada, following the lead of other countries that have co-located their synchrotrons and research reactors.

SUMMARY

In this paper, the authors give a brief overview of the isotope crisis, outline the broader R&D benefits of a new multi-purpose reactor and summarize their proposal for the Canadian Neutron Source.

SOLVING THE ISOTOPE CRISIS

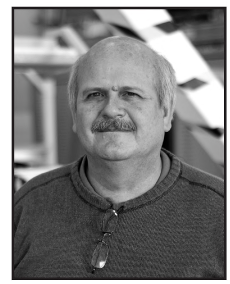
Canada's NRU reactor at Chalk River has historically provided 30-40 percent of the global supply of molybdenum-99 (Mo-99), the parent isotope of the short-lived technetium-99m (Tc-99m) used in millions of medical tests for cancer, heart and bone disease.

Canada's health care system relies on a stable supply of medical isotopes to diagnose and treat thousands of patients every day. Doctors use isotopes in nuclear imaging 30,000 times every week to quickly and accurately diagnose illness including many forms of cancer. They use isotopes for approximately 300 brachytherapy treatments (in which radiation from isotopes controls or eliminates cancerous growths) every week. As of 2016, Canada will need a new source of supply for these isotopes, and, if it wants the supply to be home-grown, it can choose between production using reactor-based or the newer proposed accelerator-based techniques.

The reactor technique relies on the neutron-induced fission of U-235, of which Mo-99 is a byproduct about six percent of the time. The Mo-99 is chemically removed from the U-235 target and absorbed into generators that are shipped to hospitals and clinics. When the Mo-99 decays (~66-hour half-life) into Tc-99m (~six-hour half-life), the Tc-99m is eluted or washed out with saline solution and used in the nuclear medicine procedure.

Accelerator-based techniques use high-energy electrons from linear accelerators or protons from cyclotrons to create isotopes. The former create high-energy gamma radiation from impinging the electrons onto a converter target. These gammas can be used to split U-238 or U-235 via photo-fission. This process has the distinct advantage of creating Mo-99 using either uranium isotope. Alternatively, the gammas can be used to transmute Mo-100 into Mo-99 by ejecting a neutron. The proton cyclotron approach utilizes protons striking a Mo-100 target to create Tc-99m. This direct conversion method would only provide a local supply of Tc-99m due to its

* The authors and the University of Saskatchewan are partners in a consortium to establish the Canadian Neutron Source research reactor facility.



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short half-life, and therefore, a single site would not supply the whole country.

In 2009, the Government of Canada convened an expert panel to compare these techniques and their advantages and disadvantages against specific criteria, namely: technical feasibility; business implementation; timeliness; regulatory issues; and benefits to Canadians. In its final report [1] dated November 2009, the report stated:

> *"We recommend that the government expeditiously engage in the replacement of the NRU reactor as we believe a multi-purpose research reactor represents the best primary option to create a sustainable source of molybdenum-99, recognizing that the reactor's other missions would also play a role in justifying the costs."*

In other words, this is a recommendation that the Government of Canada build a new, multi-purpose, research reactor as well as the expanded facilities for processing isotope targets made with low-enriched uranium. Even though this option is costly, it is the guaranteed, long-term solution to Canada's security of isotope supply, and furthermore offers the most associated benefits to Canadians in areas of enduring value — energy and materials research. The decision to invest in this key element of Canada's infrastructure for science and industry should be taken as soon as possible.

BEYOND ISOTOPES: STRENGTHENING CANADA'S R&D CAPACITY

Nuclear Medicine Training, Research and Development

Canadian scientists have pioneered a number of medical applications, such as the production and use of medical isotopes that began with the supply of cobalt-60 for nuclear medicine procedures. The result was the world's first cobalt-60 cancer treatment, which revolutionized cancer radiation therapy worldwide and greatly improved survival rates for people suffering from formerly untreatable cancers, including cancer of the bladder, prostate and cervix. Canada also introduced the use of isotopes for diagnostic imaging of disease and continued its leadership in nuclear medicine by supplying a variety of medical isotopes, including the previously mentioned 30-40 percent of the global supply of Mo-99, via the NRU reactor.

Nuclear medicine offers non-invasive imaging of biochemical changes in living organisms that is not possible with other imaging modalities. Isotopes can reveal how organs and bodily systems are functioning, not just what they look like, as with X-rays. This is key to tracking the progress of disease and the effectiveness of drugs, as well as reducing exposure to ineffective and possibly toxic treatment. Current applications include diagnosis of diseases such as cancer, neurological disorders and cardiovascular disease at early stages, enabling earlier treatment. Applications have grown to include visualizing intracellular processes, enzyme trafficking and receptors, and gene expression.

Canada must continue to innovate and develop new applications through leading-edge research to stay ahead of evolving treatment and diagnostic needs. Particularly exciting is the promise of delivering molecularly targeted treatments for some cancers and endocrine disorders, leaving healthy cells alone. The use of isotopes and the imaging technologies around them is creating the opportunity to individualize treatment and medication based on a person's unique genetic profile and response to disease (personalized medicine).

Shortage of nuclear medicine scientists

Aging facilities and a shortage of nuclear medicine scientists and clinical personnel are hampering the advancement of nuclear medicine and critically important research in Canada. The declining number of reactors in North America since the mid-1970s has limited research into new radiopharmaceuticals and reduced opportunities to train highly qualified personnel in preparing therapeutics. There is now a shortage of clinical and research personnel in all aspects of nuclear medicine that has affected the ability of universities to provide training. Canada needs to act now to revitalize its capacity for neutron-based science and train the next generation of nuclear medicine scientists and practitioners.

The need for both highly qualified personnel and research facilities argues strongly for linking new isotope-generating reactor facilities with a university — ideally, a national centre for nuclear research and training which would promote the training of undergraduate and graduate students, as well as post-doctoral fellows.

NEUTRON SCATTERING CHALLENGES AND OPPORTUNITIES

Arguably, Canada invented neutron research in the 1950s when National Research Council (NRC) researcher Bertram Brockhouse realized that these particles could be used to provide completely new insight into matter — a discovery for which he shared the Nobel Prize in 1994.

Due to their uncharged nature, neutrons can penetrate deep within materials without damaging them to reveal their structure and dynamics. This property makes neutrons the probe of choice for investigating stress in large objects and for characterizing the molecular and atomic-level structure and behaviour of materials ranging from metals and ceramics to plastics and blood. The ability to easily exchange energy with the nuclei of materials provides insight into the dynamics of systems.

Neutrons are sensitive to differences among isotopes of elements and can reveal structural information that cannot be

1. "Report of the Expert Review Panel on Medical Isotope Production," Presented to the Minister of Natural Resources Canada, 30 November, 2009. Available for download at: http://nrcan.gc.ca/eneene/sources/uranuc/pdf/panrep-rapexp-eng.pdf

gained through X-ray or other techniques. For instance, hydrogen is very difficult to see with X-rays because it contains very little charge and so is nearly invisible to the X-ray photons. However, deuterium has a significantly different neutron signature than hydrogen, which allows one to "see" the water-hydrating protein molecules that are key to investigating biological systems such as membranes, protein-protein interactions and DNA/protein complexes — knowledge that provides important clues into disease processes and how to treat or cure disease.

Neutrons can be "polarized" to investigate magnetic properties of materials, something very difficult to do with X-rays. This is important for basic research and industrial applications, such as development of materials for next-generation information storage on hard drives. As well, neutron sources can replace conventional thermal or ion-implantation methods for silicon doping electronic components and is emerging as a major advance in "green electronics."

As the national centre for neutron beam research through the NRC's Canadian Neutron Beam Centre (CNBC), the impending loss of the NRU reactor will have a significant impact on the research community, threatening the research of hundreds of scientists who will be forced to move their programs abroad. This would be a tremendous loss of Canadian expertise. The CNBC provides domestic and foreign scientists with specialized facilities to obtain new understanding of materials, improve products and services, and conduct research that supports the growth of Canadian industry and solves national challenges in health, climate change, the environment, clean energy and other fields.

To complicate matters further, as researchers expand the range of applications, the fewer than 45 neutron beam laboratories worldwide are increasingly oversubscribed.

Canada risks falling behind internationally in neutron research capability. Other nations have made continuing commitments to neutron science: Australia has just completed the OPAL reactor; in Europe the European Spallation Source is to be built in Lund, Sweden; the Netherlands completed the conceptual design and vendor pre-selection of a new research reactor; and other countries, such as the United States and Japan, are investing heavily in new, advanced neutron sources.

However, Canada has its own opportunity. Coupling a research reactor that delivers medical isotopes with a state-of-the-art neutron beam facility could maintain and restore its historical lead in neutron and medical research, and meet the demand for neutrons that will give the nation a competitive edge in basic science, medicine, materials and industrial innovation.

The Canadian neutron scattering community — well organized through the Canadian Institute for Neutron Scattering (CINS), which represents 15 organizational members from industry, government and academia — supports the call for a new reactor. CNIS's long-term planning culminated in the 2008 document, Planning to 2050 for Material Research with Neutron Beams in Canada, which calls for a world-class facility to address the three missions — reactor development and production of both isotopes and neutrons — that the NRU now fulfills.

This vision — to deliver medical isotopes while strengthening Canada's R&D capacity — is the driving force behind a joint proposal by the Government of Saskatchewan, the University of Saskatchewan and their partners for a new multi-purpose research reactor, the Canadian Neutron Source.

THE CANADIAN NEUTRON SOURCE

The Canadian Neutron Source (CNS) is a joint proposal of the Government of Saskatchewan, the University of Saskatchewan and their partners to build a new 20-megawatt, low-enriched uranium (LEU) research reactor facility, optimized to serve two purposes:

1. delivery of medical isotopes — specifically, with a preliminary goal of 2,000 six-day Curies of Mo-99 per week (or about one-sixth of global demand) to serve the Canadian and export market; and
2. delivery of neutron beams for neutron science — to serve the needs of Canadian science in industry and the public sector.

The focus on only these two missions — which excludes a potential third mission to support R&D on fuel for nuclear power generation — is a deliberate choice to minimize cost and technical risk. Accommodating R&D on nuclear fuel is important but would require a larger reactor core, which would significantly increase costs and represent a marked departure from the proven OPAL design on which the CNS is based (see Figure 1).

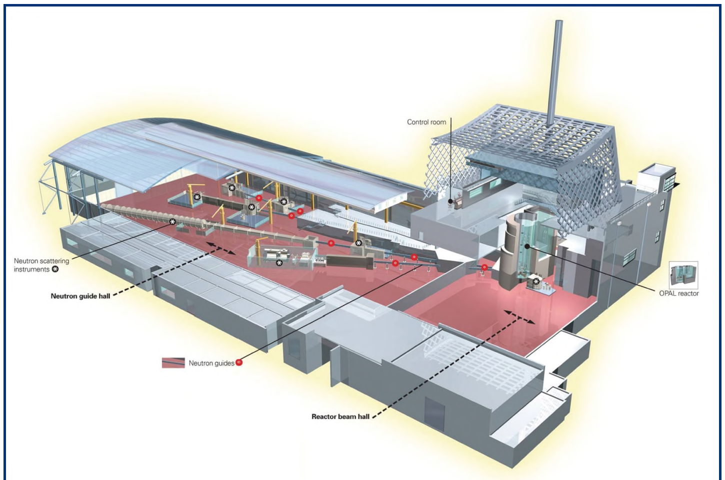

Fig. 1 Cut-away view of the OPAL reactor facility. This dual purpose (medical isotopes and neutron research) facility is similar to the proposed Canadian Neutron Source.

The CNS proposal has the support of over 20 scientific, medical, business and community organizations, each of which have provided a letter of support. These organizations are local, provincial, national and international, and include the Saskatchewan Cancer Agency, the Saskatchewan Health Research Foundation, the Canadian Light Source (CLS), Cameco Corporation, MDS Nordion, the Canadian Institute for Neutron Scattering (CINS), the Bragg Institute (Australia), and Institut Laue Langevin (France).

The Australian OPAL research reactor (see Figure 1) on which the CNS is based is a multi-purpose reactor capable of meeting the dual mission of the CNS. It is a proven design, minimizing technical risk. It uses low-enriched uranium to minimize the risk of proliferation, and it aligns with global efforts at phasing out highly enriched uranium in research reactors.

The consortium estimates total project development and construction costs at between $500 million to $750 million, the majority of which will come from the federal government and the remainder from the Saskatchewan government. Operating costs are expected to come from a partnership between federal and provincial governments and industry (isotope sales and industrial science).

As the expert panel recommended, the federal government must act quickly to minimize any gap between the permanent shutdown of the NRU and the start-up of a new reactor. The next most important milestone in the process is for the federal government to commit to the project — to develop a national policy around a new reactor — since its scale and complexity preclude Saskatchewan's provincial government from going ahead alone. Ultimately, the completion date (see bullet on Timeliness below) will depend upon a range of factors, including time required to secure the commitment of funding partners, the environmental and regulatory review process and the completion of public input processes. This timeline is based on initial conversations with the Canadian Nuclear Safety Commission (CNSC) and several partners.

Harnessing photons and neutrons to probe matter

Locating a facility that delivers medical isotopes and neutrons adjacent to Canada's newest, largest photon research facility — the CLS synchrotron — would create a synergy found in only a few places in the world.

The potential to apply neutron science to biomedical research and structural biology is recognized internationally as an emerging area for deeper understanding of the molecular basis for health and disease. The complementary application of photon and neutron techniques is probing the frontiers of science at the interface of chemistry and biology and has motivated the international community to promote the co-location of the next generation of synchrotrons and neutron sources.

Co-locating the proposed CNS on the University of Saskatchewan campus with the existing CLS synchrotron would create the synergistic research environment to pioneer novel approaches to issues of human health and treatment of disease. Furthermore, synergistic neutron/photon research in structural biology and in the study of soft matter is at the cutting edge of innovation in molecular biology, biotechnology and nanomaterials. The emerging international calibre excellence in research in medical imaging, diagnostics and therapy at the CLS would be significantly enhanced by complementary research into radioisotope applications.

The collaborative research and partnerships that would grow from co-location research synergies would lead to other new joint facilities that benefit the CNS and CLS. These could include biological preparation laboratories, crystal preparation facilities, metrology labs, advanced instrumentation and data collection collaborations, common data storage and visualization and detector development. The synergies of co-location would promote high-calibre science and attract world-leading scientists.

CONCLUSION

With the planned shutdown of the NRU in 2016, Canada stands to lose its domestic source of medical isotopes, weaken its capacity in nuclear medicine and lose its historic leadership in neutron science.

Two categories of technology (reactor- and accelerator-based) exist to produce substantial quantities of medical isotopes. The authors agree with the key finding of the Natural Resources Canada Expert Panel on Medical Isotope Production, namely that a reactor represents the best primary option for producing Mo-99 and offers the most associated benefits to Canada.

Canada needs a new research reactor. The authors believe that the CNS is the facility that best meets this need because it addresses the issue of a secure supply of medical isotopes and also supports the R&D opportunities of neutron science. Furthermore, with a proposed location near the CLS and the University of Saskatchewan, the CNS would be ideally suited to exploit the synergies between photon and neutron science, and to train the next generation of nuclear medicine professionals.

ACKNOWLEDGEMENTS

The authors acknowledge the advice of those individuals they drew upon in the writing of this paper and the contribution of the many people and organizations that provided information and support to the Expression of Interest[2] submitted by the Government of Saskatchewan and University of Saskatchewan to Natural Resources Canada Expert Review Panel on Medical Isotope Production.

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A SHORT TERM SOLUTION TO THE MEDICAL ISOTOPE CRISIS VIA DIRECT PRODUCTION OF TC-99M AT LOW ENERGY: A PIECE OF THE PUZZLE

BY THOMAS J. RUTH, TRIUMF

The recent unexpected shutdown of the Chalk River, Canada reactor has caused a major disruption in the supply of the most important radionuclide used in medicine today, Mo-99. Mo-99 is the source of Tc-99m used in more than 80% of all nuclear medicine imaging procedures. There are only 5 reactors that are presently used in the production of Mo-99 and all of these reactors are over forty years old, the one in Chalk River, the NRU, is 52 years old. The NRU and the HFR reactor in the Netherlands account for more than 60% of the world's supply. The NRU is closed because of a heavy water leak in the containment vessel releasing tritiated water into the holding tank. The HFR reactor had a leak in a coolant pipe earlier in 2009 and is due for an extended shutdown in 2010 to repair this leak.

With these shutdowns the supply of Mo-99 has caused major shortages around the world causing major challenges in diagnosing patients with heart disease and cancer.

With most solutions for obtaining a reliable supply of Mo-99 taking 5 or more years, short term solutions need to be examined. Some of the long term solutions involve the use of accelerators including using electron linacs to generate photon beams for photo induced fission of natural uranium or photo induced neutron emission on Mo-100 yielding low specific activity Mo-99. Other proposals include the use of proton spallation sources to generate secondary neutrons for neutron induced fission of uranium-235. However these large projects require several years of planning and construction before the conceptual ideas can become a reality and would not be able to supply commercial quantities of Mo-99 before 2016-2020.

SUMMARY

The shutdown of the NRU reactor in Chalk River, Ontario, and the planned shutdown of the HFR reactor in the Netherlands in 2010, has caused major shortages in the supply of Mo-99 around the world, causing major challenges in diagnosing patients with heart disease and cancer.

In the recent National Academy of Sciences report *Medical Isotope Production without Highly Enriched Uranium* [1], it was suggested that direct production of Tc-99m could be used to alleviate shortages in regions close to a low energy cyclotron. It turns out that the ^{100}Mo(p,2n)^{99m}Tc reaction peaks at around 16 MeV and the entire useful excitation function is covered from about 15 MeV to 24 MeV. (see Figure 1) From the literature it appears that the production rate for this reaction is 17 mCi/μAh. [2-7] At this rate it is possible for existing low energy cyclotrons to produce tens of curies of Tc-99m per day at somewhat modest beam currents (100 μA protons). Thus existing cyclotrons such as those with proton energies of 17-19 MeV could produce significant amounts of Tc-99m for local use on a daily basis. The chemistry for isolating Tc-99m from the Mo-100 target is fairly straightforward and less complex than what is used to extract Mo-99 from the fission products and allows for the recycling of the Mo-100 for subsequent irradiations [.8]

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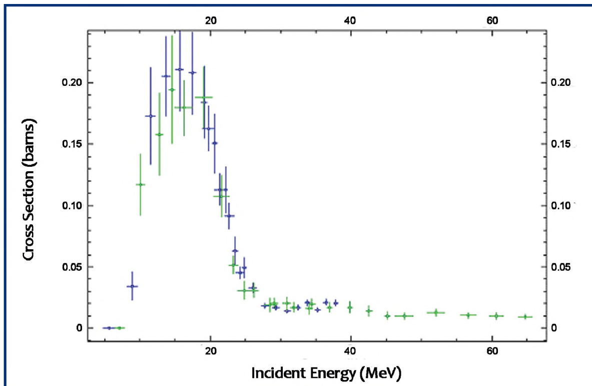

Fig.1 Production cross section for the ^{100}Mo(p,2n) ^{99m}Tc reaction. Exfor, Nuclear Data Center, BNL.

While this approach is not a *fix* it does provide for an alternative that could be implemented in the short term to alleviate demands for Tc-99m from generator produced Mo-99. Such a relief would allow for the scarce Mo-99 generators to be used in locations more distant from the cyclotrons. Another layer of sophistication that should be explored is to form a network of existing cyclotron facilities that could coordinate production and supply. A distributed supply provides for redundancy. Such a network was funded by NSERC and CIHR in response to their special call for proposals in August 2009 seeking alternative to the existing Tc-99m based radiopharmaceuticals. This network is being explored in Canada among 5 centers in 4 cities across the country; in Vancouver (TRIUMF and the BC Cancer Agency), Edmonton (Cross Cancer Institute), London (Lawson Health Science Centre) and Sherbrooke (CHUS).

The proposal was to develop the targetry for the low energy cyclotrons (three TR19 cyclotrons, one GE PETrace and a CP42 variable energy cyclotron. The TR cyclotrons and the PETrace can operate at 50 to 100 μA while the CP42 can reach 200 μA at 24 MeV. In addition to producing Tc-99m the investigators will produce Tc-94m as a PET alternative to the SPECT based Tc-99m with the aim of determining if the existing Tc-based radiopharmceuticals can be used in PET with the direct substitution of Tc-94m (72% β+, 52 min $t_{1/2}$) for Tc-99m (140 keV γ-ray, 6 h $t_{1/2}$). Because of the shorter half life there may be radiopharmaceuticals not amenable to this approach. The project mandate is to bring the cyclotron based Tc-99m radiopharmaceuticals into human use within 2 years (Fall 2011).

While this paper does not address the directions of accelerator usage in medicine for the future it is aimed at demonstrating the utility of existing cyclotrons and of their potential for benefit to society through coordinated efforts, concepts that should be kept in mind as plans for the future are examined.

ACKNOWLEDGEMENTS

Helpful discussions with Drs. Francois Benard, Steve McQuarrie, Suzanne Lapi, Mike Kovacs, Frank Prato and Doug Abrams are gratefully acknowledged. The concept of building a dedicated cyclotron for this purpose described here has been initiated by ACS, Incorporated in Richmond, BC.

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Medical Isotope Production Using Commercially-Available Accelerator and Processing Technologies

by Randy Kobes, Jeff Martin, Kennedy Mang'era and Chris Saunders

The recent shutdown of the Chalk River nuclear reactor and the subsequent worldwide shortage of medical radioisotopes have been topics of national concern. Much of this interest is on the political and medical front, but it has also spurred significant scientific research. In order to decide how to proceed in addressing this problem, Natural Resources Canada invited proposals last year by the private and public sectors for alternatives to producing Molybdenum-99/Technetium-99m, the key medical isotopes currently in short supply around the world. An expert review panel was established to evaluate the proposals, and in early December 2009, a report was delivered containing its recommendations [1]. This article will describe the proposal submitted by PIPE – the Prairie Isotope Production Enterprise, which is a non-profit organization with membership consisting of a number of groups from Manitoba and Saskatchewan [2].

Radioisotopes are used in medicine both for diagnostic and therapeutic uses, with about 90% of the procedures performed with them being diagnostic. The reason that they are so useful is that they can be attached to a chemical compound that, when introduced into a body, preferentially accumulates in a targeted area. Once there, the isotope decays by emitting gamma radiation. By measuring the amount and the energy of this radiation, one can use an external camera to non-invasively construct detailed images of the area where the radioisotope originated in a way that is less harmful than biopsy, surgery, etc. A common radioisotope used for this purpose is technetium-99m (Tc-99m). This isotope has a half-life of about six hours and decays by emitting gamma rays of about the same energy as a conventional X-ray. The short half-life makes it useful for diagnostic purposes, but also makes it inconvenient for transport over long distances. For this reason, a Tc-99m generator is used. The generator contains molybdenum-99 (Mo-99), which has a half-life of about 66 hours and produces Tc-99m when it decays. Areas of the body that are commonly imaged using this isotope include the brain, thyroid, heart, lungs, liver, kidney, spleen and bone marrow.

Summary

Natural Resources Canada invited proposals last year by the private and public sectors for alternatives to producing Molybdenum-99/Technetium-99m, the key medical isotopes currently in short supply around the world. This article will describe the proposal submitted by PIPE – the Prairie Isotope Production Enterprise, which is a non-profit organization with membership consisting of a number of groups from Manitoba and Saskatchewan.

The standard way to produce Mo-99 is in a nuclear reactor through neutron-induced fission, whereby an intense neutron flux bombards highly enriched Uranium-235, causing a cascade of fission products that includes Mo-99 about 6% of the time. The Mo-99 is then separated in a processing facility and the product supplied to Mo-99/Tc-99m generator fabricators. However, as recent events have shown, it is important to have alternative production processes and facilities available so that a critical shortage doesn't result when an unexpected shutdown of one of the sources occurs. Three such alternative processes that have been examined in this regard are [3]:

- A neutron-capture process, in which an intense neutron beam generated by a nuclear reactor adds one neutron to a Mo-98 target to produce Mo-99.
- A photo-neutron process, where an intense photon beam generated by an electron accelerator removes a neutron from a Mo-100 target to produce Mo-99.
- A photo-fission process, where an intense photon beam generated by an electron accelerator causes a uranium target to fission to produce Mo-99.

Based on an evaluation of the currently available Tc-99m production methods, economics, the time needed to get products to patients, environmental considerations, regulatory issues, and availability of suitable linear accelerator technologies, particularly in Canada, PIPE has selected photon irradiation of selected Mo-100 compounds and physical forms as the process platform.

A critical aspect to be addressed is that, once the Mo-based target materials are irradiated with photons, the materials must then be processed to produce the Mo-99/Tc-99m

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Fig. 1 Linear accelerator used by PIPE Research Team.

generators or Tc-99m solutions for direct delivery to hospitals. The commercially available processing technologies in this regard include:

- Production of a gel-moly (zirconium or titanium molybdate) solid containing Mo-99. The gel-moly–based generators are shipped to radiopharmaceutical facilities, Tc-99m is eluted as per the standard practice, and the generators are returned for recycling.
- A generator that extracts Tc-99m from molybdenum trioxide using a melt technology. As before, the generators are returned for recycling after the Tc-99m is consumed.
- A generator that extracts Tc-99m from molybdenum trioxide crystals (powder technology), with a dissolution and recrystalization step between milkings.

A major question arising (and which we at PIPE hope to answer) in the use of this accelerator-based approach is the scalability – will this process produce enough Tc-99m to be economically viable? A study by Nelson *et al.* estimates that a 40 MeV, 14 kW accelerator can produce over 18,000 Ci per year of Tc-99m [4], which represents about 70% of Canada's current demand for Tc-99m. This will have to be confirmed through detailed studies and realistic trials. Such investigations will also determine the effects of various parameters on the production rate, such as

- Variation of Mo-99 production with beam energy
- Effects of target design and beam position, including dependence on
  - o The radial offset of the beam.
  - o The shape of the target.
  - o The effects of a tungsten layer on the Mo target.
  - o The use of a target enriched with Mo-100 isotope.

Our R&D program to address production, purification, and generator development has already begun. We have successfully produced Mo-99 by exposing natural Mo targets to an electron beam from our accelerator at Acsion Industries (Pinawa, MB). We are now preparing to make larger quantities of Mo-99 and to proceed with generator fabrication. This work has so far been done on a 10 Mev, 4 kW accelerator and ultimately a higher power accelerator is desirable. Our plan calls for the support of a 30-40 MeV machine running above 50 kW. Such accelerators are commercially available from Mevex Corporation (Ottawa, ON). Our operations would thus be expanded to generate a significant fraction of the Canadian demand if our facility were to receive funding support.

Although research and development needs to be done to answer with certainty these and other questions on the use of this technology, there are a number of significant benefits to Canada should this prove feasible, including:

- Availability of a reliable Canadian source of Tc-99m, with the potential to have multiple such facilities to ensure a consistent supply;
- A relatively short development period, with initial production beginning within 2 years and full-scale production a year after that;
- No long-term radioactive waste streams (*e.g.* with uranium) are present and product recycling is incorporated into the production process;

Probably the most important lesson to be learned from the current crisis is that neither one technology nor facility should be relied upon for producing the bulk of medical isotopes.

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USING THE ^{100}MO PHOTONEUTRON REACTION TO MEET CANADA'S REQUIREMENT FOR ^{99m}TC

BY CARL ROSS, RAPHAEL GALEA, PATRICK SAULL, WALTER DAVIDSON, PETER BROWN, DAVID BROWN, JIM HARVEY, GEORGE MESSINA, RICHARD WASSENAAR, AND MARK DE JONG

The most widely used isotope for medical imaging is ^{99m}Tc. In Canada alone, it is used for about 5500 scans per day. Most ^{99m}Tc, which has a half-life of about 6 hours, is derived from the decay of the parent isotope, ^{99}Mo. Because the half-life of ^{99}Mo is about 66 hours, the time scale during which ^{99m}Tc can be stored and shipped is extended by an order of magnitude compared to the direct production of ^{99m}Tc.

Until recently, the NRU reactor at Chalk River was a major producer of the world's supply of ^{99}Mo. The unexpected, and ill-defined, maintenance requirements of the NRU have led to a world-wide shortage of ^{99}Mo and the current isotope crisis.

Natural Resources Canada (NRCan), in response to the crisis, formed an Expert Review Panel to review Expressions of Interest (EoI) on ways to solve the isotope crisis. The National Research Council (NRC), with three collaborators, submitted an EoI which proposed the use of electron accelerators to produce ^{99}Mo using the ^{100}Mo photoneutron reaction.

SUMMARY

Drawing on work carried out at the Idaho National Laboratory in the 1990s, we show that a single national facility operating two 35 MeV, 100 kW electron accelerators to produce ^{99}Mo using the ^{100}Mo photoneutron reaction could supply all of Canada's requirements for ^{99m}Tc. Suitable industrial-grade accelerators are available from Mevex Corporation, and NorthStar Medical Radioisotopes has developed a ^{99m}Tc separator for low-specific activity material. An economic analysis indicates that the production cost of ^{99m}Tc would be less than the present market price. Using the NRC 35 MeV linac, we have tested all the steps in the process. Attractive features of the (γ, n) approach include: no use of uranium of any kind; simple chemistry for target dissolution; no significant radioactive waste; less than 24 hours between end-of-bombardment and the shipping of ^{99}Mo solution to nuclear pharmacies; and no significant change to the operation of nuclear medicine departments and pharmacies.

Our proposal drew heavily on work carried out at the Idaho National Laboratory in the mid 1990s, where they had proposed the same approach [1]. They examined in detail how a single accelerator could supply the needs of the state of Florida, which has a population about half that of Canada, and showed that the economics were competitive with ^{99}Mo produced by reactors. The viability of the Idaho model was re-examined several years later by Nelson *et al* [2].

Using the NRC 35 MeV electron accelerator, we have demonstrated all the steps in the production process. We have also considered the economics of the process and conclude that a single national facility could produce all of Canada's requirements for ^{99}Mo and at a cost below that presently paid by nuclear medicine departments.

We will review the main features of our proposal, including the science underlying it, the key enabling technologies that are available, the economics of the process and work that we have done at NRC to confirm expected yields.

BASIC REQUIREMENTS

In order to define the technical requirements for a facility to produce ^{99}Mo, we must have estimates of the required production rates. From published work [3] one can determine that Canada requires at least 420 "six-day curies" of ^{99}Mo per week. The concept of the six-day curie is illustrated in Figure 1 and is intended to allow for delays in processing reactor-produced ^{99}Mo and building the ^{99m}Tc generators. If we were to assume the same model applies to accelerator-produced ^{99}Mo the end-of-bombardment (EoB) production rate must be at least 360 Ci/day.

An alternative estimate can be obtained by considering the demand for ^{99m}Tc. There are about 5500 scans per day in Canada, and each scan requires on average 20 mCi of ^{99m}Tc, giving a daily national requirement of 110 Ci.

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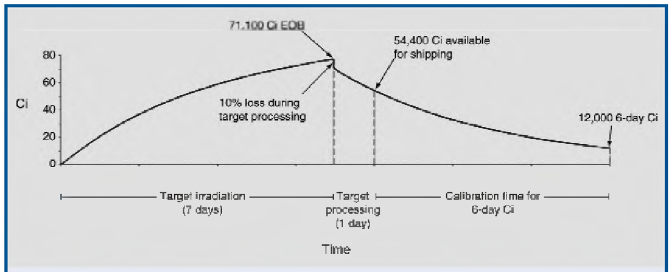

Fig. 1 ^{99}Mo production is specified in terms of the six-day curie. This means the end-of-bombardment target activity must be a factor of about 6 greater than the activity of the material supplied to the customer. (Taken from the US NRC study on "Medical Isotope Production without Highly Enriched Uranium".)

Figure 2 shows how a supply of ^{99}Mo can be milked on a 24-hour schedule to recover ^{99m}Tc, and thus the need for new ^{99}Mo should correspond to the loss over a 24 hour period, or about 31 Ci per day. The time from EoB to delivery of ^{99}Mo should be less than 24 hours, leading to a production requirement of about 40 Ci per day. This estimate is a factor of nine smaller than our earlier estimate and is largely because of the losses illustrated in Figure 1. In what follows, we assume the need to produce 360 Ci per day, but we believe the required production rate of a properly designed accelerator facility will be considerably less.

The giant dipole resonance in the (γ, n) reaction was discovered more than 60 years ago. For medium to heavy nuclei the cross section peaks between 10 and 20 MeV and has a width of several MeV. Photo-induced reactions in the molybdenum isotopes were first studied by Gellie and Lokan [4] and the maximum of the cross section for ^{100}Mo was observed at about 15 MeV.

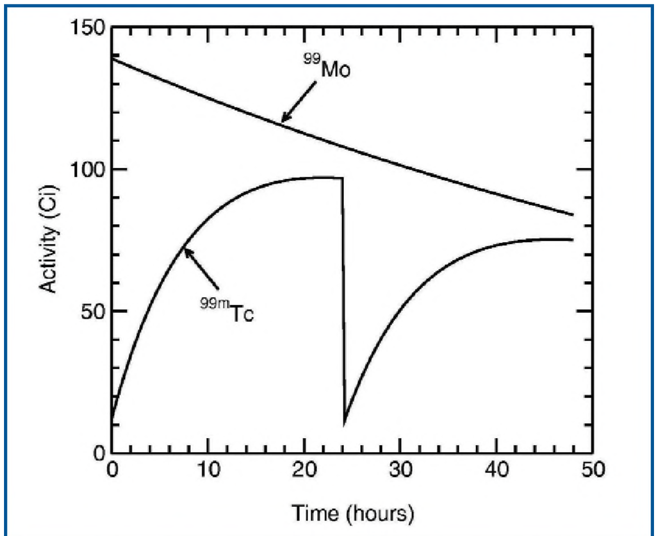

Fig. 2 A solution containing ^{99}Mo can be milked on a 24 hour cycle to recover the ^{99m}Tc activity. The branching ratio for the decay of ^{99}Mo to ^{99m}Tc is about 0.88 and an elution efficiency of 0.9 has been assumed.

^{100}Mo is technically not a stable nuclide, but its half-life of almost 10^{19} years means that, for practical purposes, in can be considered stable. It forms about 9.7 % of the isotopic composition of naturally-occurring molybdenum. Isotopic enrichment facilities, such as those operated in the Netherlands by Urenco, can produce molybdenum enriched to greater than 95 % in ^{100}Mo. Recent work on double beta decay [5] has used more than 1 kg of molybdenum enriched to 98 % in ^{100}Mo.

The bremsstrahlung process, whereby a high-energy electron is scattered by an atomic nucleus, can be used to produce a beam of high-energy photons [6]. The photon spectrum is continuous, with the fluence rate increasing smoothly from zero as the photon energy decreases below the kinetic energy of the incident electron. This means that the energy of the incident electron beam must be significantly higher than the energy of the peak of the photoneutron cross section. There is a trade-off between electron energy and beam power but an electron energy between 30 and 50 MeV is likely optimum [1,3].

Bennett *et al* [1] used Monte Carlo calculations that were tested against measured ^{99}Mo yields to determine the optimum target geometry. They concluded that a cylindrical target, 1 cm in diameter and 2 cm long would be a satisfactory compromise. Their calculations showed that such a target, irradiated for 24 hours by a 14 kW, 40 MeV beam, would yield 25 Ci of ^{99}Mo. This result is consistent with calculations carried out by Diamond and summarized in the TRIUMF task force report [3]. Using the above estimates, two 100 kW machines could produce 360 Ci of ^{99}Mo per day.

After irradiation, the metal targets must be dissolved so that the ^{99m}Tc, which is continually being formed from the decay of ^{99}Mo, can be extracted. Molybdenum can be dissolved in nitric acid or hydrogen peroxide to form MoO_3. A wide range of techniques have been developed to separate the technetium from the molybdenum oxide. The Idaho group developed a sublimation process that takes advantage of the difference in vapour pressures between the technetium and molybdenum oxides. However, most techniques use columns that selectively bind either the technetium or molybdenum while in solution.

KEY TECHNOLOGIES

Electron Linear Accelerators

Industrial electron linear accelerators delivering 50 kW of beam power at 10 MeV are in routine use for radiation processing. Typically, these machines do not operate at energies greater than 10 MeV to avoid activating the product. The beam current required to deliver 50 kW at 35 MeV is less by a factor of 3.5 than that required at 10 MeV. Thus, current injection and transport is not a limitation to achieving 100 kW at 35 MeV. Furthermore, the energy of a linear accelerator can be increased by adding identical accelerating sections, perhaps the most famous example being the Stanford linear accelerator.

Mevex Corporation (http://www.mevex.com/) has extensive experience building high-power, industrial grade, linear accel-

Fig. 3 A Mevex 25 MeV, 25 kW electron accelerator. The machine uses two identical accelerating sections, each fed by an S-band klystron.

erators. Figure 3 shows a 25 MeV, 25 kW machine recently installed in Germany. Adding two additional accelerating sections and associated modulators will produce a 35 MeV, 100 kW electron beam. The overall length of the machine will be about 3 m and will require about 650 kW of electrical power.

Isotope Enrichment

The availability of molybdenum highly enriched with ^{100}Mo gives a ten-fold increase in yield over what could be achieved with naturally occurring molybdenum. There are at least two facilities that can produce large quantities of ^{100}Mo using gas centrifuges. The amount of material required for a national facility is largely determined by the frequency at which one recycles target material. Assuming the spent solutions are allowed to decay for 40 days, an inventory of about 1200 g of ^{100}Mo would be required. Even at the present cost of 2 k\$/g, the purchase price of an adequate supply of ^{100}Mo is much less than the cost of the accelerators. Furthermore, one supplier has indicated that the cost will drop significantly once production rates are increased and orders for ^{100}Mo approach the kg range.

^{99m}Tc Separators

The operation, characteristics and advantages of the NorthStar automated radionuclide separation (ARSII) are discussed in detail in a recent paper [7]. In the most common technetium generator, the Mo is retained on an alumina column and the technetium washed off. Although this approach works well if the specific activity of the ^{99}Mo is high, as is the case for ^{99}Mo obtained as a fission product, it is not practical for ^{99}Mo produced by the photoneutron reaction, where the specific activity is two orders of magnitude smaller. The ARSII reverses the approach of the conventional generator and uses a column that selectively retains the technetium as the parent solution passes over it. Thus, the technetium can be extracted from a relatively large volume of parent solution. Once the column is cleared of the parent solution, a separate saline rinse of the column removes the technetium as sodium pertechnetate, meeting the same specifications as the solution obtained from a conventional generator.

The ARSII, shown in Figure 4, is designed with a view to obtaining regulatory approval and is already in clinical trials for the separation of other daughter-parent isotopes. Although the chemistry involved is quite different than that of a conventional generator and the device is technically more complicated, it should not lead to any significant changes in the operation of nuclear pharmacies. Whereas the conventional generator is shipped to the pharmacy the ARSII would be permanently installed and only the solution containing the ^{99}Mo would be transported.

Fig. 4 The Automated Radionuclide Separator (ARSII) developed by NorthStar. The parent solution, in a lead container, is connected to the unit on the left and the product is delivered on the right. A typical run takes about 60 minutes and is fully automated.

ECONOMICS

We estimate that two 100 kW electron accelerators could easily meet Canadian requirements for ^{99}Mo. The capital costs for a single national facility are estimated to be about 35 M\$ and are dominated by the cost of the accelerators. The variable costs are dominated by the cost of capital but utilities, maintenance and staff salaries are also significant contributions. We estimate the variable costs to be about 10 M\$ per year, and lead to a production cost of ^{99m}Tc well below the current price of about 100 ¢/mCi to the end user. A single scan requires about 20 mCi of ^{99m}Tc so the cost of the isotope is a small part of the total cost of a scan, which is estimated to be about \$200.

RESULTS FROM NRC

The NRC 35 MeV, 2 kW electron accelerator is well suited for testing the photoneutron production of ^{99}Mo. Although the Idaho study was comprehensive, their work was based largely on calculated yields so independent tests of the production rates are important. Another important goal is to test the operation and separation efficiency of the ARSII. While the NRC linac cannot produce clinically relevant quantities, it can produce enough material for a robust test of all the steps from irradiation through to the elution of ^{99m}Tc solution which, in principle, is ready to be injected into a patient. Although we have purchased small quantities of molybdenum enriched in ^{100}Mo all our tests to date have been with natural molybdenum.

For one test, we measured and calculated production rates as well as the radial distribution of activity within the target. Two molybdenum disks, each 2 cm in diameter and separated by 1.8 cm were irradiated as shown in Figure 5. The total activity of each disk was measured using a Ge detector with a known efficiency. The activity as function of position on each disk was also determined by mounting the molybdenum disk behind a 1 mm lead collimator and measuring the count rate as the disk position was changed.

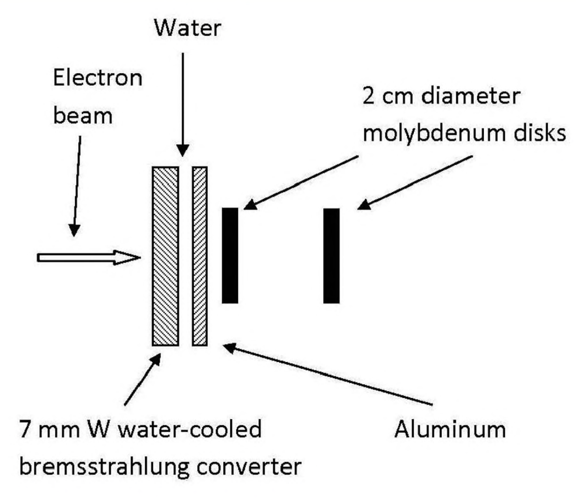

Fig. 5 Irradiation geometry. The electron beam energy was 35 MeV and the average beam current 40 µA. Each molybdenum disk was 1 mm thick and they were separated by 1.8 cm. The figure is not to scale.

The Monte Carlo calculations were carried out using the MCNP5 code and the (γ, n) cross section for ^{100}Mo was taken from the work of Beil *et al* [8]. The electron beam was simulated as a pencil beam having a radius of 2.5 mm.

The measured and calculated yields are given in Table 1. There is an indication that the calculated yields are about 25 % larger than the measured values, although results with smaller uncertainties are needed for a definitive conclusion. The measured and calculated profiles for the upstream disk are shown in Figure 6. The results are plotted as activity per unit radial distance, to give an indication of the relative importance of various parts of the disk to the total activity.

TABLE 1

Comparison of the measured and calculated ^{99}Mo yields for the two disks irradiated as shown in Figure 5. The disks were irradiated for about 1 hour at a beam power of 1.5 kW. More specifically, 0.15 C of charge was stopped in the converter.

	Upstream plate	Downstream plate
Measured (mCi)	0.57 (+/- 10 %)	0.32 (+/- 10 %)
Calculated (mCi)	0.72 (+/- 10 %)	0.38 (+/- 16 %)
Differences	25 %	20 %

Electron scattering in the fully-stopping tungsten converter tends to broaden the angular distribution of the photon beam and the tungsten also attenuates the photons. We have done a model study in which we calculated the induced ^{99}Mo activity as the thickness of the converter was decreased. The yield is largest for a 1 mm tungsten converter, but only by a few percent compared to using no converter at all. Figure 7 shows the activity for the case when the electron beam impinges directly on a cylindrical molybdenum target, 1 cm in diameter and 2 cm long. The beam parameters corresponding to those proposed for the national facility have been used.

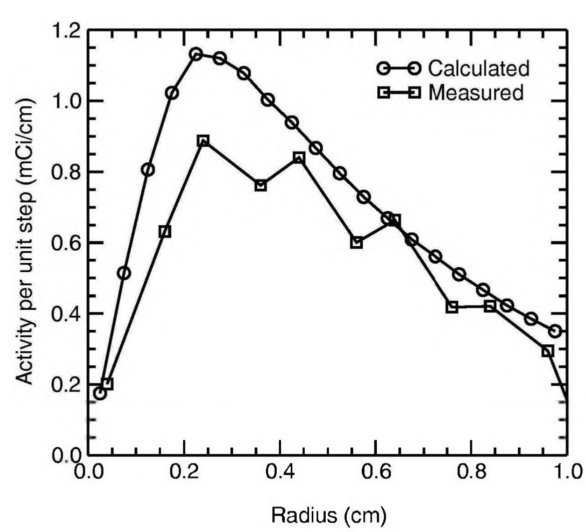

Fig. 6 Measured and calculated profiles of ^{99}Mo activity for the upstream disk, irradiated as shown in Figure 5. The results are shown as activity per unit radial distance to better indicate the contribution of various parts of the disk to the total activity. There is little contribution from the centre of the disk because there is little material there, even though that is where the photon fluence rate is largest.

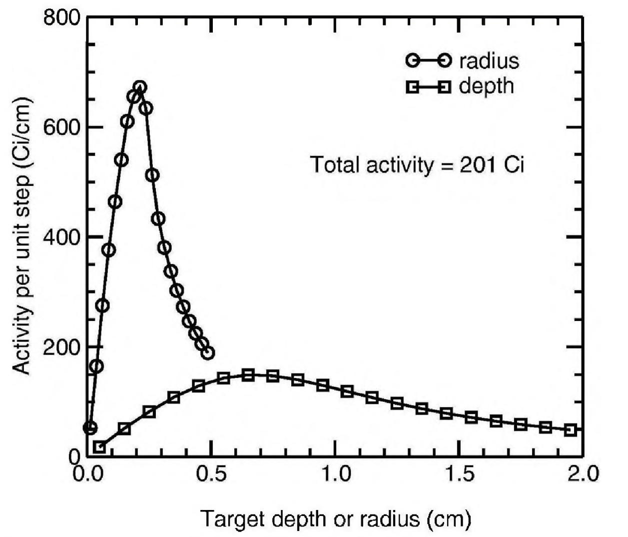

Fig. 7 Calculated activity for a 35 MeV, 100 kW, electron beam impinging on a cylindrical target of ^{100}Mo, 1 cm in diameter and 2 cm long. The simulated irradiation period was 24 hours. The radial profile was calculated for cylindrical rings the length of the target while the depth profile was calculated for radial slices across the target.

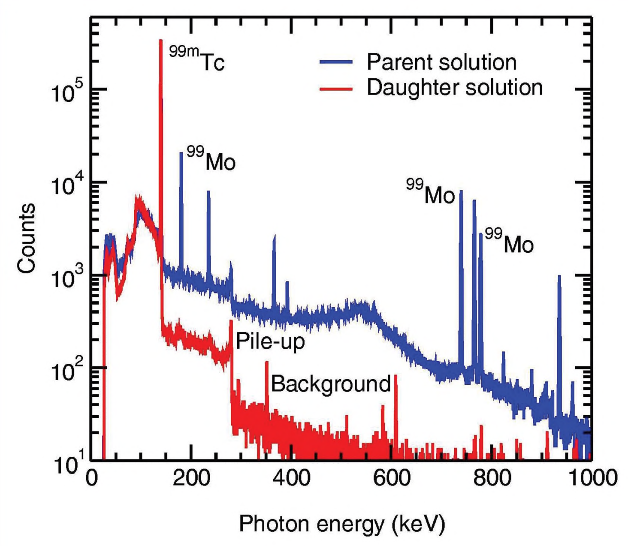

Fig. 8 Gamma-ray spectra of the parent solution (blue) presented to the ARSII separator and of the product solution (red). The edge at 280 keV is due to the pile-up of two ^{99m}Tc lines.

In order to test the performance of the ARSII separator, we have irradiated molybdenum pellets, 1 cm in diameter and 1 mm thick. The pellets were dissolved using 30 % H_2O_2 to form MoO_3, and the oxide was dissolved in 6 M NaOH. The ^{99m}Tc activity of the saline product was measured and compared to that of the parent solution. Separation efficiencies of about 90 % have been observed, consistent with values reported in the literature. Figure 8 compares the spectra of the parent and daughter solutions. Apart from lines related to the natural background, only the 140 keV ^{99m}Tc line is present in the product solution.

IMPLEMENTATION

We envision a single national facility to produce ^{99}Mo for the Canadian market. The facility would be designed to accept two 35 MeV, 100 kW linacs, but would likely begin operations with only one while the market and distribution network was established. Each linac would irradiate a 15 g target of ^{100}Mo for a 24 hour period. The target would be removed and over the next 12 to 24 hours it would be dissolved and aliquoted for shipping in shielded containers designed to connect to the input of the ARSII separator.

At the nuclear pharmacy, the aliquot would be milked once a day for up to 10 days using the ARSII to recover the ^{99m}Tc. The spent aliquot would be stored for several days at the nuclear pharmacy before being returned to the central facility. Because only a few µg of ^{100}Mo are transmuted for each 100 Ci of ^{99}Mo produced, the target material would be recycled.

OUTLOOK

After reviewing all 22 EoIs, the NRCan Expert Panel concluded that "The lowest-risk path to new ^{99}Mo/^{99m}Tc production capacity is to build a new multi-purpose research reactor." With regard to linear accelerator options they stated "… we prefer the technology based on ^{100}Mo transmutation since the projected economies appear better, and it largely avoids nuclear waste management issues".

Potential investors are reviewing the details of our photoneutron approach to determine if a viable business case can be made. They must be satisfied that they have robust access to the key technologies and that they will have fair access to the isotope market.

As part of our EoI, we proposed the construction and operation of a full-scale demonstrator before constructing a national facility. We identified a suitable location on NRC grounds and have estimates for preparing the site and establishing the necessary infrastructure. The demonstrator would be used to test and refine all the steps in producing large-scale quantities of ^{99}Mo. Subject to regulatory approval, it could also be used in the short term to produce clinically relevant quantities of ^{99}Mo. We estimate the time from the beginning of site preparations to the conclusion of the demonstrator phase to be about two years at a cost of 12 M$. Most of the equipment would be available for the national facility and represents about 9 M$ of the cost.

Although our focus has been on the production of ^{99}Mo because of the dominant role of ^{99m}Tc for medical imaging, the photoneutron reaction can be used to produce other isotopes that have applications for imaging or therapy. In particular, ^{123}I can be produced via the $^{124}Xe(\gamma, n)^{123}Xe$ reaction, with ^{123}Xe decaying to ^{123}I with a 2-hour half-life. Xenon gas, enriched in ^{124}Xe, is commercially available and there have been several investigations of the production rate using low-power linacs.

Other than a nuclear reactor, which is at least an order of magnitude more expensive, we believe that the electron accelerator route is the best option for producing large quantities of ^{99}Mo. We are cognizant of the fact that the Idaho proposal in the 1990s seemed equally compelling but was never exploited commercially. A major reason may have been the reluctance of the business community to invest in a process that would be in competition with the Maple reactors. The present climate may be more favourable to a new approach, given the fragile nature of the present, reactor-based, supply chain.

CONCLUSIONS

Several possible solutions to the isotope crisis are under consideration. Most of these propose alternative methods for producing ^{99m}Tc, but some look for ways to lessen the dependence on ^{99m}Tc.

The established advantages of ^{99m}Tc suggest that it will remain an important isotope for medical imaging, assuming a reliable and inexpensive supply is available. We believe that the transmutation of ^{100}Mo using electron accelerators represents the best option for producing ^{99}Mo on a national scale. The process eliminates concerns surrounding the use of uranium, generates almost no waste, can be implemented on a relatively short time scale, produces minimum disruption to the operation of nuclear medicine departments and is economically competitive with reactor-produced ^{99}Mo.

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EXECUTIVE SUMMARY OF THE REPORT BY THE EXPERT PANEL ON MEDICAL ISOTOPE PRODUCTION[1]

The Expert Review Panel on Medical Isotope Production (the Panel) was established on June 19, 2009, to advise the Government of Canada on the most viable options for securing a predictable and reliable supply of the key medical isotope technetium-99m (Tc-99m) in the medium to long term. This report is the culmination of that work, and presents recommendations that, in our opinion, will move Canada toward a new model for sustainable and secure long-term production of medical isotopes. We recognize that the government must ultimately select the best path forward for Canada, taking into account the broader nuclear energy and health care policy considerations that are outside the mandate of the Panel.

As part of this work, an expression of interest (EOI) process was launched to solicit ideas for alternative production of molybdenum-99 (Mo-99)/technetium-99m (Tc-99m) for the Canadian market in the medium to long term. We received 22 EOIs from a range of public and private sector organizations and reviewed the EOIs against specified criteria:

- Technical Feasibility;
- Business Implementation;
- Timeliness;
- Regulatory Issues; and
- Benefits to Canadians.

The EOIs proved very useful in identifying broad classes of technology options available. We greatly appreciated the time and effort invested by the proponents - we reviewed and assessed every EOI, and they played an important role in forming the content and recommendations presented here.

We also engaged medical, technical and regulatory experts to enhance our understanding of the many considerations involved in a long-term plan to secure medical isotope supplies. Among others, we received information from:

- Atomic Energy of Canada Limited;
- the Canadian Association of Medical Radiation Technologists;
- the Canadian Association of Nuclear Medicine;
- the Canadian Association of Radiologists;
- the Canadian Association of Radiopharmaceutical Scientists;
- the Canadian Institutes of Health Research;
- the Canadian Medical Association;
- the Canadian Society of Nuclear Medicine;
- the Canadian Society of Senior Engineers;
- individual nuclear medicine specialists;
- International Safety Research Inc.;
- the Ontario Association of Nuclear Medicine;
- the Royal College of Physicians and Surgeons of Canada - Nuclear Medicine Specialty;
- SECOR Inc.;
- SNC Lavalin Inc.;
- 15 independent and internationally known technical experts;
- other national and international stakeholders; and
- a Tc-99m generator manufacturer.

Throughout, our focus and attention remained on the best interests of patients and their families and the health care needs of Canadians.

Our report is structured around major classes of technology, with each technology option assessed against the specified criteria. The technologies are:

- Reactor technology
  1. New multi-purpose research reactor - fission option
  2. Dedicated Isotope Facility - fission option
  3. Existing reactors - fission option
- Accelerator technology
  4. Linear accelerator - photo-fission option
  5. Linear accelerator - Mo-100 transmutation option
  6. Medical cyclotron - direct Tc-99m option

SUSTAINABILITY AND SECURITY

Through our work and our assessments, we established parameters to define a sustainable and secure supply of Tc-99m in the medium to long term. A sustainable supply of Tc-99m to serve the needs of Canadian patients would:

1. be viable for the foreseeable future, likely for at least 15 to 20 years, and may include options that begin producing in the short to medium timeframe but that promise to remain viable;
2. comprise options that could each meet a meaningful portion of the Canadian demand, but that would not necessarily be exclusively Canadian-based and may or may not serve the U.S. or other markets;
3. have a sound business model that may or may not include government involvement; and
4. be free of highly enriched (weapons-grade) uranium (HEU) because of Canadian and global commitment to non-proliferation.

1. A copy of the full report and background information can be found at http://nrcan.gc.ca/eneene/sources/uranuc/mediso-eng.php (English) or http://nrcan.gc.ca/eneene/sources/uranuc/mediso-fra.php (français).

A **secure** supply of Tc-99m would:

5. improve redundancy at all points in the supply chain to avoid the "single point of failure" risk associated with a linear supply chain;
6. use diverse technologies to hedge against a failure that could arise if all suppliers used the same technology;
7. collocate irradiation and processing facilities to minimize decay losses and avoid shipping losses and risks; and
8. ensure sufficient capacity to accommodate short-term outages of some sources.

Establishing these parameters for sustainable and secure supply helped to frame how we assessed the likelihood of various technology options contributing to a stable isotope supply in the long term.

KEY FINDINGS FOR TECHNOLOGY OPTIONS

The most significant findings for each technology are given below. A full assessment of each technology option against all established criteria is given in Chapter 5.

1. New Multi-purpose Reactor Option

The lowest-risk path to new Mo-99/Tc-99m production capacity is to build a new multi-purpose research reactor. The research reactor also promises the most associated benefits to Canadians based on its multiple purposes.

Research reactors are shared facilities that have all the benefits associated with multi-use facilities, including the benefit of costs being spread over a large base of activities. However, this is the most expensive of the options, with high capital and operating costs. Costs associated with the processing facility, training, licensing requirements, security, and waste management are also very significant.

Revenue from isotope production would likely offset only approximately 10–15% of the costs of the reactor; building a new reactor would have to be justified, in large part, based on its other missions.

Given the established parameters for sustainability, any new reactor-based source of Mo-99 should be based on low enriched uranium (LEU) targets; some research and development (R&D) would be required to optimize the process and deal with the increased volumes of waste.

Of all the technology options, this one has the highest potential for concomitant benefit to Canadians based on the promise of the broad-based research that would be undertaken, and its associated potential for generating intellectual property, job creation and training.

2. The Dedicated Isotope Facility (DIF) Option

This option involves restarting the DIF project, which included two Multi-purpose Applied Physics Lattice Experiment (MAPLE) reactors, the New Processing Facility (NPF) and associated waste management structure. These facilities were never fully commissioned, and are in an extended shutdown state.

The DIF was designed and optimized to use HEU targets. Moreover, the design of the MAPLE reactors, the NPF and the associated waste management structure was heavily customized and dedicated to isotope production. This customization would pose significant challenges for possible modification and conversion to LEU, which, in our opinion, is mandatory for any medium- to long-term plan.

Furthermore, even if the existing infrastructure were to come at no cost, the ongoing economics for this project remain questionable because high operating costs cannot be shared across multiple uses. The fact that no dedicated isotope production reactors have been built and operated or are in planning anywhere in the world (with the exception of the DIF) suggests that others recognize the economic difficulties of this option.

Estimates for the timeline range from two to eight years. Although the best-case scenario of two years to market is attractive, we expect the timeline to be longer given the challenges with the processing facility, in addition to the licensing challenges.

3. Existing Reactor Option

Other existing research or power reactors, either domestically or internationally, could be used to irradiate targets for the production of Mo-99. Generally, projects associated with existing reactors are based on the use of modified processing facilities at AECL and the existing supply chain. Because research reactors are less powerful and consequently less efficient for isotope production, they require the use of HEU targets to achieve worthwhile yields.

While conversion to LEU would be possible, it may not be justifiable based on the limited remaining lifespan of the facilities. Nonetheless, HEU-based options in this category should be considered as options to address short-term supply shortages.

4. Linear Accelerator — Photo-fission Option

A particle accelerator is a device that uses electric fields to accelerate ions or charge subatomic particles to high speeds in well-defined beams to bombard targets for research and isotope production.

In this option, a high-power electron linear accelerator is used to bombard a converter to produce an intense photon beam to generate Mo-99 through nuclear interactions with natural uranium.

The required accelerator is not currently available, but the development is technically low risk. Substantial R&D is needed for the target and converter design, the cooling capacity and overall process optimization.

To meet the required production levels, the accelerators would be dedicated to isotope production, and would not be available for research or any other purpose. This option suffers from poor economics because capital investment is relatively high and cannot be shared across multiple missions.

Although the cost of an individual accelerator is much less than that of a reactor, as many as four accelerators would be needed to meet Canadian demand, and they would be relatively expensive to build and operate based on the high power requirement. When costs associated with processing and waste management are included, the total costs of the option could exceed $500M.

As a fission-based approach, this option would likely fit well into the existing supply chain; however, significant quantities of nuclear waste would be generated.

5. Linear Accelerator — Mo-100 Transmutation Option

An electron linear accelerator can produce Mo-99 through the transmutation of enriched Mo-100.

The Mo-100 option requires significant R&D regarding targetry and cooling capacity, as well as the development and marketing of a new type of generator. There is some concern that hospitals may not accept the new generators, and that this new product may not be able to compete with the traditional generators, presenting significant business risk.

Currently, there is no commercial production of purified Mo-100. The cost of the quantity needed could be substantial and may prove to be a barrier to commercialization. A full recycling of Mo-100 could reduce the cost substantially by minimizing loss, but recycling is yet to be demonstrated, and significant R&D would be required.

As in the case of photo-fission, the accelerators used for Mo-100 transmutation would likely need to be dedicated to isotope production to achieve the desired production levels, making this a single-use option. Return on investment would be difficult given the current price for Mo-99 and the significant costs, which cannot be shared across multiple missions.

A significant advantage of this option from an environmental and cost point of view is that it does not generate nuclear waste.

6. Cyclotron Option

A cyclotron is also a particle accelerator device. This option is based on bombarding Mo-100 with protons to extract Tc-99m directly from the irradiated product.

This is the only option in which Tc-99m is produced directly without first generating Mo-99.

Because the production of Tc-99m using cyclotrons is at an early stage of development, it is difficult to say how much of the Canadian market could be or would be served by cyclotrons. However, it is attractive because the cyclotron infrastructure could be in place and used for other purposes, but could still offer surge capacity to augment other sources.

Although significant R&D is required, the infrastructure to undertake the research, demonstration and initial production is presently available. Therefore, costs are relatively low and timelines for the R&D are relatively short.

This option can be implemented on a gradual basis since the model is for a distributed system with each cyclotron serving only local radiopharmacies and nuclear medicine departments. Communication and collaboration between medical cyclotron operators could ensure redundancy in supply and avoid single point of failure in the supply chain.

The cyclotron option is not a complete solution; because the half-life of Tc-99m is short, only hospitals and radiopharmacies close to a cyclotron would be served. More remote locations would continue to be served by Tc-99m generators, likely through existing supply chains. As a result there will be a need for Mo-99 to meet Canadian needs for the foreseeable future, although this could coexist with direct Tc-99m production.

Difficulties with this option include the requirement for R&D associated with target design and Mo-100 recycling. This option may require more validation from a Health Canada regulatory perspective. Currently, there is no commercial production of purified Mo-100. The cost could be high and may prove to be a barrier to commercialization.

An important consideration is that this option does not produce nuclear waste, which results in economic and environmental benefits over fission-based options.

The cyclotron option has the potential to be the timeliest option. Commercial production of Tc-99m could begin between 2011 and 2014, depending primarily on results of R&D and health regulatory issues.

GENERAL RECOMMENDATIONS

1. Strive for diversity and redundancy throughout the supply chain.

We recommend adopting a supply strategy offering technological diversity, and redundancy at every step in the supply chain.

2. Leverage multi-use infrastructure.

We recommend investing in infrastructure that is designed to have multiple purposes and is more likely to remain useful over the long term, regardless of how the use of medical isotopes evolves.

3. Continue with international coordination, and seek processing standardization within North America.

We recommend that the government continue to inform itself of all international isotope initiatives, and work with other countries to better coordinate worldwide efforts around isotope production and distribution. We also encourage the government to start laying the groundwork now for establishing target and target processing compatibility, especially for any new sources developed in North America.

4. Recognize that HEU options are viable only in the short to medium-term.

We recommend that any option reliant on HEU be dismissed as a long-term solution. As a proponent of non-proliferation, Canada must work to eliminate HEU from civilian use. Because many options associated with existing reactors are based on using HEU targets, they should be considered only within a short-term context.

TECHNOLOGY-SPECIFIC RECOMMENDATIONS

1. Make policy decisions on the requirement for a new research reactor.

We recommend that the government expeditiously engage in the replacement of the NRU reactor as we believe a multi-purpose research reactor represents the best primary option to create a sustainable source of Mo-99, recognizing that the reactor's other missions would also play a role in justifying the costs. With the National Research Universal (NRU) reactor approaching the end of its life cycle, a decision on a new research reactor is needed quickly to minimize any gap between the start-up of a new reactor and the permanent shutdown of the NRU. If the decision is to not build a new research reactor, the issue of securing supply of Tc-99m will have to be revisited in light of how cyclotron/accelerator options are advancing, and what new foreign sources of isotopes have materialized.

2. Support an R&D program for cyclotron-based Tc-99m production.

We recommend that the cyclotron option for direct production of Tc-99m, which has many attractive features, be explored further. Although this option requires significant R&D, the infrastructure and know-how to undertake that work is readily available in Canada so costs associated with the R&D remain relatively low. Assuming technical viability, the infrastructure necessary to demonstrate this approach in selected centres across Canada is already in place. Indeed, Canada has an opportunity to be a leader in this area and strengthen its existing related businesses.

3. Achieve better use of Tc-99m supply through advanced medical imaging technologies.

We recommend deployment of newer single photon emission computed tomography (SPECT) technologies (software and hardware), as well as investment in positron emission tomography (PET) technology, to reduce demand for Tc-99m now and over the longer term, which would reduce the impact of future shortages of reactor-produced isotopes.

OTHER CONSIDERATIONS

1. Linear accelerator options

The two linear accelerator options have limited prospects for multi-purpose use, require significant R&D, and may not have significant cost advantages over reactor technologies. Nonetheless, a modest R&D investment could be considered as a hedge against the risk of failure of other options. Of the two linear accelerator options, we prefer the technology based on Mo-100 transmutation since the projected economics appear better, and it largely avoids nuclear waste management issues.

2. Dedicated Isotope Facility (DIF) infrastructure

Cost and timeline estimates associated with the commissioning and licensing of the DIF varied widely. Although it may be possible to bring them into operation, the business case is such that even if the DIF facilities could be licensed immediately at no cost, the ongoing revenues from isotope sales would be insufficient to cover the ongoing operating expenses, particularly with the anticipated reduced throughput from future conversion to LEU targets. A dedicated isotope facility based on a private sector cost-recovery model would be a good solution assuming a private sector organization would be willing to accept the full commercial risk associated with this model.

The Expert Review Panel on Medical Isotope Production was comprised of Mr. Peter Goodhand (Chair), Mr. Richard Drouin, Dr. Thom Mason, and Dr. Eric Turcotte.

Creating the Future of Chalk River

by Zin Tun, on behalf of CREATE (Chalk River Employees *Ad hoc* TaskforcE)

With the federal government planning to restructure Atomic Energy of Canada Limited and split off the CANDU reactor business from Chalk River Laboratories (CRL), the future of Canada's main nuclear research infrastructure is uncertain. Furthermore, the 52-year old NRU reactor is showing its age, being shutdown for repairs since May 2009. The NRU reactor is the flagship of CRL, performing three missions simultaneously: (1) It produces neutrons beams for advanced materials research, (2) it is a platform for in-core testing of materials for nuclear R&D, and (3) it is the word's largest producer of medical isotopes. While the National Research Council is responsible for research with neutron beams, AECL is the owner and operator of the reactor and performs the latter two missions.

In response to the restructuring of AECL and to the need for a new, multi-purpose research reactor, the Chalk River Employees *Ad hoc* TaskforcE for a national laboratory (CREATE) was formed in August 2009. CREATE is a grass-roots, non-partisan group of volunteers that includes current and former employees at Chalk River. These volunteers developed a concept for a future Chalk River National Laboratory (CRNL), consulted with CRL staff, and obtained their support. CRNL would include a new multipurpose reactor for research and isotope production. Such a reactor is otherwise known to CAP as the Canadian Neutron Centre proposed by the Canadian Institute of Neutron Scattering (http://www.cins.ca/CINSplan.html).

In October 2009, CREATE submitted its report to Natural Resources Canada and Cheryl Gallant, Member of Parliament for Renfrew-Nipissing-Pembroke (Figure 1). The report in both French and English is available at www.futurecrl.ca.

"CREATE has provided Canadians with a vision of what the future of science at Chalk River could be, by evolving

Summary

In response to the restructuring of AECL and to the need for a new, multi-purpose research reactor, the Chalk River Employees *Ad hoc* TaskforcE for a national laboratory (CREATE) was formed in August 2009. This is a summary of this initiative.

Fig. 1 CREATE presents its report proposing its concept for the future of Chalk River to MP Cheryl Gallant (centre). Left to right: John Hilborn, Gordon Tapp, Zin Tun, and Blair Bromley.

its mission to one of a national laboratory. I intend to make sure the report is widely circulated among my colleagues on Parliament Hill," Gallant said.

In CREATE's proposed vision, CRNL will be Canada's premier laboratory for nuclear and related sciences (illustrated in Figure 2) and an international centre of excellence. It will be a resource for researchers from across a broad spectrum, from fundamental sciences to industrial applications, rather than being restricted to research and development that is mainly focused on supporting CANDU nuclear power reactors, as is the case today.

The new mission of CRNL will be very outward looking, partnering and impacting at all levels of Canadian society. That outward focus includes several new functions: leading diverse research programs beyond nuclear energy; partnering broadly with universities, industries, and government; commercializing knowledge; providing a training ground for Canada's future generation of research scientists and engineers; and fostering a science and technology culture in Canada. By serving as a unique, major resource for science and industry, CRNL will deliver enduring value for Canada.

While the need for a new facility has long been recognized, the Expert Review Panel on Medical Isotope Production concluded in November "a multi-purpose research reactor represents the best primary option to create a sustainable source of Mo-99, recognizing that the reactor's other missions would also play a role in justify-

Zin Tun, a Principal Research Officer with the NRC's Canadian Neutron Beam Centre at Chalk River, is acting on behalf of the volunteer working group CREATE in submitting this article to *Physics in Canada*. With regard to this article he can be reached through the website at www.futurecrl.ca .

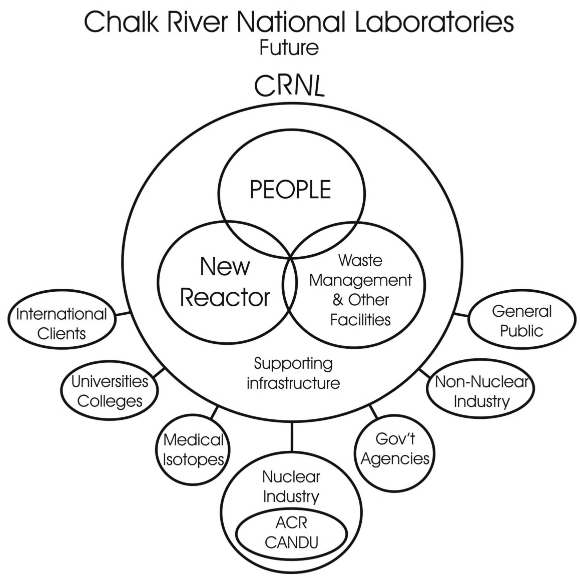


Fig. 2 A functional diagram of the proposed laboratory, illustrating key points, as follows: CRNL will serve Canada, proactively seeking partners with universities and industries. Clients in the nuclear industry will continue to be very important, including CANDU and other nuclear technologies. Expert people at CRNL are directly accessible to clients to streamline the flow of knowledge to clients. A new multi-purpose research reactor is an essential component of the new CRNL, with capabilities equal or better than the current NRU reactor.

ing the costs. With the [NRU] reactor approaching the end of its life cycle, a decision on a new research reactor is needed quickly to minimize any gap between the start-up of a new reactor and the permanent shutdown of the NRU," and such "a decision is needed within the next year." This option "has the highest potential for concomitant benefit to Canadians based on the promise of the broad-based research that would be undertaken, and its associated potential for generating intellectual property, job creation and training." [1]

CREATE hopes that the government's response to that recommendation for a new reactor may be announced in the March budget. An initial investment of about $10 million for planning steps is needed. In the meantime it is focusing on getting the word out and gathering public support. CREATE is reaching out to the national scientific, nuclear, and medical communities, because it is a truly national issue with international implications.

On February 2, CREATE launched an internet-based petition for all supporters of its vision to show their support on its website (www.futurecrl.ca). The site sends a customizable letter to the Prime Minister and key federal Ministers and opposition politicians allows individuals to voice their support for such a facility. Participants can also choose to list their name publicly on the site as a supporter. CREATE aims to achieve thousands or even tens of thousands of participants before Natural Resources Canada announces its decision on the future of Chalk River.

1. Report of the Expert Review Panel on Medical Isotope Production. Presented to the Minister of Natural Resources Canada. 30 November 2009. pp. v, xi, 41.

GETTING INSIDE HEARTS AND MINDS OF JOURNALISTS WILL HELP SCIENTISTS MAKE BETTER USE OF THE MEDIA

BY PETER CALAMAI

One of the show-stoppers in the musical My Fair Lady comes when Professor Henry Higgins laments "Why can't a woman be more like a man?"

Without intending to trivialize the concern and even angst of many Canadian researchers over media coverage of the fate of the NRU reactor and related issues, I believe that a large part of the problem is that scientists often want journalists to be more like them. Or more precisely, to think more like them.

It would indeed be good for journalists to better appreciate the scientific ethos and culture. But it would also be beneficial for scientists to improve their understanding of the journalistic ethos and culture. A better appreciation of what makes the media tick would allow the research community to develop strategies that could change the reporting of issues such as securing a supply of medical isotopes for Canada and the future of neutron scattering. A few examples of these possible new strategies are spelled out below.

My view is that the public and political dialogue about the production of medical isotopes in Canada has suffered from half-truths, fundamental misconceptions, ignorance of basic nuclear science, and a lack of historical perspective. As well, with most of the public focus on medical isotopes the other crucial issue – the clouded future of neutron scattering research in Canada – has received short shrift.

SUMMARY

Without intending to trivialize the concern and even angst of many Canadian researchers over media coverage of the fate of the NRU reactor and related issues, I believe that a large part of the problem is that scientists often want journalists to be more like them. Or more precisely, to think more like them.

Some, but not all, of the blame for this can be laid at the feet of the mass media whose coverage of the crisis has largely failed to move beyond the episodic approach of breaking news and whose narrative frame for the story has been predominately one of crisis and conflict.

Several further observations must be allowed to temper this assessment:

- all media are not the same. Some coverage has striven to present the complexities of the issue. As far back as Nov. 1, 1998 the *Toronto Star* printed a 1,300-word news feature I had written about the looming global "neutron gap" and the essential role of these "unstoppable explorers of the atomic world." On Feb. 25, 2008, the *Star* devoted the front page main article and two complete pages inside the first section to an investigation into the original NRU shutdown. In *The Globe and Mail*, reporters Patrick White and Anna Mehler Paperny have been assiduous in keeping tabs on the bigger picture, with a half-dozen articles in 2009 alone.

- one definitive contrast between scientific writing and journalism is the emphasis on narrative. Scientific communication emphasizes the destination, while journalism is all about the journey. Hence the challenge for science writers: researchers may draw a ringing conclusion, but the task of bringing that conclusion to a lay audience involves describing what went on beforehand.

- an episodic approach focusing on crisis and conflict is the default mode for the media for many stories, not just those with a scientific component.

Scientists regularly bemoan the media's preoccupation with *sturm und drang* and active seeking out of controversy. "I suppose those sorts of headlines sell newspapers," is a common refrain conjuring up images of boys in knickerbockers on street corners shouting "Read all about it." The reality is that most daily newspapers in Canada are "sold" a month in advance, through home delivery subscriptions, and that headlines have minimal impact on day-to-day circulation. Similarly radio listeners or TV viewers aren't drawn primarily by the presentation style but by the intrinsic news value of the items. A senior edi-

Peter Calamai is a freelance science journalist and communications consultant living in Ottawa. He was a founding executive member of the Canadian Science Writers' Association in 1970 and national science reporter for the Southam newspapers and subsequently the *Toronto Star*. A director of the Science Media Centre of Canada, Calamai was awarded CAP's Peter Kirky memorial medal for science communications in 2008.

tor of *The Times* said at a London conference last summer that the three stories which attracted the most reader interest in 2008 were the election of Barack Obama, the financial crisis at British banks and the start-up of the Large Hadron Collider at CERN.

The fact that many scientists so readily voice the headlines-equals-sales claim suggest they haven't applied the same intellectual rigour to understanding what makes the media tick that they devote to scientific questions. Yet without applying that intellect to develop insight into the media ethos and culture, scientists are unlikely to succeed in getting coverage that reflects their concerns, whether we're dealing with H1N1, climate change or the fate of the NRU.

Consider the following as potential jumping-off points:

1. **Journalists will put the most energy into topics that they believe can be made to resonate with their audience. First those topics have to resonate with journalists.**

The topics need not be sexy or even high-profile to start. Look at how the media in the 1990s latched onto the notion of eliminating the deficit. Journalists could easily grasp the notion that a nation's finances should abide by the same rules as their own.

2. **Journalists are in the news business.**

A topic remains attractive to journalists only so long as there are new angles to exploit. They need not be truly new angles; they simply have to lend themselves to being tarted up as new.

3. **As a corollary, because journalism is fixated on the new it often ignores background crucial to understanding the current story**

4. **In journalism, the urgent almost always trumps the important.**

Again, it need not be true urgency but it must appear to be urgent. That's why a story which says something will happen today will almost always be given more prominence than a story which says something happened yesterday. Even when the yesterday event is intrinsically more important.

5. **Names make news.**

And the bigger the name, the bigger the boost in news value for the topic being reported.

6. **Conflict, disagreement and controversy are more innately interesting (and more newsworthy) than peace, agreement and accord.**

This holds except in the cases where the norm has been conflict and peace breaks out, viz Northern Ireland or Question Period in the Commons.

Now apply these observations to the fate of the NRU reactor, the supply of medical isotopes and the future of neutron scattering research.

1. Medical isotopes certainly resonate with journalists (who tend to lead unhealthy lives and are prone to hypochondria). The fate of the NRU reactor resonates less but still has some attraction because of its age and iconic status. Neutron scattering simply isn't on the media radar.

   Suggestion: Media accounts mostly repeat the same few examples of the application of neutron scattering (e.g. the Challenger shuttle welds). Yet if hundreds of scientists across Canada rely on NRU for neutron scattering research, it should be possible to find scores of examples of how that research intersects with the lives of ordinary Canadians. These would resonate in communities most directly affected and with journalists whose reports reached those communities.

2. All three topics present limited opportunities for even the most inventive journalists to develop ostensibly new angles. There's a noticeable absence of real people whose health can be shown to have suffered because of delays in diagnostic procedures, despite the repeated doom-laden pronouncements from nuclear medicine advocates. There was a brief burst of new angles with the various competing schemes to replace the NRU reactor and the release of the expert panel report in early December but that petered out quickly. The Canadian Institute for Neutron Scattering repeats the same very valid points. But these, by definition, are no longer newsworthy after so many repetitions.

   Suggestion: Those multiple (but unspecified) real-life applications of neutron scattering could be packaged into new angles through comments from the affected end-users, rather than the researchers. Corporate executives holding a news conference to stress how vital such research is to their products could almost be guaranteed to attract media coverage. Especially with "before" and "after" examples available for visuals.

3. The international standing once accorded nuclear research at Chalk River may be well-known to many scientists but doesn't rank in the public consciousness with Banting and Best. As well, the steady erosion of that expertise through funding cuts and poor strategic direction from Ottawa is hardly common knowledge. Finally, the nature of the difficulties with the Maple isotope replacement reactors, although elucidated by journalist Alison Motluk on CBC radio's *Quirks and Quarks*, remains a mystery to most people.

   Suggestion: Any pronouncements by researchers about isotopes, neutron scattering or the fate of NRU should include a potted history covering these points so journalists can help the public understand how this complicated story arrived at its current juncture.

4. Almost all the coverage has been "yesterday" reporting rather than "today."

   Suggestion: Instead of hoping that journalists will attend hearings of the Commons natural resources committee into the NRU issue and then report what's said, media-savvy researchers would make sure key journalists had advance copies of their prepared submissions, embargoed for the day of the hearings. This is the same procedure followed every week by *Science*, *Nature* and other major research journals.

5. The media have dutifully reported the comments of officials representing organizations such as the Canadian Institute for Neutron Scattering and the Ontario Nuclear Medicine Association. To increase the prominence given such news reports, however, requires names with some public recognition.

   Suggestion: When the first Canadian Neutron Facility was proposed by AECL and NRC in 1998, the proponents lined up support from the likes of Fraser Mustard, Burt Brockhouse, a raft of university presidents and Tom Brzustowski, then NSERC president. Names of similar weight today would be more likely to attract current media attention. The best science stories also thrive on characters, something alien to the scientific mindset while eschews emphasis on personality.

6. There's been a surfeit of conflict and controversy in this unfolding story, starting with a nasty spat between officials of AECL and the Canadian Nuclear Safety Commission, escalating to Prime Minister Stephen Harper's partisan attack on CNSC President Linda Keen, segueing into lawsuits between MDS Nordion and AECL and most recently descending into the Prime Minister's communications director characterizing AECL as "dysfunctional" and a $30-billion "sinkhole" for taxpayer money.

   Scientists are no strangers to conflict and controversy over purely scientific matters (after all, Thomas Kuhn wrote about "scientific revolutions") but they tend to avoid similar levels of engagement in the public arena. As the current furor over climate change demonstrates, however, it is bad tactics to leave a vacuum even if a debate has become excessively polarized.

   Suggestion: Many reporters might find it newsworthy if the research community spoke up more forcefully and with a more united voice about what scientists see as a serious threat to Canada's standing as a nation that claims G-8 status. One opportunity was missed at the science policy conference held in Toronto last October. Another will present itself in May when the Professional Institute of the Public Service of Canada is staging another science policy meeting in Ottawa. It would also likely strike many journalists as newsworthy if the various interests which are promoting competing proposals to replace NRU could nonetheless agree on a strong joint public statement about the wisdom or folly of doing nothing.

These few thoughts are far from an exhaustive complete media strategy. There is another important initiative that intends to address the continuing lack of communication and understanding between journalists and scientists.

This is the nascent Science Media Centre of Canada (www.sciencemediacentre.ca). One of the first programs planned by the Centre is "Science 101 for journalists," a half-day workshop for journalists which will explain the scientific method, examine how scientists view the world, discuss why scientists appear overly cautious to reporters etc. In summary, let journalists peer inside the hearts and minds of scientists.

But the Centre also intends to offer a counterpart workshop that will help researchers peer inside the hearts and minds of journalists. It will examine journalist value systems, dissect what makes news, explore media economics and discuss how journalists view the world. Such a program, called "Introduction to the Media", has been hugely popular with researchers in the U.K. where the Science Media Centre concept originated in 2002.

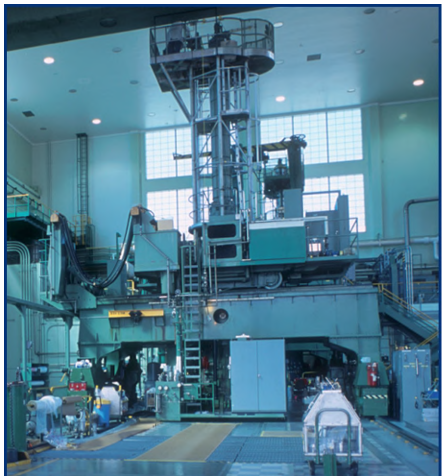
The intention of the workshops isn't to have journalists suddenly thinking like scientists or, horrors, scientists thinking like journalists. Success could be as simple as having both groups gain an appreciation of what underlies the actions and attitudes of the other.

Right now the Science Media Centre of Canada consists of an Executive Director and administrative assistant in modest office space donated by the Canada Science and Technology Museum in Ottawa. The Canadian Association of Physicists contributed $1,000 to this beginning by becoming the first scientific society Charter Member.

Before it can open its doors, the Centre needs to raise about $2 million for initial start-up costs and to guarantee first year operations. The SMCC will concentrate on hooking non-specialist reporters up with credible and communicative experts in all fields of research across the country. The counterpart workshops to improve understanding and communication between journalists and scientists are an another early priority.

FOCUS ON NUCLEAR PHYSICS OR 'HOW TO TAKE ADVANTAGE OF OUR HIGHER VISIBILITY?'

Nuclear physics has never made Canadian headlines as often as in the past two years. First came in the fall of 2007 the wrestling match between Linda Keen, President of the Canadian Nuclear Safety Commission, and the federal government regarding security problems with the Chalk River nuclear reactor (NRU), which ended with Keen being forced to resign by Stephen Harper's government. Eighteen months later, in May last year, the reactor was once again shut down because of a heavy water leak. We are still awaiting its reactivation, pushed back several times and scheduled to reopen this spring. In parallel to the setbacks of the Chalk River reactor, its importance to the medical community getting the media's full attention, several provinces have aging nuclear facilities which are receiving (or will shortly) important upgrades, while Ontario is not easily recovering from its tendering process in the summer of 2009. The province was expecting to pay $7 to 8 billion for two 1,200 MW reactors, but the bids received amounted to around $25 million, casting doubt on the viability of this energy source.


The NRU reactor is one of the most versatile research reactors in the world which also provided the knowledge required for the development, maintenance and evolution of the fleet of CANDU nuclear reactors in Canada.

These headlines are not ideal for the promotion of nuclear physics or physics in general. Be that as it may, at least this discipline is being discussed and CAP members must take advantage of the situation by expressing their opinion in a public forum and defending the importance of this technology. The CAP's Executive has taken a stance in an open letter published in July 2009 in various newspapers across the country. In this letter, our President Robert Mann officially offered the CAP's help with the NRU reactor and expressed that it is essential that Canada develop alternate solutions to replace this aging reactor which services a large number of researchers and engineers, as well as the medical community (see the July 9, 2009 link in the News Bulletin Archives on the CAP web site). During the same period, Robert also sent a letter to the Minister of Natural Resources at the time, Lisa Raitt, urging her to broaden the mandate of the expert panel in charge of studying accessibility to medical isotopes to include all aspects of nuclear physics and engineering in Canada.

Although the mandate of the expert panel was not modified, their report published at the end of November 2009 (see www.isotopes.rncan.gc.ca) clearly supports the construction of a new versatile research reactor capable of meeting the needs of all the present users of the NRU. Even if there is no consensus between CAP members on the best solution to adopt, as can be read elsewhere in this issue of PiC, our community can greatly appreciate seeing the importance of its needs being recognized by the expert panel. In any case, the struggle is not over and the CAP and its members will need to work even harder to convince the government to carry out the recommendations of its panel.

The CAP's Executive jointly with the Division of Nuclear Physics will therefore continue to increase awareness and communicate with the government in order to avoid that the after-NRU issue be forgotten no sooner the existing reactor running again.

However, in the present political and economic context, these efforts, although necessary, will not be sufficient. They must continuously be supported by the entire community if we want them to be successful. But beyond the NRU, the entire physics community must also take advantage of the great visibility of this issue to take a public stance and maintain a debate based on scientific facts, not on irrational fears. We are not advocating an ideology nor rejecting the participation of non-specialists. Physicists across the country must rather use the great openness of the public, and especially of the media, regarding these issues to demonstrate the importance of research and its support to the social and economic development of the country. Defending the interests of the community should not be left only to the Executive of the CAP; it is the responsibility of all its members.

by Normand Mousseau
CAP's Director of Communications

PLEINS FEUX SUR LA PHYSIQUE NUCLÉAIRE OU « COMMENT PROFITER DE NOTRE VISIBILITÉ ACCRUE ? »

La physique nucléaire n'aura jamais été autant dans l'actualité canadienne que depuis deux ans. Il y eut, d'abord, à l'automne 2007, la confrontation entre Linda Keen, la présidente de la Commission canadienne de sûreté nucléaire, et le gouvernement fédéral au sujet de problèmes de sécurité avec le réacteur nucléaire de Chalk River (NRU), confrontation qui s'est terminée par la démission forcée de Mme Keen par le gouvernement de Stephen Harper. Un an et demi plus tard, en mai dernier, le réacteur est de nouveau arrêté, à cause d'une fuite d'eau lourde; on attend toujours sa remise en activité, repoussée à quelques reprises et annoncée pour ce printemps. En parallèle avec les déboires du réacteur de Chalk River, dont l'importance pour la communauté médicale retient l'attention des médias, de nombreuses provinces ont des centrales nucléaires vieillissantes qui sont soumises (ou le seront sous peu) à d'importants travaux de remise à jour, tandis que l'Ontario se remet difficilement de son appel d'offres de l'été 2009. Alors que la province avait espéré payer 7 à 8 milliards $ pour deux réacteurs de 1200 MW, les soumissions reçues se chiffraient plutôt aux alentours de 25 milliards $, jetant un doute sur la viabilité de cette filière énergétique.

Ces nouvelles ne représentent pas vraiment une vitrine idéale pour la promotion de la physique nucléaire ou de la physique en général. Mais peu importe, on parle au moins de cette discipline et les membres de l'ACP doivent profiter de cette situation pour s'exprimer sur la place publique et défendre l'importance de cette technologie. L'Exécutif de l'ACP a pris position avec une lettre ouverte publiée début juillet 2009 dans nombreux quotidiens à travers le pays. Dans ce texte, notre président, Robert Mann, proposait officiellement l'aide de l'ACP dans le dossier du réacteur NRU et soulignait qu'il est essentiel que le Canada se dote d'une solution de remplacement pour ce réacteur vieillissant qui dessert une large communauté de chercheurs et d'ingénieurs, en plus de la communauté médicale (voir le lien du 9 juillet 2009 dans l'archive des nouvelles du site web de l'ACP). Durant la même période, Robert faisait aussi parvenir une lettre à la ministre des Ressources naturelles de l'époque, Mme Lisa Raitt, l'enjoignant à élargir le mandat du comité d'expert chargé d'étudier la question de l'accès aux isotopes médicaux afin d'inclure tous les aspects de la physique et du génie nucléaires au Canada.

Bien que le mandat du comité d'expert n'ait pas été modifié, le rapport de celui-ci, publié à la fin novembre 2009 (voir www.isotopes.rncan.gc.ca) privilégie clairement la construction d'un nouveau réacteur de recherche polyvalent pouvant combler les besoins de tous les utilisateurs actuels du NRU. Bien que les avis demeurent partagés parmi les membres de l'ACP sur la meilleure solution à adopter, comme on le peut le lire ailleurs dans ce numéro de PaC, notre communauté peut se réjouir de voir l'importance de ses besoins reconnus par le comité d'experts. Pour autant, la partie n'est pas gagnée et il faudra que l'ACP et tous ses membres redoublent d'efforts pour convaincre le gouvernement de suivre les recommandations de son comité.

L'Exécutif de l'ACP de concert avec la Division de physique nucléaire vont donc continuer leur travail de communication et de sensibilisation auprès du gouvernement, afin d'éviter que la question de l'après NRU ne soit pas oubliée sitôt la remise en marche du réacteur actuel.

Dans le contexte politique et économique actuel, toutefois, ces efforts, bien que nécessaires, ne seront pas suffisants. Ils devront être appuyés de manière soutenue par toute la communauté, si l'on veut qu'ils portent fruits. Mais au-delà du NRU, la communauté physicienne dans son ensemble doit également profiter de la grande visibilité du dossier pour se positionner sur la place publique et assurer un débat ancré sur des faits scientifiques et non seulement sur des peurs irrationnelles. Il ne s'agit pas de prôner une idéologie ni de rejeter du revers de la main la participation de non-spécialistes. Il faut plutôt que les physiciennes et physiciens à travers le pays utilisent la plus grande réceptivité du public et, surtout, des médias, envers ces questions pour démontrer l'importance de la recherche et de son soutien pour le développement social et économique du pays. Car la responsabilité de défendre les intérêts de notre communauté n'appartient pas seulement à l'exécutif de l'ACP, mais à tous ses membres.

par Normand Mousseau
Directeur des communications de l'ACP

PIC NEWS

NEXT ISSUE - LA PROCHAINE NUMÉRO

PERIMETER INSTITUTE - L'INSTITUT PERIMETER
2010 APRIL-JUNE - AVRIL À JUIN 2010

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A TRIPLE SLIT TEST FOR QUANTUM MECHANICS,
by Urbasi Sinha, Christophe Couteau, Fay Dowker, Thomas Jennewein, Gregor Weihs, and Raymond Laflamme

ANALOG GRAVITY AND BLACK HOLES
by William G. Unruh

The Editorial Board welcomes articles from readers suitable for, and understandable to, any practising or student physicist. Review papers and contributions of general interest of up to four journal pages in length are particularly welcome.

Le comité de rédaction invite les lecteurs à soumettre des articles qui intéresseraient et seraient compris par tout physicien, ou physicienne, et étudiant ou étudiante en physique. Les articles de synthèse d'une longeur d'au plus quatre pages de revue sont en particulier bienvenus.

In 2005, the Division of Nuclear Physics (DNP) created a PhD Thesis Prize competition for best thesis in Experimental or Theoretical Nuclear Physics by any student receiving their PhD degree from a Canadian University in the current or prior calendar year. The DNP is pleased to announce that the recipient of the 2008-09 DNP Thesis Prize is Robert MacDonald. Dr. MacDonald was awarded his PhD by the University of Alberta in November 2008 for the work "A Precision Measurement of the Muon Decay Parameters Rho and Delta". A summary of Dr. MacDonald's thesis work appears below.

A Precision Measurement of the Muon Decay Parameters ρ and δ

by Robert Paul MacDonald

The Standard Model of particle physics is an amazingly successful model of the way matter and energy interact at the quantum mechanical level, passing nearly any experimental tests we care to throw at it. SNO, the Sudbury Neutrino Observatory, has shown that neutrinos have mass, contrary to the Standard Model. But this is one of the only tests the model hasn't passed. That said, it has some quirks. The most basic peculiarity is that there are nineteen free parameters, such as the mass of the electron or the strength of the weak force; these values could be anything in the Standard Model, and must simply be measured. Many of the details of the model are curious, as well. For example, there are six quarks, and six leptons; why are they the same number? And why not eight, or four?

Through challenging experiments, we're steadily improving our understanding of the Standard Model's quirks, moving towards a more complete explanation of what's going on "underneath". The TWIST experiment [1] (the TRIUMF Weak Interaction Symmetry Test) is studying one of the quirks of the weak interaction. It turns out that particles come in "left-handed" and "right-handed" varieties — related to their tendency to prefer spinning one way more than the other — but the weak interaction has been seen to affect only left-handed particles or right-handed antiparticles. The TWIST experiment is a high-precision study of the weak interaction, to see if this is universally true.

Summary

The TWIST experiment is a high-precision study of the weak interaction, examining billions of muon decays to look for evidence for interactions not predicted by the Standard Model of particle physics. The spectrum of muon decays can be described by a set of decay parameters whose values depend on the fundamental nature of the weak interaction. This work presents TWIST's intermediate measurements of the decay parameters ρ and δ, which strengthened the Standard Model's predictions and significantly tightened the constraints these parameters place on competing theories.

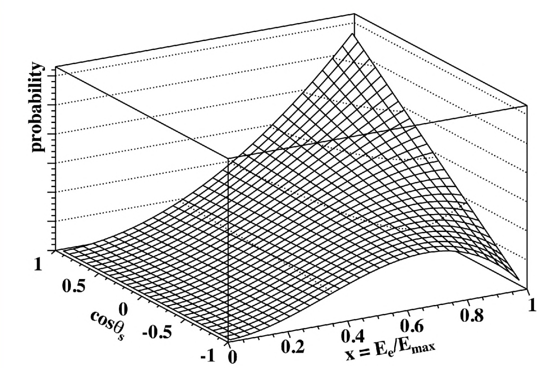

Fig. 1 Theoretical muon decay spectrum. θ_s is the direction of the emitted positron; $\cos\theta_s = 1$ is the direction of muon spin. $x = E_e / E_{max}$ represents the positron energy. The vertical axis is proportional to the probability that a positron will have the given x and $\cos\theta_s$. The TWIST experiment measures a large portion of this spectrum simultaneously; the measured region is not rectangular, but the range approximately covers $0.5 < |\cos\theta_s| < 1$ and $0.4 < x < 1$.

Specifically, TWIST is studying the decay of the positive muon into a positron and two neutrinos, $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$. Since there are no quarks involved, the strong interaction is entirely absent, leaving only the weak and electromagnetic interactions; the latter is very well understood and can be very precisely accounted. This makes muon decay an excellent choice for studying the weak interaction.
The distribution of energies and angles is called the decay spectrum, and its shape depends on the details of the weak interaction. The theoretical decay spectrum, shown in Fig. 1, is given by

Robert Paul MacDonald <rmacdon@phys.ualberta.ca>, Centre for Particle Physics, University of Alberta, Edmonton, AB T6G 2G7

$$P(x,\cos\theta)\ \alpha\ x\left(x(1-x)+\rho\left(4x^2-3x\right) + P_\mu \xi \frac{1}{3} x\left[1-x+\frac{2}{3}\delta(4x-3)\right]\cos\theta_s \right) \quad (1)$$

where $x = E_e / E_{max}$ represents the positron energy, and P_μ is the degree of polarization of the muons — that is, the degree to which the muon spins are aligned. Here the dependence on the electron mass and the radiative corrections have been left out for simplicity. The parameters ρ, δ, and ξ govern the shape of the decay spectrum; each depends on the details of the weak interaction and the handedness of the particles involved. There are other parameters as well, which can be determined by measurements involving e.g. the polarization of the decay electron. TWIST is designed to measure the positron energies and angles over a large portion of the decay spectrum, which allows it to measure ρ, δ, and ξ simultaneously to high precision: ρ controls the overall momentum dependence of the spectrum, δ controls how the angular asymmetry depends on momentum, and ξ controls the overall asymmetry. (The parameter ρ, and the parameter η related to the electron mass, are often called the Michel parameters.) The muon polarization will obviously affect the measured decay asymmetry as well, and $P_\mu\xi$ can only be measured as a product. Prior to the TWIST experiment's measurements, the uncertainty on ρ was ~3 x 10^{-3}, the uncertainty on δ was ~4 x 10^{-3}, and the uncertainty on $P_\mu\xi$ was ~9 x 10^{-3} [2]. This work in particular is focused on an intermediate measurement of ρ and δ [1] which reduced the uncertainties on these two parameters by about half, putting significantly tighter limits on right-handed muon decay. The final TWIST measurements, using later data, are to be published this year!

EXPERIMENT

The TRIUMF muon beam used by TWIST supplies us with about 2500 muons per second; a beam of protons strikes a carbon target, which produces pions, and some of these stop at the target surface. The muons are produced when the pions decay. The kinematics of pion decay mean that the muons created are essentially 100% polarized.

The heart of TWIST is a stack of high-precision tracking chambers [3], shown schematically in Fig. 2. The muons slow down as they pass through the detectors, stopping in a 71 µm thick foil of high-purity aluminum (>99.999%) at the centre of the spectrometer. Decay positrons are then tracked to determine their energy and direction. The stack of chambers sits inside a large solenoidal magnet — a surplus MRI magnet — contained within a 3 m purple cube-shaped steel yoke; the strong 2 Tesla magnetic field focusses the incoming beam, maintains the polarization of the stopped muons, and allows the reconstruction of the momenta of decay positrons.

The spectrometer consists of 44 drift chambers (DCs) and 12 multiwire proportional chambers (PCs), arranged symmetrically about the aluminum stopping target. (The wires — over 4000 of them — were all positioned with a precision of a few microns, by hand.) The PCs, which have very short reaction times (typically less than 20 ns), are used mainly for timing; the DCs, which have much longer reaction times (hundreds of nanoseconds), are used for high-precision tracking.

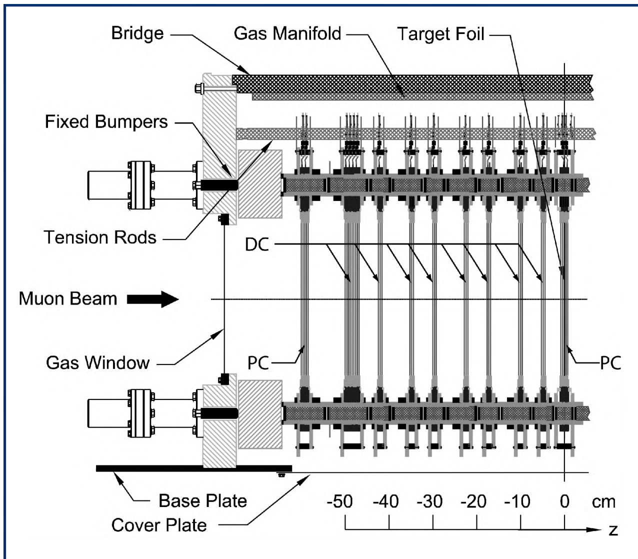

Fig. 2 Schematic drawing of the upstream half of the TWIST spectrometer, showing the arrangement of the drift chambers (DCs) and multi-wire proportional chambers (PCs). Muons enter from the left in the figure, slow down in the chambers, and stop in the aluminum target foil at the centre. The detector is symmetric about the target foil.

Data are taken around the clock, which means having TWIST personnel on site around the clock; for some reason, a large portion of the graveyard shifts are taken by graduate students. A variety of conditions were used — deliberately reduced polarization, increased muon rate, even detector temperature — in order to test for sensitivities to the experimental conditions. Obtaining consistent measurements of the muon decay parameters under these and other conditions provides useful confirmation of the simulation and analysis.

DATA ANALYSIS

One of the benefits of working on a relatively small experiment — TWIST involves just over 30 scientists — is that everybody is involved in every part of the project. For example, rather than working with a single aspect of the simulation or a particular analysis step, I was able to work on the entire analysis chain (and one of the things I learned from wading through that much C++ and Fortran programming is the value of good comments!)

The TWIST analysis software fits a helix to the positron tracking information from each muon decay event; the size and pitch of the helix depend on the momentum and direction of the decay positron. A matching simulation is run for each data set using the GEANT software from CERN; this simulation includes every detail of the TWIST spectrometer, down to pieces of tape. The decay spectra from data and simulation are then calibrated against each other for consistent momentum reconstruction.

The shapes of the calibrated decay spectra are then compared using a "spectrum fitter". This determines the differences ($\Delta\rho$, $\Delta\delta$, $\Delta P_\mu\xi$) in the muon decay parameters between data and simulation. If we know the values of the decay parameters used in the simulation, this tells us what the parameters are in the real world: $\rho_{data} = \Delta\rho + \rho_{sim}$, etc. In TWIST we hide the simulation's muon decay parameters until all analysis is complete — performing a *blind* analysis. A blind analysis is important to prevent "human bias," where the analysis is tuned and adjusted to bring the results more in line with what the experimenter is expecting — or hoping for! — or the experimenter stops looking for possible errors only when the results agree with expectations.

SIMULATION VALIDATION

Since TWIST determines the muon decay parameters by comparing the shape of a measured decay spectrum to the shape of a simulated spectrum, validation of the simulation is vital — in a high precision experiment, you can trust nothing.

The interactions between the decay positrons and the detector materials will influence track reconstruction, potentially affecting the decay spectrum. In particular, when a muon decays in the target, the tracking only begins after the positron has left the target, so it is especially important that the simulation correctly reproduce spectrum-distorting effects such as scattering and energy loss in the target region.

One of the studies used to validate the simulation uses a specialized data set and its corresponding simulation. The beam momentum is lowered, so that most muons are stopped in material just before ("upstream" of) the spectrometer. A decay positron produced in the downstream direction then passes through the entire length of the detector. The first data of this type were taken accidentally — somebody left something in the path of the beam after some other tests — but it was so useful that several more sets of this type of data have been taken since. The "upstream" and "downstream" halves of the positron's path are reconstructed separately, and their momentum and track angle compared. Energy loss, scattering, track fitting biases, and reconstruction resolution can all result in differences in the properties of the two tracks. Distributions of momentum differences, track angle differences, etc. then allow the direct examination of positron interactions in the detector — and hence the comparison of the positron interactions in the simulation to those in the real detector — independent of the shape of the muon decay spectrum. Figure 3 shows an example comparing the measured energy loss between data and simulation. There is a slight shift in the average energy loss, and a slight difference in resolution, both of which have to be accounted for, but otherwise the shape of the simulated distribution agrees with data across more than three orders of magnitude.

SYSTEMATIC UNCERTAINTIES

The precision of the TWIST experiment is limited by its systematic uncertainties rather than by statistics, and many sources of error other experiments would consider "negligible" had to be carefully examined for TWIST. The improvements we made over the first TWIST ρ and δ measurements [4,5] are in reducing these systematic uncertainties in a number of ways, and in better determining them.

Once a possible source of error is identified and its uncertainty determined, its impact on the decay parameter measurement can be assessed using the spectrum fitter, the same mechanism

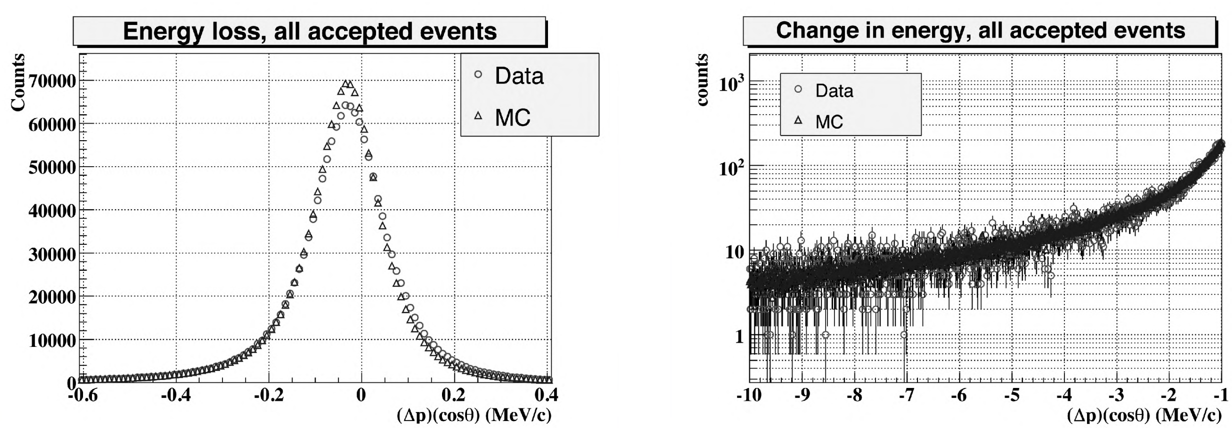

Fig. 3 Normalized distributions of reconstructed momentum loss from validation data and simulation. Momentum loss is multiplied by cosθ to account for angle dependence of energy loss. The left plot shows the peak energy loss region; the right plot shows the distribution for large energy loss events.

by which the decay parameters themselves are determined. The source of error is exaggerated in some way, usually by modifying the simulation or making some change to the analysis. A decay spectrum is produced under this exaggerated condition, and is compared to a standard data set or simulation to determine how the exaggeration affected the decay parameters. This is used to translate the original source of error into a systematic uncertainty in the decay parameters.

RESULTS AND CONCLUSIONS

After all systematic uncertainties are evaluated, the hidden values of the muon decay parameters used in the simulation are revealed and the measured decay parameters are determined. We find [1] $\rho = 0.75014 \pm 0.00017$ (stat) $\pm$ 0.00044 (syst) $\pm$ 0.00011 (η), where the last uncertainty is due to the uncertainty in the decay parameter η, and $\delta = 0.75067 \pm 0.00030$ (stat) $\pm$ 0.00067 (syst). Both results are consistent with the Standard Model values of 3/4. These represent factor of two improvements over the previous TWIST measurements [4,5]. Any modifications to the Standard Model will have to work within these tighter limits; for example, these measurements significantly reduce the possibility that the weak interaction affects right-handed particles at all.

ACKNOWLEDGEMENTS

I'd like to thank my supervisors Art Olin and Roger Moore, as well as my former supervisors Manuella Vincter and the late Nathan Rodning, and the members of the TWIST collaboration and the staff at TRIUMF, particularly Glen Marshall, David Gill, Dick Mischke, and Carl Gagliardi. The funding from the National Science and Engineering Research Council, and the support of the University of Alberta, are gratefully acknowledged. The TWIST experiment was also funded by grants from the National Science and Engineering Research Council, and from from the U.S. Department of Energy. Computing resources for the analysis were provided by WestGrid.

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DIGITAL SUNDIALS ON THE INTERNET, A NEW WAY OF USING ANCIENT TECHNOLOGY

BY J.M.K.C. DONEV, P.P. LANGILL*, M.D. WILLIAMS, AND M.J. RUSSEL

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The sundial is one of the oldest scientific instruments; its principle is simple: a gnomon casts a shadow based on the Sun's position. By recording the position of the gnomon's shadow, one can track the motion of the Sun across the sky. While sundials have typically been used as a way to gauge the passage of time, they remain a useful pedagogical tool since it shows unexpected (to the student) details about the Sun's motion across the sky. We have built a sundial and put it on the internet. By storing pictures on a website of the gnomon's [1] shadow taken at regular intervals, teachers can present data about the Sun's motion across the sky so fast that it can match any student's attention span (Figure 1). Students all the way from the University and College level to the Elementary School level can learn aspects of space and astronomy, from the comfort of the classroom and without having to monitor home-made apparatus out of doors from dawn till dusk.

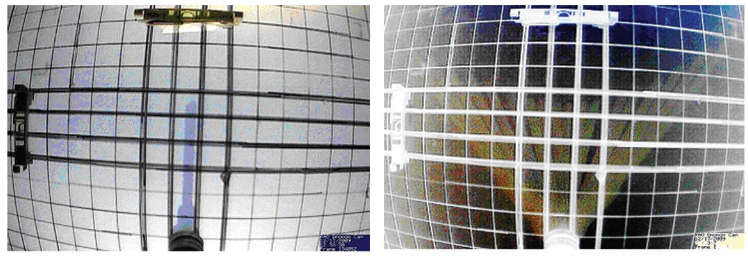

Fig.1 (left) A single image of the gnomon's shadow and (right) a composite image of many shadows by the gnomon over the course of a day (December 17th, 2009). The image is taken from a digital camera placed inside the box and looking up at the glass surface. The lines are 2 cm apart for easy measurement. The digital camera provides some distortion to the image; further advances in this project will hopefully include a way of manipulating the image to compensate for this distortion.

Since the Sun's motion across the sky changes from day to day, and month to month, and clouds frequently obscure the Sun, data from several years are often necessary to really explore and understand how the Earth's elliptical orbit and tilt affect the passage of the Sun across the sky. This web-based data collection and storage system will enable students to make such studies. We are hopeful that other institutions will set up similar systems at their locations. With this type of Sun shadow data coming from different positions on the Earth, one can see firsthand why man-made time zones are so convenient, and even attempt to measure the actual size of the Earth.

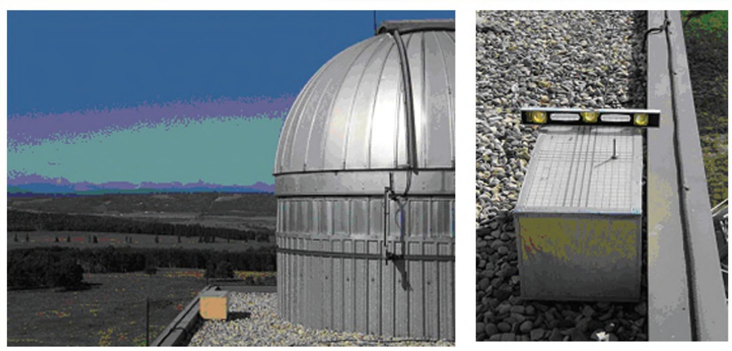

Fig. 2 Our digital sundial box in its position atop the roof of the Rothney Astronomical Observatory. The grid has 2 cm graduations. The gnomon is 6.5 cm tall in this picture, but was later reduced to 3 cm in order to maximize the usefulness of the shadow.

Our new advance to the sundial is located at the University of Calgary's Rothney Astrophysical Observatory [2]. It was constructed and implemented as part of International Year of Astronomy activities at the RAO [3]; the device is shown in Figure 2. An example of the images and data obtained via a webcam inside the wooden box are shown in Figures 1 and 3, and are discussed below.

Students have many misconceptions about the Sun's motion across the sky and a sundial system can be a fun and interactive way for students to re-think their model of the Earth-Sun system. The major disadvantage has been the amount of time needed for students to collect data. Long before interesting conclusions can be reached most students become bored and want to go surf the web. Here is a preliminary list of possible concepts that this system can help the students explore relatively quickly:

1. Does the Sun really rise exactly east and set exactly west?
2. At what time of the day is the Sun due south in the sky?
3. Why are the days longer in the summer than in the winter?
4. Where is the Sun in the sky during the colder time of year compared to the warmer time of year?
5. Why does Santa ride a sleigh in Canada and a surfboard in Australia?
6. Why is Canada colder than the tropics? Is it because the tropics are closer to the Sun?
7. What's the significance of the five special latitudes on a standard classroom globe: the equator, the tropics of Cancer and

1. A gnomon is "A pillar, rod, or other object which serves to indicate the time of day by casting its shadow upon a marked surface; esp. the pin or triangular plate used for this purpose in an ordinary sun-dial." According to the second edition of the Oxford English Dictionary.
2. The website that links to the data and more information www.ucalgary.ca/rao/skywatch
3. The precise position of the RAO is +50° 52.10' Latitude -114° 17.30' Longitude.

* <pplangil@ucalgary.ca>

Capricorn and the Arctic and Antarctic circles?

As simple as most of these concepts may seem to an instructor, students are inclined to hold on to their preconceived notions unless they carefully trod their own path to understanding. As has been shown in many papers [1], simply telling students that they are wrong has little to no effect on their model for understanding the universe. This system will allow students to actively play with real, and comprehensible, data and even have fun with it. Excellent inquiry based teaching modules have already been developed [2,3] which could be modified to use this data. Personal experience from some of the authors is that many of these misconceptions persist at various grade levels, through college, despite instruction to the contrary. Students seem to place information for tests into a different bin in their mind than information about the real world. Careful observation by the student and careful questioning by the instructor are needed to reformulate these models of the world.

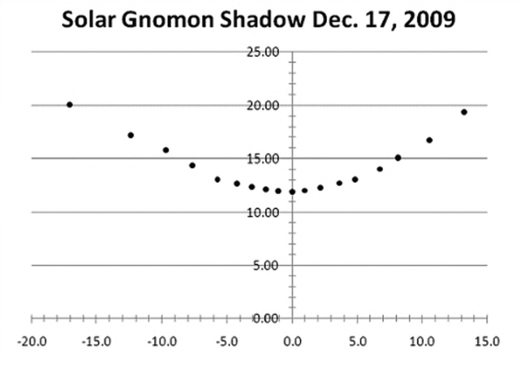

Fig. 3 Here's an example of a typical shadow plot. The dots represent the position of the tip of the gnomon's shadow. The units of the axes are cm, and the gnomon is at (0,0). East is to the left, West to the right, and North is up. Chronologically, time runs from the upper right corner (NW) to the upper left (NE). Uncertainty in determining the position of the shadow tip increases as the shadow length grows. The uncertainty also increases when the Sun is veiled by clouds. The Sun's shadow is shortest when it is pointing straight north (the Sun is due south) and occurred between 12:33 and 12:34 local time on this day.

Our setup has a box with a grid on the top surface (Figure 2b). The grid is on a translucent piece of plexiglass, with 2 cm gradations. The grid lines are carefully oriented N-S and E-W, and bubble-levels verify that the grid sits horizontally. There is a 3.0 cm tall bolt sticking through the grid to act as the gnomon. The web camera sits safely inside of the box looking up at the gnomon's shadow. An example of what the webcam sees is shown in Figure 1a. Since web cameras are somewhat susceptible to weather, it was felt that hiding the camera in the box was optimal. With this system, the computer takes a picture of the underside of the grid and the shadow usually has a distinct tip. This picture is then time stamped so that the user can tell both the local date and time that this picture was acquired. A series of these pictures over the course of the day can show the Sun's relative motion across the sky. An example from Dec. 17th, 2009 is shown in Figure 1b.

By allowing students to use real data to generate shadow plots (Figure 3), it's possible for the students to reconstruct the Sun's apparent motion for themselves. Unlike many activities in teaching science, students can understand almost all of the nuances for the data collection, which gives the instructors more room to allow the students to explore their own questions in addition to the questions of the instructor.

The RAO's computers can store months or even years of webcam images which can easily be retrieved. It is thus possible to compare shadow plot data on the same day from different years and see if there are any differences. Instructors know that the path of the Sun across the sky will be the same, but the timing of that path could be a bit different because of the leap-year effects (and that things repeat over a 4 year cycle). Students could be invited to make predictions before examining the data to see if their ideas are correct. An important concept to emphasize to students is that the Sun's yearly motion is not random, but is repeatable.

An archive of retrievable images also allows students to explore many other concepts. Seasonal effects like how the Sun's maximum altitude is related to the length of day can be explored. The unique features of the Sun's path across the sky on the days of the solstices and equinox can also be explored. Best of all, this can be done from the comfort of the classroom.

Another key advantage of using technology is that information can be shared over a wide area. If other digital sundials can be set up at different latitudes and longitudes, the Sun's apparent position as a function of geography can be explored. By comparing sundials at exactly the same time students will hopefully be able to start thinking about the Earth as a large spherical object that has different shadows at different times of the day and different locations. Also, the climate at different latitudes can be discussed by seeing the Sun's relative position in the sky.

While it is beyond the scope of what has been done so far by this group, it is hoped that instruction using the digital gnomon would commence with instructors showing an actual sundial to the students. Perhaps this could be done in a darkened room with a flashlight, to show how moving the flashlight in a particular way could lead to particular shadows. Perhaps also students could collect a day's worth of data themselves, as a group, so they get a feel firsthand for how the process goes. This would possibly help understand the data more personally.

We feel that this project is off to an exciting start. Image archiving and web retrieval tools are in place but will be expanded. The project will be more exciting as data is collected and more sundials are set up. Please contact the authors of this paper if you are interested in discussing building your own digital sundial, to make sure that we have some consistency in design. It is also hoped that future papers will discuss in deeper detail what numerical data can be extracted from the Sun's shadow data collected using this new twist on ancient technology.

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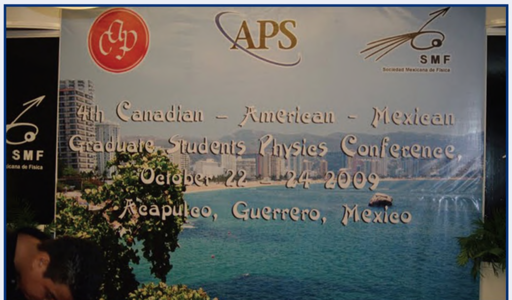
CANADA-AMERICA-MEXICO 2009 PHYSICS GRADUATE STUDENT CONFERENCE

BY ADRIAN BUZATU, MCGILL UNIVERSITY



CAM2009 display board at registration desk.

The fourth edition of the biannual North-American physics graduate student conference (Canada-America-Mexico 2009) took place from October 22 to October 24, 2009 in Acapulco, Guerrero, Mexico. The conference provided the opportunity for physics graduate students to share their work with fellow students from across North America, as well as network with them in a very attractive tropical environment. A total of 136 graduate students, post docs and professors attended the conference.

This is the report on the CAM 09 conference that was prepared for the Council of the Canadian Association of Physicists by Adrian Buzatu <adrian.buzatu@ mcgill.ca> from McGill University, who was the CAP's Graduate Student representative on the international organizing committee.

CONFERENCE ORGANIZATION

As a real international conference, there was an international advisory committee, an international organizing committee, international invited speakers and international participants.

International Advisory Committee

Canada was represented by Gordon W.F. Drake (University of Windsor, Director of International Affairs, Canadian Association of Physicists).

USA was represented by Dr. Amy K. Flatten (Director of International Affairs, the American Physical Society).

Mexico, the host country, was represented by Luis Felipe Rodríguez (President of the Mexican Physical Society, Mexico, Radio Astronomy and Astrophysical Center, Morelia, UNAM, Mexico), José Luis Rodríguez López (Director of International Affairs, Mexican Physical Society), Carmen Cisneros (Physical Science Institute, UNAM, Cuernavaca, Morelos, Mexico), Guillermo Espinosa (Physics Institute, UNAM, Mexico City), Octavio Costaños (Nuclear Sciences Institute, UNAM, Mexico City), Victor Romera Rochin (Physics Institute, UNAM, Mexico City) and José Luis Morán López (Faculty of Sciences, UNAM, Mexico City).

International Organizing Committee

The General Chairman of the International Organizing Committee was José Luis Rodríguez López (Advanced Materials Department, IPICYT, San Luis Potosi, Mexico).

The Canadian Chairman and coordinator was Adrian Buzatu (McGill University, Councillor at Large (Graduate Students) for the Canadian Association of Physicists).

The American coordinators were Ivelisse M. Cabrera, Chairwoman and Coordinator (John Hopkins University, USA) and Benn A. Olsen, Coordinator (Princeton University).

Other Mexican coordinators were Ma. Luisa Marquina (Faculty of Sciences, UNAM, Mexico City), Heinrich Terborg (Physics Institute-UNAM, Mexico City), Brenda Carballo (Nuclear Sciences Institute-UNAM, Mexico City), Guadalupe Mendoza Uribe (Materials Department, IPICYT, San Louis Patosi, SLP, Mexico) and José Ramón Hernandez Balanzar (Science and Technology Council of Guerrero, Mexico).

International Invited Speakers

There were two invited speakers per country.

Canadian invited speakers were Prof. Adriana Predoi-Cross (University of Lethbridge, Alberta, Canada), "Molecular Spectroscopy Applied to Remote Sensing of Planetary Atmospheres" and Prof. Alex Vitkin (University of Toronto, Ontario, Canada),"Biophotonics: Medical Uses of Optical Technology to Diagnose and Treat Disease".

American invited speakers were Prof. Jaymant Kumar (Department of Physics, University of Massachusetts, Lowell, MA, USA), "Recent Developments in Organic Molecular and Polymeric Solar Cells" and Prof. Collin Broholom (Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD, USA), "Science and Technology with Neutron Scattering".

Mexican invitead speakers were Prof. Karo Michaelian (Physics Institute, Experimental Physics Department, UNAM, Mexico), "Thermodynamic Origin of Life" and Prof. Noel Carbajal (Applied Geoscience Department, IPICYT, San Luis Potosi, Mexico), "Numerical Modeling of Geophysical Fluids Dynamics Phenomena Impacting The Ecology of México".

Profs. Gordon Drake, Michael Steinitz, and Adriana Predoi-Cross pose with 23 of the 32 Canadian student delegates. All are wearing the t-shirts supplied by sponsor, Canberra Inc.

International Participating Students

Oral presentations were given by 82 students (28 from Canada, 33 from USA and 21 from Mexico).

Poster presentations were given by 36 students (4 from Canada, 6 from USA and 26 from Mexico).

Conference Program

The conference started on Thursday October 22nd with Welcoming Remarks offered by José Luis Rodríguez López (Mexico), Carmen Cisneros (Mexico), David Ernst (President of the Board of Directors for the National Society of Hispanic Physicists, member of the American Physical Society Executive Board, USA) and Gordon Drake (CAP, Canada).

There were usually three parallel sessions of oral talks. Here is the list of all the sessions in chronological order.

Thursday, Oct. 22, 10h00-10h45

1. Particle Physics I
2. Nanostructures - Electronic Properties, Calculations and Simulations
3. Astrophysics and Cosmology I

Thursday, Oct. 22, 11h00-12h00

1. Particle Physics II
2. Fundamental Physics Phenomena I
3. Astrophysics and Cosmology II

Thursday, Oct. 22, 15h00-16h45

1. Particle Physics III
2. Applied Physics I: Biology, Medicine and Technology
3. Astrophysics and Cosmology III

Friday, Oct. 23, 10h00-10h45

1. Fundamental Physics Phenomena II
2 Superconductivity I
3. Nanostructures - Synthesis and Characterization I

Friday, Oct. 23, 10h00-12h00

1. Fundamental Physics Phenomena III
2. Superconductivity II and Strongly Correlated Electron Systems
3. Nanostructures - Synthesis and Characterisation II

Saturday, Oct. 24, 09h00-10h45

1. Fundamenal Physics Phenomena IV and Energy Conservation and Storage
2. Nuclear, Atomic and Molecular Physics
3. Applied Physics: Geosciences and Nanostructured Devices

Thursday night - a banquet was organized at the hotel.

Friday afternoon - the poster and international booths session was organized.

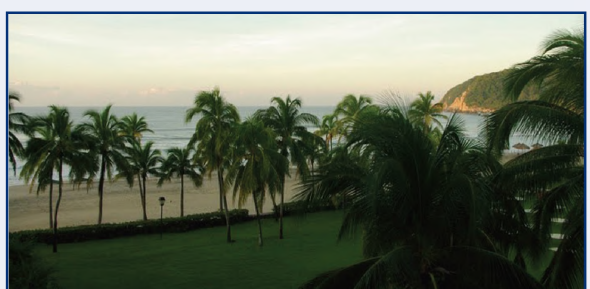
Friday night - a visit to the Acapulco Fortress Museum was organized.

Saturday morning there was a panel discussion with the title “New Frontiers in Physics: Interrelations of Physics and Other Disciplines (Medicine, Biology, Geosciences, Nanosciences, etc.)”. The professors at the panel table were: David Ernst (USA), Gordon Drake (Canada), Luis Felipe Rodríguez (Mexico) and Michael Steinitz (Canada).

The panel discussion was followed by the closing remarks given by Luis Felipe Rodríguez (Mexico), José Luis Rodríguez-López (Mexico), Ivelisse Cabrera (USA) and Adrian Buzatu (Canada).

Conference Venue

The accommodation and the conference were both hosted at the “Fairmont Pierres Marques” Hotel in Acapulco, Guerrero, Mexico, a tourist resort on the beach of the Atlantic Ocean. Situated in the tropical region, the temperatures were around 27 degrees Celsius. The hotel was located directly on the beach and provided three swimming pools. Everybody was more than enchanted by the atmosphere in Mexico and by the short escapades to the beach. A banquet at the hotel and a visit to downtown Acapulco and Acapulco Historic Museum (located at San Diego Fort) was also kindly provided by the local organizers.



A congress venue appreciated by all.

CANADIAN PARTICIPATION

There were 32 students, 2 invited speakers, 2 other professors, and two booths promoting Canadian universities and the *Canadian Journal of Physics* at CAM 09. The Canadian participation at CAM09 was organized through the Canadian Association of Physicists.

Canadian Students

Through the generosity of the sponsors, CAP was able to offer 30 scholarships to physics graduate students studying in Canada. A competition was organized. Students were asked to send a CV, a publication list and a letter of support from their supervisor. More than 30 students took part in the competition.

The best 30 applications were selected. Each of the students received a $500 (CA) reimbursement towards their airfare cost thanks to our generous sponsors (details below), a paid registration fee ($200 US) thanks to the contribution of CAP and three nights at the hotel (about $225 US) thanks to the Mexican organizers.

It is to be noted that two other Canadian students attended on their own while paying their own expenses. There were, therefore, 32 Canadian students in total, out of which 28 offered oral talks and 4 poster presentations.

Canadian Invited Speakers

Initially, the local organizers suggested that each country should nominate 3 names for invited speakers. The CAM09-CAP Committee organized a few phone conferences and came up with a plan to involve the Canadian physics community in the nomination of potential invited speakers. About a dozen names were submitted. Several groups of Canadian graduate students were asked to come up with an ordered list.

Later the local organizers decided to have only 2 invited speakers per country, as to allow more time for student talks. The Canadian organizers submitted the names of the top four recommended speakers and invited the international committee to select the two whom they felt best fit into the program. The international committee selected Prof. Adriana Predoi-Cross, from the University of Lethbridge, who gave a talk on “Molecular Spectroscopy Applied To Remote Sensing of Planetary Atmospheres” and Prof. Alex Vitkin, from the University of Toronto, who gave a talk on “Biophotonics: Medical Uses of Optical Technology to Diagnose and Treat Disease”.

Other Canadian Participants

Two other Canadian professors participated in the conference.

Prof. Gordon Drake participated in his capacity as Director of International Affairs for CAP and the Canadian participant in the International Advisory Committee for CAM09. He made a short presentation about CAP during his welcoming words at the beginning of the conference.

Prof. Michael Steinitz participated in his capacity as Editor of the *Canadian Journal of Physics*. He organized a booth to promote the journal during the conference.

They both participated as panelists in the ”New Frontiers in Physics” Saturday morning panel session.

There was another Canadian booth dedicated to promoting Canadian physics graduate departments. CAP collected brochures and posters from the majority of Canadian Universities and they were displayed for the duration of the conference, adjacent to the poster panels. Canadian students offered information about Canadian universities at this booth throughout the conference.

Sponsors for Canadian Participants

We are grateful to the following Canadian sponsors for their generous contributions: Canberra Inc, Institute of Quantum Computing, Perimeter Institute of Theoretical Physics, Atomic Energy of Canada Limited, Canadian Light Source, Nelson Education, and Plasmonique Inc. Many thanks are due to Francine Ford, Executive Director of CAP, who lead this successful fundraising effort. Thanks to it, 30 Canadian students were funded with $500 CA each towards their travel expenses, thus making the conference more affordable to more Canadian students.

We are also grateful to the Canadian Association of Physicists who payed the conference registration fee for 30 Canadian students. Its value was $200 US per person. Also, we appreciate the efforts of the Mexican organizers that made sure that each of the 30 scholarship-winning Canadian participants was provided with complimentary accommodation for three nights, including breakfasts. Through the generosity of the Mexican organizers, Adrian Buzatu, our Canadian student organizer, was provided with two extra days of accommodation to allow him to extend his stay to participate in additional pre and post conference meetings for the organizers. Furthermore, the Mexican organizers covered all of the local expenses for the two Canadian invited speakers, Prof. Adrian Predoi-Cross and Prof. Alex Vitkin (they only had to pay for the transportation to and from Acapulco). Many thanks to the Mexican organizers for this effort!

CONCLUSIONS

In conclusion, the fourth Canada-America-Mexico Graduate Student Conference in 2009 has been a real success. There were 136 participants in total and they all enjoyed both the scientific environment and the tourist resort. As the Canadian student organizer, I felt honoured to work closely together with my Canadian CAP colleagues, especially Francine Ford, Carmen Harvey and Gordon Drake, as well as with our friends in USA and Mexico.

I encourage Canadian students to participate in the fifth CAM confernece, that will be hosted two years from now (in 2011) in the USA.

PhD Physics Degrees Awarded in Canadian Universities
Doctorats en physique décernés par les universités canadiennes

December 2008 to November 2009 / décembre 2008 à novembre 2009

Carleton University

ARCHAMBAULT, J.P., "Monte Carlo Studies of the ATLAS Forward Calorimeter and of the Supersymmetric Top Quark", (M. Vincter), February 2009, now at: Ionizing Radiation Standards, National Research Council.

KING, B., "Accurate Measurement of the X-Ray Coherent Scattering Form Factors of Tissues", (P. Johns), September 2009, now a Postdoctoral Research Fellow at the University of Newcastle/Calvary Mater Hospital, Newcastle, New South Wales, Australia

LARUSSA, D., "The effect of low-energy electrons on the response of ion chambers to ionizing photon beams", (D. Rogers), September 2009, now a Medical Physics Resident at the Ottawa Hospital Regional Cancer Centre.

OLARIU, E., "Analysis of water diffusion in white matter using a hydration layers model", (I. Cameron), September 2009.

OLIVIER, S., "Measurement of the Survival Probability and Determination of the Three-Flavor Neutrino Oscillation Parameters at the Sudbury Neutrino Observatory", (A. Bellerive), August 2009, now a Research Associate at: CEA, Saclay, France.

TESIC, G., "Extraction of Active and Sterile Neutrino Mixing Parameters with the Sudbury Neutrino Observatory", (A. Bellerive), November 2008, now a Research Associate at University McGill, Montreal.

WANG, L., "Study of the replacement correction factors for ionization chamber radiation dosimetry by Monte Carlo simulations", (D. Rogers), April 2009, now a Research Associate at MD Anderson Cancer Centre, Houston TX.

Dalhousie University

CHEVRIER, V., "First Principles Studies of Si as a Negative Electrode Material", (J. Dahn), October 2009, now a Post Doctoral Fellow, Massachusetts Institute of Technology.

FERGUSON, P., "Studies of Tin-Transition Metal-Carbon Alloys Prepared by Mechanical Milling for Lithium-Ion Battery Negative Electrodes", (J. Dahn), October 2009.

JAKUBINEK, M., "Thermal and Electrical Conductivity of Carbon Nanotube Materials", (J. Dahn), October 2009, now a Post Doctoral Fellow, Department of Chemistry, Dalhousie University.

SANDERSON, R., "Application of a Spatial Composition Spread Approach to the Preparation of Thin Film Cuprate Superconductor Libraries", (K. Hewitt), October 2009, now a Sputtering Technologist Institute for Research in Materials, Dalhousie University.

TODD, A., "Tin Transition Metal Carbon Alloys for Li-Ion Battery Negative Electrodes" (J. Dahn), October 2009, now a Research Associate, Institute for National Measurement Standards, Nation Research Council, Canada.

École Polytechnique

BUSSIÈRES, F., « Intrication temporelle et communication quantique », (N. Godbout). En janvier 2010 sera: Boursier postdoctoral au GAP Optique, Université de Genève, Suisse

GIRARD-LAURIAULT, P-L., « Polymérisation par plasma à pression atmosphérique: caractérisation des dépôts et leurs applications en biotechnologies », (M. Wertheimer), mai 2009, présentement boursier postdoctoral, Federal Institute for Materials Research and Testing,Berlin, Allemagne.

HASSANI, A., "Plasmonic and Nano-Photonics Sensors from Visible to Terhertz", (M. Skorobogati), septembre 2009, présentement boursier postdoctoral industriel à l'INRS, Varennes, P.Q.

Guelph-Waterloo Physics Institute

University of Guelph

AHMED, M.A.M.S., "Dynamics and Induced Structure of Intrinsically Disordered Myelin Proteins by NMR Spectroscopy", (V. Ladizhansky), August 4, 2009, now a Post Doctoral Research Fellow in the Department of Physics at the University of Guelph, Guelph, Ontario, Canada.

PHILLIPS, A., "Structure of $^{186,188}Os$ Studied with (^{3}He,d) Reactions", (P. Garrett and C. Svensson), August 19, 2009, now a part time Post Doctoral Research Fellow in the Department of Physics at the University of Guelph, Guelph, Ontario, Canada.

SCHUMAKER, M., "Coulomb Excitation Structure Studies of ^{21}Ne, $^{20,21}Na$", (C. Svensson), April 21, 2009, now a Post Doctoral Research Fellow at the Sudbury Neutrino Observatory (SNO-LAB), Sudbury, Ontario, Canada.

VIVCHARUK, V., "Phase Behaviour of DOPC/DPPC/Cholesterol Mixtures Revealed by ^{2}H NMR Spectroscopy and Confocal Fluorescence Microsopy", (J. Davis and F. Sharom), May 7, 2009, now a Research Associate at the Department of Medical Physics, Juravinski Cancer Centre, Hamilton, Ontario, Canada.

University of Waterloo

AZIMLU SHANJANI, M., "A Study of Molecular Clouds Associated with H II Regions", (M. Fich), September 14, 2009, now a Post Doctoral Research Fellow in the Department of Physics and Astronomy at the University of Western Ontario, London, Ontario, Canada.

BROWNSTEIN, J., "Modified Gravity and the Phantom of Dark Matter", (R. Mann and J. Moffat), June 1, 2009, now a Post Doctoral Researcher at the Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada.

JALILI, H., "Materials Physics of Half-Metallic Magnetic Oxide Films by Pulsed Laser Deposition: Controlling the Crystal Structure and Near-Surface Properties of Sr_2FeMoO_6 and CrO_2 Films", (K. T. Leung), January 15, 2009, now a Post Doctoral Research Fellow at the Massachusetts Institute of Technology, Somerville, Massachusetts USA

MADAIAH, C., "Quantum Walks - Its Dynamics and Applications", (R. Laflamme), August 17, 2009. Follow up information is currently unavailable.

PASSERINI, P., "On Holographic Non-local Operators and Multiple M2-Branes Theories", (J. Gomis and R. Myers), June 1, 2009, now a Postdoctoral Research Fellow at Humboldt University zu Berlin, Berlin, Germany.

QI, D.,"On Near-Free-Surface Dynamics of Thin Polymer Films", (J. Forrest), April 16, 2009, now a Postdoctoral Research Fellow in the Department of Physics and Astronomy, University of Waterloo, Waterloo, Ontario, Canada.

SHERIDAN, L., "Reference Frames and Algorithms for Quantum Information Processing", (R. Laflamme and M. Mosca), August 13, 2009, now a Post Doctoral Research Fellow at the Centre for Quantum Technologies, National University of Singapore, Singapore.

STASIAK, P., "Theoretical Studies of Frustrated Magnets and Dipolar Interactions", (M. Gingras), December 7, 2009, to start January 2010 as a Research Assistant and IT Technician at the University of Reading, Whitenights Reading, United Kingdom.

WAN, Y., "Emergent Matter of Quantum Geometry", (Z.-Y. Chen and L. Smolin), June 11, 2009, now Post Doctoral Research Fellow at Kinki University, Higashi-Osaka, Japan.

WAPLER, M., "Holographic Experiments on Defects", (R. Myers), August 19, 2009, now a Research Associate at the Center for Quantum Spacetime (CQUeST), Sogang University, Korea.

McMaster University

ABU-ARISH, A., "Spatial Localization and Mobility of the Ran GTPase and the Bicoid protein in Live Systems", (Cecile Fradin), December 2008, now a post doctoral fellow at McGill university in the group of Dr. Paul Wiseman.

CHEN, J., "Study of the Astrophysically Important States in ^{26}Si via the p(^{27}Si,d)^{26}Si Reaction and the p(^{25}Al,p)^{25}Al Elastic Scattering", (Alan Chen), June, 2009; Jun Chen will stay in the department for a bit longer to continue work with Alan Chen.

CROLL, A., "Droplets, films and edges: studies of the physical character of diblock copolymers", (Kari Dalnoki-Veress), February, 2009, now a post doctoral fellow at UMASS at Amherst in the Polymer Science and Eng. Dept.

KRISTOFFERSEN, A., "Terahertz Spectroscopy of Optically Excited $YBa_2Cu_3O_7$ Thin Films", (John Preston), April 2009.

NGUYEN, J., "The Linewidth and Hyperfine a Constant of the 2P1/2 State of a Magnesium Ion Confined in a Linear Paul Trap", (Brian King), October, 2009, now a post doctoral fellow at Northwestern University in Evanston, Illinois.

NING, F., "^{75}As and ^{59}Co NMR STUDY of the ELECTRON DOPED Ba(Fe $_{1-x}$ Cox)^{2}As$_2$", (Takashi Imai), October 2009, now staying in the department to work with Dr. Takashi Imai.

PETITCLERC, N., "Dense Core Formation Simulations In Turbulent Molecular Clouds With Large Scale Anisotropy", (James Wadsley), April 2009, moving on to a job in quantitative finance for a company in Toronto.

RAEGEN, A., "Micromechanical and Optical Experiments on Soft Condensed Matter Systems", (Kari Dalnoki-Veress), February 2009, now a post doctoral fellow, University of Freiburg, Freiburg, Germany.

RODRIGUEZ, J., "Study of the magnetic properties of the Ising system $LiHo_xY_{1-x}F_4$ using muon spin rotation/relaxation", (Graeme Luke), June 2009, now a post doctoral fellow at the PSI laboratory in Villigen, Switzerland.

WOODLEY, K., "The Globular Cluster System of NGC 5128", (Bill Harris), October, 2009, now a post doctoral Fellow at UBC.

Memorial University of Newfoundland

BLOKHINA, M., "Shoaling Internal Solitary Waves", (D. Bourgault), October 2009.

BROMBEREK, M., "Phase Transitions in $K_{1-x}(NH_4)_xH_2PO_4$ Single Crystals", (M. Clouter), May 2009, now a Post Doctoral Fellow at the Department of Physics and Physical Oceanography, Memorial University, St. John's, NL.

CHATMAN, S., "Electronic Properties of Electrodeposited Semiconductor Junctions", (K. Poduska), October 2009, now a Post Doctoral Fellow at the Pacific Northwest National Laboratory in Richland, WA, USA.

LIKO, T., "Extending the Isolated Horizon Phase Space to String-Inspired Gravity Models", (I. Booth), May 2009, now a Post Doctoral Fellow at the Department of Physics, Penn State University, University Park, PA, USA.

Queen's University

CHEN, X., "Numerical Studies of the Combined-Effects of Interactions and Disorder at Metal-Insulator Transitions", (R.J. Gooding), October 2009, now a Postdoctoral Fellow in Hong Kong.

MacLELLAN, R., "The energy calibration for the solar neutrino analysis of all three phases of the Sudbury Neutrino Observatory", (A.B. McDonald/A.L. Hallin), October 2009, now Postdoctoral Fellow at the University of Alabama.

MARK, A., "Domain Boundaries of the 5x5 DAS Reconstruction", (A.B. McLean), October 2009, now Postdoctoral Fellow at the University of Liverpool, UK.

MARTIN, R., "An Analysis of the ^{3}He Proportional Counter Data from the Sudbury Neutrino Observatory Using Pulse Shape Discrimination", (A.L. Hallin/A.B. McDonald), October 2009, now Postdoctoral Fellow at the University of California, Berkeley.

WANG, D., "An excitonic approach to the ultrafast optical response of semiconductor nano-structures", (M.M. Dignam), May 2009, now Postdoctoral Fellow at the University of Arkansas.

WEYMOUTH, A., "Scanning Tunneling Microscopy Studies of Small Aromatic Molecules on Semiconductor Surfaces", (A.B. McLean), October 2009, now Postdoctoral Fellow at the University of Regensburg, Germany.

WHITE, S., "A Barkhausen Noise Testing System for CANDU® Feeder Tubes", (L. Clapham), October 2009, now working at Queen's University and Royal Military College.

WRIGHT, A., "Robust Signal Extraction Methods and Monte Carlo Sensitivity Studies for the Sudbury Neutrino Observatory and SNO+ Experiments", (M.C. Chen), October 2009, now Postdoctoral Fellow at Princeton University.

ZHANG, Y., "Polymer electrochemical light-emitting devices and photovoltaic cells", (J. Gao), October 2009, now a Research Associate at the National Research Council.

Simon Fraser University

BUKER, J.W., "The electroluminescence and scanning tunneling microscopy of single molecules", (George Kirczenow), June 2009.

GILLBERG, D. I., "Discovery of Single Top Quark Production", (Dugan O'Neil), April 2009.

KARDASZ, B., "Anistropies and spin dynamics in ultrathin magnetic multilayer structures", (Bret Heinrich), April 2009, now a research Associate for the Surface Science Laboratory, SFU.

LI, W., "Hot electron transport through molecular diodes", (Karen Kavanagh), April 2009.

Université de Montréal

BRELIER, B., « Étude de la production associée ZH/WH, H → $\gamma\gamma$ avec le détecteur ATLAS », (G. Azuelos), décembre 2008, cotutelle avec l'Université Joseph Fourier.

FERLAND, J., « Potentiel d'observation de la technicouleur à l'aide de l'expérience ATLAS », (G. Azuelos), juillet 2009, présentement programmeur-analyste au RQCHP à l'Université de Montréal.

GIRARD, F., « Importance de l'hélice 4 et des bouches interhélicales du domaine I dans le mécanisme de formation des pores par la toxine Cry1Aa du bacille de Thuringe », (R. Laprade), septembre 2009, complète présentement une maîtrise en physique médicale à l'Université de Montréal.

IDARRAGA, J., "Vector Boson Scattering at High Energy at the LHC", (G. Azuelos et C. Leroy), janvier 2009, présentement boursier postdoctoral à l'Université de Montréal.

IMBEAULT, M., « Sujets variés concernant les désintégrations hadroniques mésons B », (D. London), juin 2009.

LEBEL, C., « Effets de rayonnement sur les détecteurs au silicium à pixels du détecteur ATLAS », (C. Leroy), août 2008, présentement boursière postdoctorale à l'Université de Montréal.

MARQUETTE, I., « Superintégrabilité avec intégrales d'ordre trois, algèbres polynomiales et mécanique quantique supersymétrique », (P. Winternitz), février 2009.

MORALES, L., "A new Avalanche Model for Solar Flares", (P. Charbonneau), avril 2009.

MUNGER, D., « Stabilité magnétohydrodynamique des cuves d'électrolyse : aspects physiques et idées nouvelles », (A. Vincent), août 2008.

POLLAK, J., « Développement et utilisation de sources de plasma pour stériliser des instruments médicaux », (M. Moisan), février 2009.

VAN GROOTEL, V., « Étude des étoiles de la branche horizontale extrême par l'astériosismologie », (G. Fontaine), septembre 2008, cotutelle avec l'Université de Toulouse III – Paul Sabatier.

UNIVERSITÉ DE SHERBROOKE

CHASSÉ, D., « Effets Josephson généralisés entre antiferroaimants et entre supraconducteurs antiferromagnétiques », (André-Marie Tremblay), octobre 2009, présentement en maîtrise en mathématiques financières à l'université de Montréal.

LEBOEUF, D., « Reconstruction de la surface de Fermi dans l'état normal d'un supraconducteur haute Tc: une étude du transport électrique sous champ magnétique intense », (Louis Taillefer) octobre 2009, présentement chercheur postdoctoral au LNCMI à Toulouse (France).

UNIVERSITÉ DU QUÉBEC À TROIS-RIVIÈRES

LAROUCHE, P., « La structure de l'eau liquide: une étude thermique par spectroscopie infrarouge », (Camille Chapados), février 2009, présentement enseignant de physique au collégial.

RICHARD, M.A., « Adsorption de gaz sur les matériaux microporeux: modélisation, thermodynamique et applications », (Richard Chahine), février 2009, présentement chez Hydro-Québec.

UNIVERSITÉ LAVAL

AUBRY, J.-F., « Calcul de dose avec images de tomographie à faisceau mégavoltage conique pour le développement de la radiothérapie guide par la dose », (L. Beaulieu), mars 2009, présentement physicien médical, Département de radio-oncologie du CHUM, Montréal.

BERNHARDT, J., "Stark broadening approach for measuring the plasma density inside a filament induced by a femtosecond laser pulse in a gas or gas mixture", (S.L. Chin), janvier 2009 .

JEANNETTE, D., « Contributions à l'étude des résonateurs laser à l'état solide munis de miroirs coniques et holographiques », (M. Piché), avril 2009.

LAGROIS, D., « Regard sur l'évolution dynamique des régions HII géantes. Interprétation des mouvements du gaz ionisé », (G. Joncas), juin 2009, présentement boursier Postdoctorat, Université Laval, Québec.

UNIVERSITY OF ALBERTA

AHMED, H., "*In situ* light jet energy calibration using semileptonic top quark decay with the ATLAS experiment", (D. Gingrich), June 2009.

CONNELL, P., "Particle Propagation in a Higher-Dimensional Black Hole Spacetime", (V. Frolov), November 2009.

DOGAN, F., "Fermion-Spin Interactions in 1D in the Dilute Limit", (F. Marsiglio), November 2009.

EGILMEZ, M., "Magnetotransport and magnetoresistive anisotropy in perovskite manganites", (J. Jung), November 2009.

FAN, I. H-J., "Muonium dynamics in Si and Ge probed via optical-μSR", (K. Chow), November 2009.

GAO, J., "Charge carrier photogeneration and transport in pentacene thin films", (F. Hegmann), November 2009.

MA, R., "Vortex Dynamics and Supercurrents in Bi-2212 Superconducting Single Crystals and Films", (J. Jung), November 2009.

MANSOUR, A., "Intrinsic Disorder Effects and Persistent Current Studies of $YBa_2Cu_3O_{7-\delta}$ Thin Films and Superconducting Tunnel Junctions", (K. Chow), November 2009.

MUNROE, J., "Internal wave generation by intrusions, topography and turbulence", (B. Sutherland), November 2009.

NAGHIZADEH, M., "Parametric reconstruction of multidimensional seismic records", (M. Sacchi), November 2009.

POPOV, K., "Laser based acceleration of charged particles", (R. Sydora, W. Rozmus), November 2009.

SHOOM, A., "Distorted Black Holes and Black Strings", (V. Frolov), November 2009.

TURKOGLU, E., "A magnetotelluric investigation of the Arabia-Eurasia Collision in Eastern Anatolia", (M. Unsworth), June 2009.

ZIKOVSKY, J., "Nanometer Scale Connections to Semiconductor Surfaces", (R. Wolkow), November 2009.

UNIVERSITY OF BRITISH COLUMBIA

CHENG, J., "Quantification and Optimization Techniques for Dynamic Brain Imaging in High Resolution Positron Emission Tomography", (Vesna Sossi), May 2009.

DAVIS, S., "Progress in Globular Cluster Research: Insights from NGC 6397 and Messier", (Harvey Richer), May 2009.

FULSOM, B., "A Study of B --> ccbar gamma K in the BABAR Experiment", (Christopher Hearty), May 2009.

GOODVIN, G., "Study of Polaron Properties Using the Momentum Average Approximation", (Mona Berciu), January 2009.

IVES, J., "The Measurement of the Rare Decay K-plus to Pi-plus, Neutrino and Anti-neutrino", (Douglas Bryman), May 2009.

KOLIND, S., "Myelin Water Imaging: Development at 3.0T, Application to the Study of Multiple Sclerosis, and Comparison to Diffusion Tensor Imaging", (Alex MacKay), May 2009.

MESTROVIC, A., "Integration of Daily Imaging, Plan Adaptation and Radiation Delivery for Near Real-Time Adaptive Radiation Therapy", (Karl Otto), May 2009.

PEL, J., "A Novel Electrophonetic Mechanism and Separation Parameter for Selective Nucleic Acid Concentration Based on synchronous Coefficient of Drag Alteration (SCODA)", (Andre Marziali), November 2009.

SHIEH, B., "Holographic Effective Theories for Strongly Coupled Physics", (Don Witt), November 2009.

TSUI, Y., "Through-going Muons at the Sudbury Neutrino Observatory", (Chris Waltham), May 2009.

UNIVERSITY OF CALGARY

ABU AJAMIEH, I., "Optical Properties of Driven Dense Atomic Gases", (B. Sanders)

BORVAYEH, L., "High Resolution Infrared Study of Vibration-Torsion-Rotation Interactions in Ethane-Like Molecules", (N. Moazzen Ahmadi)

RANGEL BALTAZAR, M.A., "The Objective Setting of Tolerances in RT", (P. Dunscombe).

SANGALLI, L., "Sounding Rocket Probing of the Ionospheric Collisional Transition Region", (D. Knudsen).

SHREIM, A., "On the Analysis of the State Space Networks of Discrete Dynamical Systems", (M. Paczuski).

SPANSWICK, E., "Global Evolution of the Substorm Injection Region", (E. Donovan).

WANG, Z., "Large Cross Phase Modulation using Double Electromagnetically Induced Transparency", (B. Sanders).

UNIVERSITY OF MANITOBA

FALLIS, J., "The Masses of Proton-Rich Isotopes of Nb, Mo, Tc, Ru and Rh and Their Influence on the Astrophysical rp and vp Processes", (K.S. Sharma), October 2009.

QIAO, H., "Fundamental Studies of MALDI and an Orthogonal TOF Mass Spectrometer", (E.W. Ens), May 2009.

VIDDAL, C., "Non-Equilibrium Effects in nano-particulate Assemblies, Bond-Disordered Ferromagnets, and Collections of Two-Level Subsystems", (R.M. Roshko), February 2009.

UNIVERSITY OF OTTAWA

AL-MARZOUG, S., "Luus-Jaakola optimization procedure for some problems in optics", (R. Hodgson), December 11, 2008, now an Assistant Professor, Department of Physics, King Fahd University of Petroleum & Minerals, Saudi Arabia.

AL-QADI, K., "Magnetic Properties of the Icosahedral Quasicrystals $Ag_{50}In_{36}Gd_{14}$ and $Zn_{77}Fe_7Sc_{16}$, and the 1/1 Approximant $Ag_{50}In_{36}Gd_{14}$", (Z. Stadnik) April 8, 2009, now a laboratory Technician at the University of Ottawa.

GERTSVOLF, M., "Controlled Material Modification of Transparent Dielectrics by Femtosecond Laser Pulses", (P. Corkum), September 8, 2009, now a Research Associate at the Institute for National Measurement Standards of the National Research Council in Ottawa.

PREVOST, J.P., "Theoretical Studies of the First-Row Transition Metals: Ground State and Thermal Properties", (D. Rancourt), April 29, 2009, now a sessional Lecturer at the University of Ottawa.

SMITH, J., "A high-pressure study of the heavy alkaline earth hydrides", (S. Desgreniers), April 16, 2009, now a Postdoctoral Fellow at the University of Ottawa.

WANG, P., "Magnetic properties and Mössbauer spectroscopy of novel alloys", (Z. Stadnik), May 8, 2000, now a research assistant at the University of Ottawa.

WHEELDON, J., "Group Theoretic Expressions of Optical Singularities in Photonic Crystals", (H. Schriemer), December 16, 2008, now a Postdoctoral Fellow, School of Information Technology, University of Ottawa.

ZHANG, Z., "Polarization Effects in Optical Fiber Communication and Distributed Vibration Sensing Systems", (X. Bao / L. Chen), March 19, 2009, now a research Scientist at the Wellman Center for Photomedicine at Massachusetts General Hospital, USA.

UNIVERSITY OF SASKATCHEWAN

MA, J., "Ion Velocity Distributions in Inhomogeneous and Time-Dependent Auroral Situations", (J.P. St-Maurice), April 2009.

WILLKS, R., "X-ray Spectroscopy of Organic Materials", (Alex Moewes & Gap Soo Chang), October 2009, now a Post Doc in Germany.

YAO, Y., "Structures, Bonding and Transport Properties of High Pressure Solids", (John Tse), April 2009, now an Assistant Research Officer, Steacie Institute for Molecules Sciences, National Research Council of Canada.

UNIVERSITY OF TORONTO

ADAMSON, R.B.A., "Characterization of Quantum States of Light", (A.M. Steinberg), June 2009, PDF, now doing Medical Imaging at Dalhousie University, Halifax, NS.

ANSTEY, J.A., "Influence of the Quasi-biennial Oscillation on Interannual Variability in the Northern Hemisphere Winter Stratosphere", (T.G. Shepherd), June 2009, now PDF, Canadian Climate Centre for Modeling and Analysis, Victoria, BC.

DONG, G., "Modeling and Experimental Results on Stochastic Model Reduction, Protein Maturation, Macromolecular Crowding, and Time Varing Gene Expression", (D. McMillen), November 2009, now a Postdoctoral Fellow, University of California, San Francisco, CA, U.S.A.

EXTAVOUR, M.H.T., "Fermions and Bosons in an Atom Chip", (J.H. Thywissen), November 2009, now a Quantitative Analyst, Market Risk at Ontario Power Generation, Toronto, ON.

FORD, J.G., "Gravity and Black Holes in Four and Five Dimensions", (A.W. Peet), November 2009, now an actuary, Manulife Financial, Toronto, ON.

FORTESCUE, B.P., "Application and Manipulation of Biparte and Multiparte Entangled Quantum States", (H.-K. Lo), June 2009, now a PDF, University of Calgary, AB.

GAO, D., "D-Brane Chan-Paton Factors and Orientifolds", (K. Hori), June 2009, now a PDF University of Tokyo, Japan.

GIANG, D., "The Study of Inhomogeneous Cosmologies through Spacetime Matchings", (C.C. Dyer), November 2009, now teaching.

GREENHALGH, C.A., "Nonlinear Multicontrast Microscopy for Structural and Dynamic Investigations of Myocytes", (V. Barzda), March 2009, now in and Development, ELCAN Optical Technologies, Midland, ON.

HARB, M., "Investigating Photoinduced Structural Changes in Si Using Femtosecond Electron Diffraction", (R.J.D. Miller), March 2009, now a PDF at Lund University, Sweden.

HEBEISEN, C.T., "Generation, Characterization and Applications of Femtosecond Electron Pulses", (R.J.D. Miller), June 2009, now NSERC PDF, NRC Staecie Inst for Molecular Sciences, Ottawa, ON.

HO, S.Y., "Approximation Techniques for Large Finite Quantum Many-Body Systems", (D.J. Rowe), November 2009, now a Research Fellow, Centre for Quantum Technologies, National University of Singapore (on attachment as) PDF, Institute of Condensed Matter Theory, University of Illinois at Urbana-Champaign, USA.

HUANG, J., "Seismic Imaging of Gas Hydrate Reservoir Heterogeneities", (B. Milkereit), November 2009, now a Visiting Scholar, National Lab in the Geological Survey, Ottawa, ON.

MACQUEEN, D.M., "Search for New Physics in the Missing Transverse Energy + Dijet Channel at CDF", (R.S. Orr), June 2009, now a Lab Instructor at University of Regina, SK.

MICHALIK, A.M., "Theory of Ultrafast Electron Diffraction", (J.E. Sipe), March 2009, now a looking for a position.

ROURKE, P.M.C., "Electronic States of Heavy Fermion Metals in High Magnetic Fields", (S.R. Julian), June 2009, now a PDF, University of Bristol, U.K.

ROY, C., "Quantum Theory of Phonon-Mediated Decoherence and Relaxation of Two-Level Systems in a Structured Electromagnetic Reservoir", (S. John), November 2009, now looking for a position.

SHAW, T.A., "Energy and Momentum Consistency in Subgrid-Scale Parameterization for Climate Models", (T.G. Shepherd), November 2009, now a Postdoctoral Fellow at Center for Atmosphere Ocean Studies, Courant Institute of Mathematical Sciences, New York University, NY, U.S.A.

SUN, L., "Attenuation and Velocity Dispersion in the Exploration Seismic Frequency Band", (B. Milkereit), June 2009, now a Research Geophysicist, CGG Veritas, Beijing, China.

TOOHEY, M.R,. "Comparing Remote Sounding Measurements of a Variable Stratosphere", (K. Strong), November 2009, now a PDF at IFM-Geomar, Kiel University, Kiel, Germany.

TUREL, C.S., "Probing Superconducting Order Parameter Symmetry Using Point-Contact Andreev Reflection Spectroscopy", (J.Y.T. Wei), November 2009, now a looking for a position.

WILSON, B.J., "A Method of Generating Exact Perturbations in General Relativity", (C.C. Dyer), November 2009, now looking for a position.

ZHAO, Y., "Quantum Cryptography in Real-life Applications: Assumptions and Security", (H.-K. Lo), November 2009, now a NSERC PDF at California Institute of Technology, CA, U.S.A.

UNIVERSITY OF VICTORIA

BIRD, C.S., "The Early Universe as a Probe of New Physics", (M. Pospelov), May 2009, now self employed as a consultant.

BUSH K.K., "Monte Carlo Dose Calculations in Advanced Radiotherapy", (Dr. Jirasek / S. Zavgorodni), November 2009, now a Postdoctoral Fellow at BC Cancer Agency's Vancouver Island Centre.

FRASER, W C., "The Kuiper Belt Size Distribution: Constraints on Accretion", (J.J. Kavalaars / C.J. Pritchet), November 2008, now a Postdoctoral Scholar in Planetary Sciences at California Institute of Technology.

FRIESEN R.K., "The Initial Conditions of Clustered Star Formation: An Observational Study of Dense Gas in the Ophiuchus Molecular Cloud", (J. di Francesco / C.J. Pritchet), November 2009, now a Postdoctoral Fellow, North American ALMA Science Center, National Radio Astronomy Observatory.

HAMANO, K., "Measurement of Branching Fractions and Form Factor Parameters of B -> Dlv and B -> D*lv Decays at BaBar", (R.V. Kowalewski), May 2009, now a Postdoctoral researcher in Japan Proton Accelerator Research Complex (J-Parc).

HSIAO Y.C.E., "Spectroscopic diversity of Type Ia supernovae", (C.J. Pritchet), November 2009, now a Postdoctoral Fellow, UC Berkeley, JBSSL - Space Sciences Laboratory.

KIRK H.M., "Star Formation in the Perseus Molecular Cloud: Observations of Dynamics and Comparison to Simulations", (D. Johnstone / D. VandenBerg), November 2009, now a Postdoctoral Fellow, Smithsonian Center for Astrophysics, Harvard University.

LUDLOW, A.D., "The Structure and Substructure of Cold Dark Matter Halos", (J. Navarro), May 2009, now a Postdoctoral researcher in Argelander-Institut für Astronomie, Germany.

NUGENT, I.M., "Precision Measurements of Tau Lepton Decays", (M. Roney), May 2009, now a Postdoctoral Fellow at TRIUMF and a member of the ATLAS Collaboration.

THANJAVUR K.G., "Cosmic Applications of Gravitational Lens Assisted Spectroscopy (GLAS)", (D. Crampton/J. Willis), May 2009, now a Research Associate, University of Victoria.

UNIVERSITY OF WESTERN ONTARIO

ALFORD, J., "Star formation: Submillimetre observations and data reduction techniques", (B. Chronik), October 2009.

ATTARD, M., "Star formation: Submillimetre observations and data reduction techniques", (M. Houde), September 2009.

de VET, S., "Craters in Granular Media", (J. de Bruyn), June 2009.

GILBERT, A., "From asteroids to comets: Gas and dust production of the small-bodies in the solar system", (P. Wiegert), July 2009.

HASSANZADEH, A., "Waveguide Evanescent Field Fluorescence Microscopy", (S Mittler), April 2009.

LIU, J., "Growth and characterization of hafnium silicate films", (W. Lennard), December 2009.

MOKRY, C., "Growth and characterization of light-emitting silicon nanocrystals", (P. Simpson), December 2009.

NGUYEN, H.T., "Dipole-Exchange Spin Waves in Magnetic Nanomaterials", (M.G. Cottam), May 2009.

NISTOR, R., "Simulation of charge transfer and orbital rehybridization in molecular and condensed matter systems", (M. Muser), April 2009.

OPPONG, F., "Rheology, Microrheology and Structure of Soft Materials", (J. de Bruyn), April 2009.

REZAEE A., "Control of average-spacing of OMCVD grown gold nanoparticles", (S. Mittler), December 2009.

UNIVERSITY OF WINDSOR

DANIEL, J.R., "Optical Properties of Nanostructures and Applications to Surface Enhanced Spectroscopy", (R. Aroca), March 2009, now a Postdoctoral Fellow in Fribourg, Switzerland.

QIXUE,W., "Hyperfine Structure and Hyperfine Transitions of ^{3}He", (Dr. G. Drake), May 2009, now a Postdoctoral Fellow in the Department of Physics at the University of Windsor.

YORK UNIVERSITY

AKINGUNOLA, A., "Martian Water Cycle Modeling With the Second Generation of the Global Mars Multiscale Model", (J. McConnell), June 2009, now a Postdoctoral Fellow, Canadian Space Agency, St. Hubert, Quebec.

BEATTIE, S., "Atom Interferometric Studies of Light Scattering - A New Technique For Measuring Atomic Recoil", (A. Kumarakrishnan), June 2009, now a Postdoctoral Fellow, Department of Physics, University of Cambridge, Cambridge, UK.

BORBELY, J., "Field Microwave Measurement of the n=2 3P1-TO- n=2 3P2 Fine-Structure", (E. Hessels), June 2009, now a Postdoctoral Fellow, Department of Physics and Astronomy, York University, Toronto, ON.

DAVY, R., "Studies of the Martian Boundary-Layer", (P. Taylor), October 2009, now a Postdoctoral Fellow, Department of Earth and Space Science and Engineering, York University, Toronto, ON.

LOMBARDI, L., "Progress Towards a Separated Oscillaritory Fields Measurement of the 2 3P1-to-2 3P2 Fine Structure Interval of Atomic Helium", (E. Hessels), June 2009, now a technologist, Focal Point Technolgies, Mississauga, ON.

RYAN, C., "Galaxy Interactions and Active Galactic Nuclei in the Local Universe", (M. DeRobertis), June 2009, now a Postdoctoral Fellow, Department of Physics and Astronomy, York University, Toronto, ON.

SUN, Y., "Structural and Electronic Principles for Atomic Clusters", (R. Fournier), June 2009, now a Postdoctoral Fellow, Lawrence Livermore National Laboratory, Livermore, CA, USA.

WHYTE, J., "Charm Production and F2CC Measurement in Deep Inelastic Scattering at Hera II", (S. Menary), June 2009, now searching for employment.

À vos calendriers : 7 au 11 juin, 2010
Congrès de l'ACP, Université de Toronto

Conférencier Herzberg: Dr. Charles H. Townes,
University of California (Berkeley)
"50^{ième} anniversaire du laser".

Conférenciers pléniers confirmés:

Rob McPherson (TRIUMF)
"Probing the Origin of Mass: The First Light of LHC Data"

Ken Tapping (NRC Herzberg Institute of Astrophysics)
"The Changing Rhythm of Solar Activity"

Robert Mann (CAP President)
"Progress and Prospects for the CAP"

L'ACP s'est associée avec l'APS et l'OSA pour honorer le cinquantième anniversaire du laser (LaserFest). Il y aura plusieurs sessions au congrès liées au laser et à la recherche en optique au Canada.

Pour des mises à jour et des renseignements sur le programme, visitez:
http://www.cap.ca/fr/congres/2010

PROCHAINS CONGRÈS DE L'ACP

Congrès annuel 2011, 13 - 17 juin, 2011
Université Memorial de Terre-Neuve, Saint John's, NL

Congrès annuel 2012, (dates provisoires) 4 - 8 juin, 2012
Université de Calgary, Calgary, AB

Mark your calendars: June 7 – 11, 2010
CAP Congress, University of Toronto

Herberg Public Lecturer: Dr. Charles H. Townes, University of California (Berkeley)
"50th Anniversary of the Laser"

Confirmed Plenary Speakers:

Rob McPherson (TRIUMF)
"Probing the Origin of Mass: The First Light of LHC Data"

Ken Tapping (NRC Herzberg Institute of Astrophysics)
"The Changing Rhythm of Solar Activity"

Robert Mann (CAP President)
"Progress and Prospects for the CAP"

CAP has partnered with the APS and OSA to honour the 50th anniversary of the laser through LaserFest. There will be several sessions at the Congress related to laser and optics research in Canada.

For updates and program information, bookmark the Congress web site at: http://www.cap.ca/en/congress/2010

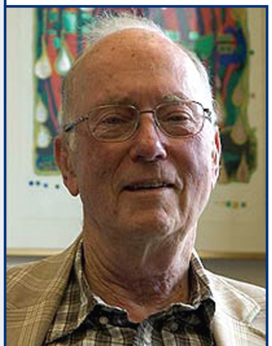
FUTURE CAP CONFERENCES

2011 Annual Congress, June 13 - 17, 2011
Memorial University of Newfoundland, Saint John's, NL

2012 Annual Congress, (tentative) June 4 - 8, 2012
University of Calgary, Calgary, AB

CONFÉRENCE COMMÉMORATIVE PUBLIQUE HERZBERG 2010

UNIVERSITÉ DE TORONTO
LUNDI, 7 JUIN 2010 - 19H00



Charles Townes
Université de la Californie à Berkeley

50e ANNIVERSAIRE DU LASER

Au début des années 50, j'ai réfléchi et je me suis employé à trouver un moyen de me procurer un oscillateur à fréquences plus élevées que celles des appareils électroniques connus afin de faire de la spectroscopie à très haute résolution. Finalement, j'ai tout à coup eu l'idée de porter suffisamment d'atomes ou de molécules excédentaires à un état supérieur et de produire une émission stimulée. Mon étudiant Jim Gordon et moi-même avons d'abord ouvré dans la gamme des micro-ondes, essentiellement à titre de test, créant ainsi le maser (amplification d'hyperfréquences par émission stimulée de radiations), qui a donné un domaine excitant dans lequel beaucoup se sont lancés pour fabriquer des oscillateurs et des amplificateurs de micro-ondes. Mais après quelques années, j'ai moi-même prôné l'adoption de longueurs d'onde beaucoup plus courtes. Arthur Schawlow et moi avons alors rédigé une communication sur la production de ces oscillateurs à émission stimulée à des longueurs d'onde aussi courtes que celles de la lumière – appelés par nous masers optiques, mais vite rebaptisés lasers (amplification de la lumière par émission stimulée de radiations). La publication de nos propos théoriques a passionné nombre de scientifiques et c'est Theodore Maiman qui a fabriqué le premier système opérationnel, un laser à rubis pulsé, aux laboratoires Hughes. Le premier système à oscillation entretenue est l'ouvre de l'un de mes anciens étudiants, Ali Javan, avec Wm. Bennett et Don Herriot, à Bell Telephone Laboratories. L'industrie avait alors reconnu l'importance de ce domaine et les premiers lasers ont tous été construits dans des laboratoires industriels. Les lasers sont maintenant un domaine de science fantastique et servent à une grande variété d'applications techniques – qui sont toutes des extensions naturelles de la spectroscopie, domaine qui a connu un grand essor grâce à Herzberg notamment.

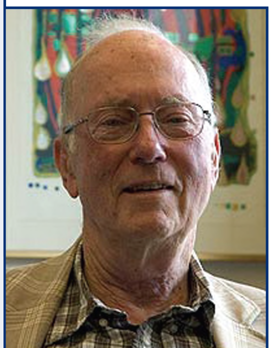
J'utilise actuellement le laser pour faire de l'interférométrie infrarouge sur les étoiles à l'aide de trois télescopes distincts. Les lasers ont aidé l'astronomie de bien des façons, produisant notamment un essor rapide de l'interférométrie dans la mesure de la taille et des formes d'étoiles. Notre interféromètre est cependant le seul à utiliser la détection hétérodyne, fournie par des oscillateurs locaux à laser, permettant ainsi l'interférométrie dans des bandes très étroites qui peuvent éviter les raies spectrales causées par les gaz environnants. Cela permet de mesurer assez directement les étoiles anciennes et actives sans interférence des gaz qu'elles émettent. Je ferai état de certaines de ces mesures, montrant les changements de taille de certaines étoiles, les enveloppes de poussières dont elles se débarrassent et leur expansion, ainsi que d'autres détails inconnus jusqu'à ce que ces techniques soient rendues possibles.

NOTICE BIOGRAPHIQUE

Charles Hard Townes est né à Greenville, en Caroline du Sud, où il se voit décerner un B.Sc. en physique et un B.A. en langues modernes par l'Université Furman. Il fait sa maîtrise ès arts en physique à l'Université Duke, puis son doctorat au California Institute of Technology. Il fait partie du personnel technique de Bell Telephone Laboratories de 1933 à 1947. À la suite de sa nomination à l'Université Columbia en 1948, il poursuit ses recherches sur les micro-ondes en étudiant la structure des atomes, des molécules et des noyaux. En 1951, le Dr Townes conçoit l'idée du maser et, début 1954, il réalise dans l'ammoniac la première amplification et génération d'ondes électromagnétiques par émission stimulée. En 1958, le Dr Townes et son beau-frère, le Dr A.L. Schawlow, démontrent théoriquement que le maser peut fonctionner dans la partie optique et infrarouge du spectre. La démonstration du premier laser opérationnel est faite (par Ted Maiman) en 1960. De 1959 à 1961, le Dr Townes est vice-président et directeur de la recherche à l'Institute for Defense Analyses à Washington, D.C., à titre de conseiller du gouvernement américain. En 1961, il est nommé vice-recteur à l'enseignement et à la recherche et professeur de physique au Massachusetts Institute of Technology, puis professeur à l'Université de la Californie en 1967, principalement au campus Berkeley. Le principe du maser/laser lui vaut (ainsi qu'aux Drs Basov et Prokhoroff) le prix Nobel de physique en 1964. Le Dr Townes siège à divers comités scientifiques conseillers d'organismes gouvernementaux et il est actif au sein de sociétés professionnelles. Il est ainsi membre et vice-président du comité consultatif des sciences du Président des États-Unis et président du comité consultatif sur le premier atterrissage de l'homme sur la Lune. Il siège aussi au conseil d'administration des sociétés General Motors et Perkins Elmer.

2010 Herzberg Memorial Public Lecture

University of Toronto
Monday, 7 June 2010 - 19h30



Charles Townes
University of California at Berkeley

50th Anniversary of the Laser

In the early 1950s I thought and worked hard at trying to find a way to obtain an oscillator for frequencies higher than those available from known electronics, in order to do very high resolution spectroscopy. Finally, I suddenly had the idea to put enough excess atoms or molecules in an upper state, and provide stimulated emission. My student Jim Gordon and I made this work first in the microwave range, primarily as a test. The resulting maser (for microwave amplification by simulated emission of radiation) generated an exciting field and many people jumped into it to make microwave oscillators and amplifiers. But after a few years I pushed myself to move on to much shorter wavelengths. Arthur Schawlow and I then wrote a paper on how such stimulated emission oscillators could be produced at wavelengths as short as those of light – we called it an optical maser, but it soon was renamed the laser (light amplification by stimulated emission of radiation). After publication of our theoretical discussion, many scientists were excited and the first working system was made by Theodore Maiman at the Hughes Labs, a pulsed ruby laser. The first continuously oscillation system was made by one of my former students, Ali Javan, with Wm. Bennett and Don Herriot at the Bell Telephone Labs. Industry by then recognized the importance of this field, and all the first lasers were built in industrial labs. Lasers are now a wonderful field for science and for a wide variety of technical applications -- all an outgrowth of spectroscopy, a field Herzberg helped develop importantly.

I presently use lasers to do infrared interferometry on stars with three separate telescopes. Lasers have helped astronomy in many ways, in particular producing a rapid growth of interferometry for measurement of stellar sizes and shapes. Our interferometer is the only one, however, which uses heterodyne detection, provided by laser local oscillators, which hence allows interferometry in very narrow bandwidths which can avoid spectral lines due to surrounding gas. This allows measurement of old and active stars quite directly, without interference from their emitted gases. I will report some of the measurements, showing the changes in size of some stars, the dust shells they have blown off and expansion of these shells, along with other details not seen until such techniques became possible.

Biography

Charles Hard Townes was born in Greenville, South Carolina and attended Furman University in Greenville, from which he received a B.Sc. in Physics and a B.A. in Modern Languages. He completed the Master of Arts degree in Physics at Duke University and then took his Ph.D. at the California Institute of Technology. He was a member of the technical staff of Bell Telephone Laboratories from 1933 to 1947. Appointed to Columbia University in 1948, he continued microwave research to study the structure of atoms, molecules and nuclei. In 1951, Dr. Townes conceived the idea of the maser and in early 1954, the first amplification and generation of electromagnetic waves by stimulated emission were obtained in ammonia. In 1958, Dr. Townes and his brother-in-law, Dr. A.L. Schawlow, showed theoretically that masers could be made to operate in the optical and infrared region. The first working laser was demonstrated (by Ted Maiman) in 1960. From 1959 to 1961, Dr. Townes served as Vice President and Director of Research of the Institute for Defense Analyses in Washington, D.C., advising the U.S. government. In 1961, Dr. Townes was appointed Provost and Professor of Physics at the Massachusetts Institute of Technology. He was appointed University Professor at the University of California in 1967, principally located at the Berkeley campus. He was co-recipient (with Drs. Basov and Prokhoroff) of the 1964 Nobel Prize in physics for the maser/laser principle. Dr. Townes has served on a number of scientific committees advising governmental agencies and has been active in professional societies. This includes being a member, and vice chairman, of the Science Advisory Committee to the President of the U.S. and Chairman of the Advisory Committee for the first human landing on the moon. He also served on the boards of General Motors and of the Perkins Elmer Corporations.

PLENARY SPEAKERS - CONFÉRENCIERS PLÉNIÈRES

Robert McPherson,
TRIUMF

Probing the Origin of Mass: the First Light of LHC Data

Four decades of experimental results and theoretical developments point us to energies of one trillion electron volts, or about a thousand times the mass of the proton, to search for the processes that give mass to elementary particles. Reaching such high energies required a new particle accelerator, the Large Hadron Collider (LHC), which has recently begun operation at the CERN laboratory in Geneva, Switzerland. The physics case for the LHC and the massive ATLAS detector which records the results of the interactions that might produce the Higgs boson or other new particles is discussed, and an LHC status report including a first look at ATLAS data from the ongoing 2010 run is presented.

Biography:

Robert McPherson is a professor at the University of Victoria and a Principal Research Scientist at the Institute of Particle Physics. He completed his PhD at Princeton University studying rare decays of kaons, and then moved to the CERN laboratory to work on the Large Electron Positron Collider where he served as overall physics coordinator of the OPAL experiment. He has been working on the ATLAS experiment at the CERN Large Hadron Collider since 2002, leading projects for detector commissioning and data quality measurements needed for robust physics results. He is currently the overall spokesperson and NSERC principal investigator for the approximately 200 Canadians working on ATLAS.

Ken Tapping,
NRC Herzberg Inst.

The Changing Rhythm of Solar Activity

Climate and other environmental change almost certainly have solar-driven components, and our increasing activities in space and dependence on international and global power, transport and communications infrastructure makes us more vulnerable than in the past.The latest generations of satellite-borne instruments for observing the sun are producing unprecedented insights into solar activity. However, when we consider the solar activity cycle and longer-term trends in solar behaviour, we are confronted with two serious problems. Firstly, until we have observed a few solar activity cycles, we won't have the context we need. Secondly, we have yet to derive the tools needed to extract from these data the key parameters applicable to longer term studies. So far, the best stethoscopes we have for looking at the rhythm of solar activity are indices of solar activity such as sunspot number and the 10.7 cm Solar Radio Flux. The first is a record of solar activity since the 17th Century, and the second record began in 1947. Since then, additional indices have come into use. Although it would be unwise to treat any single quantity as a full descriptor of the level of solar activity, we can use these long, consistent time-series to gain insight into how the solar activity cycle works. In this presentation I will discuss work on using indices to examine the solar activity cycle, with special attention to the last solar minimum, which was unusually long. We will examine some of the underlying physics and summarize our plans for the future solar monitoring in Canada.

Biography:

Robert McPherson is a professor at the University of Victoria and a Principal Research Scientist at the Institute of Particle Physics. He completed his PhD at Princeton University studying rare decays of kaons, and then moved to the CERN laboratory to work on the Large Electron Positron Collider where he served as overall physics coordinator of the OPAL experiment. He has been working on the ATLAS experiment at the CERN Large Hadron Collider since 2002, leading projects for detector commissioning and data quality measurements needed for robust physics results. He is currently the overall spokesperson and NSERC principal investigator for the approximately 200 Canadians working on ATLAS.

Robert Mann,
CAP President

Progress and Prospects for the CAP

This talk will review the main activities of the CAP over the past year and discuss its future directions and projects. Highlights include advancement of science policy, government lobbying efforts, Canada's nuclear program, impact of changes in NSERC's Discovery Grant program, and changes in membership structure.

Biography:

Robert Mann is a professor at the University of Waterloo. He is currently President of the Canadian Association of Physicists.

SPECIAL SESSIONS / SESSIONS SPÉCIALES

IDEAS TO INNOVATION / *LES IDÉES À L'INNOVATION*

DUTCHER, John, U. of Guelph
Polysaccharide Nanoparticles: from Discovery to Commercialization
REID, Matthew, UNBC
The Sometimes Bumpy Road to Commercialization at a Small Northern University
WHITEHEAD, Lorne, UBC
Practical Spin-offs: Let's Worry Less and Innovate More

NON-ACADEMIC CAREER PATHS / *DES CARRIÈRES NON-ACADÉMIQUE*

HANKEVYCH, Vasyl, Royal Bank
Physicists in Finance: Where Do They Fit and How to Get There?
LASIUK, Brian, GE Health
to be announced / à venir
STOCK, Rene, Scotia Capital, Scotiabank Toronto
to be announced / à venir
TREMBLAY, Real, Yahoo
to be announced / à venir

MEDICAL ISOTOPES - CANADA'S ROLE / LES ISOTOPES MÉDICAL - LE RÔLE DU CANADA

ROSS, Carl, NRC
Using the Mo-100 Photoneutron Reaction to Meet Canada's Requirement for Tc-99m
RUTH, Tom, TRIUMF
Direct production of Tc-99m via cyclotron irradiation of Mo-100: A piece of the puzzle
RYAN, Dominic, McGill University
Replacing NRU - It is about more than medical isotopes

INVITED SPEAKERS / CONFÉRENCIERS INVITÉS

BACCA, S. **(DNP / DPN)**
TRIUMF
Recent advances in the Theory of Neutron-rich Systems
(Nuclear Structure)

BACHYNSKI, Morrel **(DOP-DHP)**
w/ W. Clemens, MPB Technologies
The Role of Lasers through MPB's 30 Plus Year Adventure
(History of the Laser in Canada)

BAGGER, Jonathan **(PPD)**
John Hopkins U.
tobe announced / à venir (ILC)
(Energy Frontier and Future Colliders)

BANDRAUK, Andre **(DAMPhi-DOP-DPP / DPAMip-DOP-DPP)**
U. Sherbrooke
Effect of Nuclear Motion on Attosecond Electron Transfer - The Molecular Cat
(Attosecond Science and High Order Harmonics)

BATCHELAR, Deidre **(DMBP / DPMB)**
Sunnybrook/U of Toronto
to be announced / à venir
(Medical Physics II)

BEALE, Steven **(PPD-DTP / PPD-DPT)**
York U.
Highlights from the DO Experiment
(Energy Frontier and Phenomenology)

BEHR, John **(PPD-DNP / PPD-DPN)**
TRIUMF
Direct and indirect searches for new physics with TRIUMF's neutral atom trap
(Fundamental Symmetries)

BILLINGHURST, Brant **(DIMP / DPIM)**
Canadian Light Source Inc.
The Far-Infrared Beamline at the Canadian Light Source: Instrumentation, Performance and Coherent Synchrotron Radiation
(Instrumentation at the Canadian Light Source)

BOND, Richard **(DTP / DPT)**
CITA/U.Toronto
Early and Late Universe Inflation: Cosmic Sports with Lev Kofman
(Gravitation and Cosmology - Lev Kofman memorial session)

BOULAY, Mark **(PPD)**
Queen's U.
Dark Matter Search at SNOLAB with DEAP-3600
(Dark Matter Searches)

BRYMAN, Doug **(DMBP / DPMB)**
UBC
Liquid Xenon Detectors for PET
(Medical Physics I)

BURCH, Kenneth **(DCMMP / DPMCM)**
U. Toronto
Manipulating Spins on Small Scales
(Multiferroics, Spintronics, and Spin Dynamics)

CAMLEY, Robert **(DCMMP / DPMCM)**
U. Colorado
Noninear Amplification and Mixing of Spin Waves: Experiment and Theory.
(Multiferroics, Spintronics, and Spin Dynamics)

CARSWELL, Allan **(DOP-DHP)**
Optech Inc.
My Laser Adventure, 1961 to 2010: From a Solution Without a Problem to the Surface of Mars
(History of the Laser in Canada)

CHAN, Hue-Sun **(DMBP / DPMB)**
U of Toronto

Insights into Principles of Protein Folding from Coarse-Grained Models
(Molecular Biophysics)

CHANG, Zenghu **(DAMPhi-DOP-DPP / DPAMip-DOP-DPP)**
Kansas State U.
Generalized Double Optical Gating: an attosecond generation method for all
(Attosecond Science and High Order Harmonics)

CHAKRABORTY, Tapash **(DCMMP-DTP / DPMCM-DPT)**
U. Manitoba
Electronic Compressibility of Graphene: Vanishing correlations and other novelties
(Condensed Matter Theory)

CHARBONNEAU, Paul **(DPP-DASP / DPP-DPAE)**
U. Montreal
Global 3D MHD Simulations of the Solar Cycle: Progress and prospects
(Plasmas in Laboratory and Astrophysical Environments)

CHEVRIER, Vincent **(DCMMP / DPMCM)**
MIT
First Principles Studies of Silicon as a Negative Electrode Material for Lithium-ion Batteries
(Best CMMP paper in the Canadian Journal of Physics)

CHOU, Keng **(DMBP / DPMB)**
UBC
Sub-diffraction-limit Two-photon Fluorescence Microscopy for GFP-tagged cell imaging
(Cellular Biophysics)

CHUPP, T. **(PPD-DNP / PPD-DPN)**
U. Michigan
Atomic Electric Dipole Moments
(Fundamental Symmetries)

COULOMBE, Sylvain **(DPP)**
McGill U.
Plasma-Nanostructured Electrode Interactions in discharge lamp applications
(Plasmas at work in material science, medical and industrial applications)

CRAWFORD, Alan **(DHP-DOP)**
Accurex
Present at the Creation, the Gestation, Birth and Growth of two Companies that Pioneered the Development of Commercial Laser Devices
(History of the Laser in Canada)

CYBURT, Richard **(DNP / DPN)**
JINA
Nuclear and Particle Physics: Bridging the Divide
(Nuclear Astrophysics)

DAS, Saurya **(DTP / DPT)**
U. Lethbridge
Aspects of Quantum Gravity Phenomenology
(Gravitation and Cosmology - Lev Kofman memorial session)

DATTA, Alakabha **(PPD-DTP / PPD-DPT)**
U. Mississippi
Measurements in B decays and New Physics
(Rare Decays and CP Violation)

DEGENSTEIN, Doug **(DASP / DPAE)**
U. Sask.
OSIRIS on Odin - Year Nine of a Two-Year Mission
(Atmospheric Physics)

de SOUSA, Rogério **(DCMMP / DPMCM)**
U. Victoria
Electromagnon Excitations in Multiferroics
(Multiferroics, Spintronics, and Spin Dynamics)

DE STERK, Hans **(DASP / DPAE)**
U. Waterloo
Numerical Modeling of MHD Space Plasmas
(Modeling of Space Plasmas)

DISCHER, Dennis **(DMBP-DCMMP / DPMB-DPMCM)**
U. Penn.
Matrix elasticity effects on Differentiation processes with insights from the Mechanics of Protein Conformation
(Biologically-Inspired Materials)

DRAKE, Paul **(DPP-DASP / DPP-DPAE)**
U. Michigan
High-energy-density Hydrodynamics and Radiation Hydrodynamics
(Plasmas in Laboratory and Astrophysical Environments)

DUBOWSKI, Jan **(DMBP-DIMP-DIAP-DOP / DPMB-DPIM-DPIA-DOP)**
U. de Sherbrooke
Miniaturized Quantum Semiconductor Device for Photonic Detection of Viruses and Bacteria
(Biophotonics and Applied Biomedical Physics)

DURIC, Neb **(DMBP-DIMP-DIAP-DOP / DPMB-DPIM-DPIA-DOP)**
Wayne State U.
Ultrasound Tomography: A Decades Long Journey from the Lab to the Clinic
(Biophotonics and Applied Biomedical Physics)

ELLIS, Tom **(DIMP / DPIM)**
Canadian Light Source
Overview of Instrumentation at CLS
(Instrumentation at the Canadian Light Source)

FENSTER, Aaron **(DMBP-DIMP-DIAP-DOP / DPMB-DPIM-DPIA-DOP)**
U. Western Ontario
3D Ultrasound Imaging of the Carotid Arteries
(Biophotonics and Applied Biomedical Physics)

FOREST, Cary **(DPP-DASP / DPP-DPAE)**
U. Wisconsin
Plasma and Liquid Metal Dynamo Experiments
(Plasmas in Laboratory and Astrophysical Environments)

FOURKAL, Eugene **(DOP-DPP)**
Philadelphia
Acceleration of protons by high-power lasers for medical applications: Current challenges and future directions
(Relativistic laser plasma interactions and particle sources)

FRANCOEUR, Sebastien **(DOP-DCMMP / DOP-DPMCM)**
Ecole Polytechnique
Atomic Size Quantum Dots
(Advanced Materials and Photonic Crystals)

FRANKLIN, Ursula, (CEWIP / CEFEP)
Univ. of Toronto
to be announced / à venir
(CEWIP session)

FREIDEL, Laurent (DTP / DPT)
Perimeter Institute for Theoretical Physics
to be announced / à venir
(Quantum Gravity)

GESHNIZJANI, Ghazal (DTP / DPT)
Perimeter Institute for Theoretical Physics
Cuscuton Bounce, a scenario of bouncing cosmology without instabilities
(Gravitation and Cosmology - Lev Kofman memorial session)

GHEZELBASH, Masoud (DTP / DPT)
U. Saskatchewan
Atiyah-Hitchin Space in Einstein-Mawell-Chern-Simons Theory
(Mathematical Physics)

GIRT, Erol (DCMMP / DPMCM)
SFU
Exchange Stiffness and Incoherent Magnetization Reversal
(Magnetism)

GOMIS, Jaume (DTP / DPT)
Perimeter Institute for Theoretical Physics
Exact Results in Gauge Theories and 2d CTFs
(New Developments in Field Theory)

GONCHAROVA, Lyudmila (DCMMP-DSS / DPMCM-DSS)
UWO
Semiconductor-Dielectric Interfaces in the Nano Age
(Interfaces and Thin Films)

GRANT, Darren (PPD)
U. Alberta
The IceCube Neutrino Observatory: Status and Initial Results
(Neutrino Physics)

GRUTTER, Peter (DMBP-DCMMP / DPMB-DPMCM)
McGill U
Stress, Electrochemistry and Microcantilever-based Biochemical Sensing
(Biosensors and Microfluidics)

GWINNER, Gerald (DAMPhi / DPAMip)
U. Manitoba
Towards an atomic parity violation measurement with laser-trapped francium at ISAC
(Precision Physics)

HAUGEN, Harold (DOP)
McMaster U.
Femtosecond Laser Ablation and Micromachining of Semiconductors and Dielectrics
(Applications of Lasers)

HEARTY, Christopher (PPD-DTP / PPD-DPT)
UBC
Bottomonium results and new physics searches from the BaBar Upsilon resonance dataset
(Rare Decays and CP Violation)

HEGMANN, Frank (DOP-DPP)
U. Alberta
Exploring ultrafast hot electron dynamics in semiconductors with intense terahertz pulses
(THz radiation: generation and applications)

HESSELS, Eric (DAMPhi / DPAMip)
York U.
Precise Measurement of the n=2 Triplet P fine Structure of He: a path to a precise determination of the fine structure constant
(Precision Physics)

HINZER, Karin (DOP)
U. Ottawa
High Efficiency Photovoltaics
(Special Topics in Optics)

HITCHCOCK, Adam (DIMP / DPIM)
McMaster University
Chemical imaging at 30 nm spatial resolution in 2-d and 3-d with Scanning Transmission X-ray Microscopy
(Instrumentation at the Canadian Light Source)

HOCKING, Wayne (DASP / DPAE)
UWO
Middle Atmosphere Dynamical Studies with Meteor Radars
(Atmospheric Physics)

HOWLADER, Matiar (DPP)
McMaster U.
to be announced / à venir
(Plasmas at work in material science, medical and industrial applications)

IMAI, Takashi (DCMMP / DPMCM)
U. McMaster
NMR investigation of iron-based high temperature superconductors
(Spin Fluctuations and Superconductivity)

JAMES, Gordon (DASP / DPAE)
CRC
Prospects for space radio science in Canada
(Space Physics and Space Weather)

JAYACHANDRAN, P.T. (DASP / DPAE)
UNB
The Canadian High Artic Ionospheric Network (CHAIN) - Early results
(Canadian Contributions to Ionospheric Physics: Recent Advances and Innovative Techniques)

JENNEWEIN, Thomas (DAMPhi-DCMMP-DOP-DTP-DSS / DPAMip-DPMCM-DOP-DPT-DSS)
U. Waterloo
Towards global quantum communication networks with satellites
(Quantum Information)

JOHNS, Paul (DMBP-DOP / DPMB-DOP)
Carleton U.
X-Ray Scatter Imaging for Medicine
(Medical Physics I)

JUNCKER, David (DMBP-DCMMP / DPMB-DPMCM)
McGill U
Microfluidic Probe for Hydodynamic flow confinement and forming floating gradients in open space
(Biosensors and Microfluidics)

KALMAN, Calvin S. **(DPE / DEP)**
Concordia University
Enhancing Students' Understanding of Concepts by Getting Students to Approach Text in the Manner of a Hermeneutical Circle
(Teaching Physics to a Wider Audience)

KAPLAN, David **(DMBP-DCMMP / DPMB-DPMCM)**
Tufts
to be announced / à venir
(Biologically-Inspired Materials)

KOUSTOV, Alexandre **(DASP / DPAE)**
U. Sask.
Combining SuperDARN and satellite data: What have we learned about high-latitude ionosphere
(Canadian Contributions to Ionospheric Physics: Recent Advances and Innovative Techniques)

KROL, Andrzej **(DOP-DPP)**
SUNY
Development and exploration of ultrafast laser-produced plasma x-ray source for biomedical imaging applications
(Relativistic laser plasma interactions and particle sources)

KRUSHELNICK, Karl **(DOP-DPP)**
U. Michigan
Ion acceleration using ultra-high power lasers
(Relativistic laser plasma interactions and particle sources)

LAROCHE, Gaétan **(DPP)**
U. Laval
Plasma surface modification strategies for biomedical applications
(Plasmas at work in material science, medical and industrial applications)

LECLERC, Mario **(DCMMP-DOP / DPMCM-DOP)**
U. Laval
Polymeric Solar Cells
(Advanced Materials and Photonic Crystals)

LEGARE, Francois **(DAMPhi-DOP-DPP / DPAMip-DOP-DPP)**
INRS
to be announced / à venir
(Attosecond Science and High Order Harmonics)

LEVINE, Alexander **(DCMMP-DTP / DPMCM-DPT)**
UCLA
Cell Quakes: Mechanics and microrheology in living cells and active gels
(Condensed Matter Theory)

LITHERLAND, A.E. **(DHP)**
U. of Toronto
Nuclear Structure and Reaction Studies in Canada 1945-1965
(Research at Toronto and Chalk River: The beginning)

LONGTIN, André **(DCMMP-DTP / DPMCM-DPT)**
U. d'Ottawa
Sensory Neurophysics
(Condensed Matter Theory)

LOPINSKI, Greg **(DCMMP-DSS / DPMCM-DSS)**
NRC
Molecular sensing on chemically modified silicon surfaces - from gas phase to solution
(Interfaces and Thin Films)

MacDONALD, Rob **(PPD)**
U. of Alberta
Status of the PICASSO Spin-Dependent Dark Matter Search
(Dark Matter Searches)

MARJORIBANKS, Robin **(DOP-DPP)**
U. Toronto
Beyond Brunel: Controlling and managing absorption in ultra-intense laser-matter interaction
(Relativistic laser plasma interactions and particle sources)

MARSIGLIO, Frank **(DCMMP-DTP / DPMCM-DPT)**
U. Alberta
The Dynamic Hubbard Model: Results from DMFT
(Condensed Matter Theory)

MARTIN, Jeff **(PPD-DNP / PPD-DPN)**
U. Winnipeg
Experiments for an Ultracold Neutron EDM Search
(Fundamental Symmetries)

MASON, Thomas **(DMBP-DCMMP / DPMB-DPMCM)**
UCLA
Phase behavior and jammed states of Brownian polygons in two dimensions
(Biological and Soft Materials)

McCREERY, Richard **(DCMMP / DPMCM)**
U. Alberta
Resonant Electron Transport in 1-5 nm Thick Molecular Electronic Junctions
(Molecular Electronics and Graphene)

MILLER, Dwayne **(DMBP-DOP / DPMB-DOP)**
U of Toronto
to be announced / à venir
(Medical applications and dynamical molecular imaging)

MOON, Dae-Sik **(DPP-DASP / DPP-DPAE)**
U. Toronto
Hot interstellar plasma from supernova explosion and study of core-collapse supernova explosion and nucleosynthesis
(Plasmas in Laboratory and Astrophysical Environments)

MORRIS, Steve **(DPE / DEP)**
U of Toronto
Physics and Television
(Teaching Physics to a Wider Audience)

MORRISSEY, David **(PPD-DTP / PPD-DPT)**
TRIUMF
New Physics at the Energy Frontier
(Energy Frontier and Phenomenology)

MOUSSEAU, Normand **(DMBP / DPMB)**
U. Montreal
Simulating amyloid formation - challenges and progress
(Biophysics I)

MURRAY, Norman **(DTP / DPT)**
CITA, U. Toronto
The baryonic physics of galaxy and star formation
(Theoretical Astrophysics)

MYATT, Jason **(DPP-DOP)**
U. Rochester
High-intensity laser-matter interaction experiments on the

kJ-class OMEGA EP laser
(Relativistic laser plasma interactions and particle sources)

NOEL, Jean-Marc (DASP / DPAE)
RMC
The effects of ionospheric electrodynamics on low-earth orbiting satellites
(Modeling of Space Plasmas)

OFFENBERGER, Alan (DHP-DOP)
U. Alberta
High Intensity Lasers for Plasma/Fusion Science (IR to UV)
(History of the Laser in Canada)

OLIN, Art (PPD-DTP / PPD-DPT)
TRIUMF
Results of the TRIUMF Weak Interaction Symmetry Test
(Rare Decays and CP Violation)

PANTALONY, D. (DHP)
Canadian Science and Tech. Museum
Exploring Canada's Nuclear History Through Artifacts, 1945-1970
(Research at Toronto and Chalk River: The beginning)

PARAMEKANTI, Arun (DAMPhi-DCMMP / DPAMip-DPMCM)
U. Toronto
Superfluid insulator transitions, superflow instabilities, and novel pairing states of atomic fermions in an optical lattice
(Quantum Optics and Cold Atoms)

PATTON, Dave (DPE / DEP)
Trent U.
Interactive Online Assignments and Quizzes in Introductory Astronomy
(Curriculum Development and Revitalisation)

PEREPICHKA, Dmitrii (DCMMP-DSS)
McGill U.
pi-Electron Functional Organic Molecules in Flatland. Why Synthetic Chemists need Scanning Tunneling Microscopy?
(Interfaces and Thin Films)

PERRIN, Agnès (DAMPhi / DPAMip)
U. Paris
Quantitative spectrscopy for several troposheric and stratospheric molecules (formaldehyde, nitric acid, and formic acid)
(Molecular Spectroscopy)

REICHERT, Jonathan (DPE / DEP)
TeachSpin
Developing Instruments to Expand the Canon of Advanced Lab Experiments
(Curriculum Development and Revitalisation)

REID, Leslie (DPE / DEP)
U of Calgary
The Science Service Course - Examining its Impact through the Lens of Science Literary
(Interactive Teaching, Teaching with Technology, and Curriculum Development)

RHEINSTADTER, Maikel (DMBP-DCMMP / DPMB-DPMCM)
McMaster U.
Nanobiology: Membranes and proteins in motion
(Biological and Soft Materials)

RONEY, Michael (PPD)
U. Victoria
Precision Frontier at the SuperB Flavour Factory
(Energy Frontier and Future Colliders)

ROWE, David (DNP / DPN)
U of Toronto
An algebraic paradigm for nuclear structure physics
(Nuclear Structure)

RUIZ, Chris (DNP / DPN)
TRIUMF
Direct Measurements of Radiative Capture Reactions of Astrophysical Importance Using Radioactive Beams
(Nuclear Astrophysics)

RUTENBERG, Andrew (DMBP-DCMMP / DPMB-DPMCM)
Dalhousie U.
Monodisperse domains by proteolytic control of the coarsening instability
(Biological and Soft Materials)

SCOTT, Douglas (DTP / DPT)
UBC
The Cosmic Microwave Background
(Theoretical Astrophysics)

SHEPHERD, Theodore (DASP / DPAE)
U of T.
Global-scale teleconnections in the troposphere-stratosphere-mesosphere system
(Climate Processes)

SILVA, Carlos (DCMMP / DPMCM)
U. de Montréal
Excitons in lamellar polymeric semiconductors
(Molecular Electronics and Graphene)

SIMON, Christoph (DAMPhi-DCMMP-DOP-DTP-DSS / DPAMip-DPMCM-DOP-DPT-DSS)
U. Calgary
Quantum memories and quantum information processing with photons and atomic ensembles
(Quantum Information)

SINCLAIR, David (PPD)
Carleton U/TRIUMF
EXO - A Search for Neutrino-less Double Beta Decay in Xenon
(Neutrino Physics)

SINCLAIR, Tony (DIMP-DIAP / DPIM-DPIA)
U of Toronto
The Physics of Ultrasonic Nondestructive Evaluation
(Joint DIMP/DIAP Session)

SINGH, Dinesh (DTP / DPT)
U. of Regina
Assessing the Conceptual Challenges and Future of Quantum Gravity
(Quantum Gravity)

SLAVIN, Al (DPE / DEP)
Trent U.
Just-in-time-teaching: timely student feedback helps you come prepared for class
(Interactive Teaching, Teaching with Technology, and Curriculum Development)

SMOLYAKOV, Andrei **(DPP-DASP / DPP-DPAE)**
U. Saskatchewan
Zonal flows in plasmas and geostrophic fluids
(Plasmas in Laboratory and Astrophysical Environments)

SPANSWICK, Emma **(DASP / DPAE)**
U. Calgary
Auroral indicators of plasma sheet flow
(Magnetospheric Physics)

STAFFORD, Luc **(DPP)**
U. Montreal
Control of plasma-wall and plasma-substrate interactions in high-density plasma etching of complex oxides in reactive plasmas
(Plasmas at work in material science, medical and industrial applications)

STELZER-CHILTON, Oliver **(PPD)**
TRIUMF
Highlights from the CDF Experiment at the Tevatron Collider
(Collider Physics)

STOICHEFF, Boris **(DHP-DOP)**
U. Toronto
Early Canadian Development and Research in Laser Science
(History of the Laser in Canada)

TEUSCHER, Richard **(PPD)**
U. of Toronto
New High Energy Results from ATLAS at the LHC
(Collider Physics)

THEWALT, Michael **(DCMMP / DPMCM)**
SFU
Highly enriched ^{28}Si - the perfect semiconductor
(Semiconductor Materials and Devices)

THOMAS, Alec **(DPP-DOP)**
U. Michigan
Brilliant sources of x-rays from laser wakefield accelerators
(Relativistic laser plasma interactions and particle sources)

THOMPSON, Chris **(DPP-DASP / DPP-DPAE)**
U. Toronto
to be announced / à venir
(Plasmas in Laboratory and Astrophysical Environments)

TIEDJE, Tom **(DCMMP / DPMCM)**
U. Victoria
Growth and Properties of $GaAs_{1-x}Bix$: A Lattice Mismatched Semiconductor Alloy
(Semiconductor Materials and Devices)

TOKARYK, Dennis **(DAMPhi / DPAMip)**
UNB
Molecular spectroscopy using far-infrared synchrotron radiation from the Canadian Light Source
(Molecular Spectroscopy)

TORTOLI, Piero **(DIAP / DPIA)**
U. of Florence
Development and non-standard applications of a programmable ultrasound research platform
(DIAP session)

URQUHART, Stephen **(DIMP / DPIM)**
U. Saskatchewan
Chemical Microanalysis of Surfaces by X-ray Microscopy
(Instrumentation at the Canadian Light Source)

VAN LEIROP, Johan **(DCMMP / DPMCM)**
U. Manitoba
Magnetism in a macroscopic 3D nanoparticle-based crystal
(Magnetism)

VENUGOPAINA, Raju **(DNP / DPN)**
Brookhaven National Lab
to be announced / à venir
(Nuclear Matter under Extreme Conditions)

VIEIRA, Pedro **(DTP / DPT)**
Perimeter Institute for Theoretical Physics
Y-system for Scattering Amplitudes
(New Developments in Field Theory)

VITKIN, Alex **(DMBP / DPMB)**
OCI/U of Toronto
to be announced / à venir
(Medical Physics II)

WALTON, Mark **(DTP / DPT)**
U. Lethbridge
Non-standard walls in (phase-space) quantum mechanics from the Morse potential
(Mathematical Physics)

WANG, Xin-Nian **(DNP / DPN)**
Lawrence Berkeley
Magnetic properties of LuFe204+δ
(Nuclear Matter under Extreme Conditions)

WILKING, Michael **(PPD)**
TRIUMF
Status of the T2K Experiment
(Neutrino Physics)

WISEMAN, Paul **(DMBP / DPMB)**
McGill U.
to be announced / à venir
(Cellular Biophysics)

WOODS, A.D.B. **(DHP)**
AECL
Liquid Helium Research at Toronto and Chalk River in the 50s and 60s
(Research at Toronto and Chalk River: The beginning)

YAMANI, Zahra **(DCMMP / DPMCM)**
NRC
Evolution of the spin susceptibility near the superconducting critical doping in YBCO
(Spin Fluctuations and Superconductivity)

YETHIRAJ, Anand **(DMBP-DCMMP / DPMB-DPMCM)**
MUN
Novel forms of colloidal self-organization in external fields
(Biological and Soft Materials)

ZHANG, X-C **(DOP-DPP)**
Rensselaer
Air-plasma photonics: THz wave generation, detection, and its applications
(THz radiation: generation and applications)

BOOK REVIEW POLICY

Books may be requested from the Book Review Editor, Richard Hodgson, by using the online book request form at http://www.cap.ca. CAP members are given the first opportunity to request books. Requests from non-members will only be considered one month after the distribution date of the issue of *Physics in Canada* in which the book was published as being available (e.g. a book listed in the January/February issue of *Physics in Canada* will be made available to non-members at the end of March). We regret that we are no longer able to send books outside of Canada.

The Book Review Editor reserves the right to limit the number of books provided to reviewers each year. He also reserves the right to modify any submitted review for style and clarity. When rewording is required, the Book Review Editor will endeavour to preserve the intended meaning and, in so doing, may find it necessary to consult the reviewer. Reviewers submit a 300-500 word review for publication in PiC and posting on the website; however, they can choose to submit a longer review for the website together with the shorter one for PiC.

LA POLITIQUE POUR LA CRITIQUE DE LIVRES

Si vous voulez faire l'évaluation critique d'un ouvrage, veuillez entrer en contact avec le responsable de la critique de livres, Richard Hodgson, en utilisant le formulaire de demande électronique à http://www.cap.ca. Les membres de l'ACP auront priorité pour les demandes de livres. Les demandes des non-membres ne seront examinées qu'un mois après la date de distribution du numéro de la Physique au Canada dans lequel le livre aura été déclaré disponible (p. ex., un livre figurant dans le numéro de janvier-février de la PiC-PaC sera mis à la disposition des non-membres à la fin de mars). Nous regrettons qu'on n'est plus capable d'envoyer des livres ailleurs du Canada.

Le Directeur de la critique de livres se réserve le droit de limiter le nombre de livres confiés chaque année aux examinateurs. Il se réserve, en outre, le droit de modifier toute critique présentée afin d'en améliorer le style et la clarté. S'il lui faut reformuler une critique, il s'efforcera de conserver le sens voulu par l'auteur de la critique et, à cette fin, il pourra juger nécessaire de le consulter. Les critiques pour publication dans la PaC doivent être de 300 à 500 mots. Ces critiques seront aussi affichées sur le web ; s'ils le désirent les examinateurs peuvent soumettre une plus longue version pour le web.

BOOKS RECEIVED / *LIVRES REÇUS*

The following books have been received for review. Readers are invited to write reviews, in English or French, of books of interest to them. Books may be requested from the book review editor, Richard Hodgson by using the online request form at http://www.cap.ca.

A list of ALL books available for review, books out for review, and copies of book reviews published since 2000 are available on-line -- see the "Physics in Canada" section of the CAP's website : http://www.cap.ca.

Les livres suivants nous sont parvenus aux fins de critique. Celle-ci peut être faite en anglais ou en français. Si vous êtes intéressé(e)s à nous communiquer une revue critique sur un ouvrage en particulier, veuillez vous mettre en rapport avec le responsable de la critique des livres, Richard Hodgson par internet à http://www.cap.ca.

Il est possible de trouver électroniquement une liste de livres disponibles pour la revue critique, une liste de livres en voie de révision, ainsi que des exemplaires de critiques de livres publiés depuis l'an 2000, en consultant la rubrique "PiC Électronique" de la page Web de l'ACP : www.cap.ca.

GENERAL INTEREST

FLATLAND (AN EDITION WITH NOTES AND COMMENTARY), Edwin A. Abbott, William F. Lindgren, Thomas F. Banchoff, Cambridge University Press, 2009; pp. 294; ISBN: 978-0-521-75994-6 (pbk), 978-0-521-76988-4 (hc); Price: $15.00/50.

OUR PLACE IN THE UNIVERSE, Norman K. Glendenning, World Scientific Publishing Company, 2007; pp. 223; ISBN: 981-2-70068-4 (hc), 981-2-70069-2 (pbk); Price: 92hc/47pbk.

UNDERGRADUATE TEXTS

COMMUNICATING SCIENCE: PROFESSIONAL, POPULAR, LITERARY, Nicholas Russell, Cambridge University Press, 2009; pp. 324; ISBN: 978-0-521-11383-0 (hc), 978-0-521-13172-8 (pbk); Price: 99hc/32pbk.

QUANTUM MECHANICS WITH BASIC FIELD THEORY, Bipin R. Desai, Cambridge University Press, 2009; pp. 838; ISBN: 978-0-521-87760-2 (hc); Price: $95.00.

RELATIVITY, GRAVITATION AND COSMOLOGY: A BASIC INTRODUCTION (2ND EDITION), Ta-Pei Cheng, Oxford University Press, 2010; pp. 400; ISBN: 978-0-19-957364-6 (pbk), 978-0-19-957363-9 (hc); Price: 99hc/50pbk.

UNDERSTANDING FLUID FLOW, Grae M. Worster, Cambridge Unviersity Press, 2009; pp. 104; ISBN: 978-0-521-13289-3; Price: $24.99.

GRADUATE TEXTS AND PROCEEDINGS

A GUIDE TO MONTE CARLO SIMULATIONS IN STATISTICAL PHYSICS (3RD EDITION), David P. Landau and Kurt Binder, Cambridge University Press, 2009; pp. 463; ISBN: 978-0-521-76848-1; Price: $75.00.

DYNAMICS OF MARKETS: THE NEW FINANCIAL ECONOMICS, Joseph L. McCauley, Cambridge University Press, 2009; pp. 270; ISBN: 978-0-521-42962-7 (hc); Price: $75.00.

EXACT SOLUTIONS OF EINSTEIN'S FIELD EQUATIONS, H. Stephani, D. Kramer, M. MacCallum, C. Hoenselaers, E. Herlt, Cambridge University Press, 2009; pp. 701; ISBN: 978-0-521-46702-5 (pbk); 978-0-521-46136-8 (hc); Price: $90/199.

EXACT SPACE-TIMES IN EINSTEIN'S GENERAL RELATIVITY, Jerry B. Griffiths, Jiři Podolskŷ, Cambridge University Press, 2009; pp. 525; ISBN: 978-0-521-88927-8; Price: $125.00.

QUANTUM MEASUREMENT AND CONTROL, Howard M. Wiseman, Gerard J. Milburn, Cambridge University Press, 2009; pp. 460; ISBN: 978-0-521-80442-4 (hc); Price: $75.00.

QUANTUM THEORY AT THE CROSSROADS: RECONSIDERING THE 1927 SOLVAY CONFERENCE, Guido Bacciagaluppi, Anthony Valentini, Cambridge University Press, 2009; pp. 530; ISBN: 978-0-521-81421-8 (hc); Price: $126.00.

SCIENTIFIC COMPUTATION, Gaston H. Gonnet, Ralf Scholl, Cambridge University Press, 2009; pp. 236; ISBN: 978-0-521-84989-0 (hc); Price: $65.00.

STOCHASTIC PROCESSES IN PHYSICS AND CHEMISTRY, N. G. Van Kampen, Elsevier, 2007; pp. 463; ISBN: 978-0-444-52965-7 (pbk); Price: $126.50.

THE FUTURE OF THEORETICAL PHYSICS AND COSMOLOGY: CELEBRATING STEPHEN HAWKING'S CONTRIBUTIONS TO PHYSICS, G.W. Gibbons, E.P.S. Shellard and S.J. Rankin, Cambridge University Press, 2009; pp. 879; ISBN: 978-0-521-14408-7 (pbk); 978-0-521-82081-3 (hc); Price: $55/94.

THE STABILITY OF MATTER IN QUANTUM MECHANICS, Elliott H. Lieb, Robert Seiringer, Cambridge University Press, 2009; pp. 293; ISBN: 978-0-521-19118-0 (hc); Price: $50,00.

BOOK REVIEWS / CRITIQUES DE LIVRES

Book reviews for the following books have been received and posted to the Physics in Canada section of the CAP's website : http://www.cap.ca. When available, the url to longer versions are listed with the book details.

Des revues critiques ont été reçues pour les livres suivants et ont été affichées dans la section "La Physique au Canada" de la page web de l'ACP : http://www.cap.ca. Quand disponible, un lien url à une critique plus longue est indiqué avec les détails du livre.

ENSEIGNER DES CONTROVERSES, Virginie Albe, Presses Universitaires de Rennes, collection "Paideia", 2009, pp. 223, ISBN 978-2-753-50818-7 (Diffusion La Canopée).

Qu'il s'agisse de changements climatiques, de nouvelles énergies, de téléphonie mobile ou de nanotechnologies, les divergences de vues auxquelles on a longtemps assisté dans le cercle restreint des colloques scientifiques réservés aux savants et experts sont devenues progressivement des débats de société faisant la "une" dans les médias, et certains de ces débats ambivalents se sont même transportés dans les salles de cours. Ces nouveaux enjeux de société sont désormais identifiés en France sous le vocable de "Questions socialement vives".

Virginie Albe enseigne la didactique des sciences et des techniques à la fameuse École Normale Supérieure (ENS) de Cachan, en France. Pour son premier livre, elle propose de centrer les cours de sciences sur certaines controverses scientifiques et sur les débats de société qui en font l'écho. Cette approche pédagogique a l'avantage d'éviter de dire aux élèves qu'il existe une seule manière de penser et de concevoir tel problème lié à des enjeux de société comme la surpopulation ou le réchauffement climatique.

Dans sa préface, Andrée Tiberghien (du CNRS) se demande si les cours de science véhiculent toujours cette vision univoque et idéalisée d'une science infaillible et unanime qui la caractérisait pendant très longtemps : "la science enseignée et en particulier la physique a-t-elle suivi l'évolution de la citoyenneté?" (p. 7). S'inquiétant de la désaffectation récente de la jeune génération française envers les sciences physiques, Andrée Tiberghien rappelle en outre que "l'une des raisons du rejet de la physique par de nombreux élèves est liée à ce décalage entre les valeurs actuelles du citoyen et donc des jeunes et celles implicitement supposées de l'enseignement de la physique" (p. 8).

Virginie Albe reconnaît le caractère "idéologiquement chargé" des sciences (p. 112); elle conçoit que l'élaboration des sciences se fait habituellement "par consensus ou dissensus" (p. 122). Plusieurs exemples confirment qu'il est devenu plus difficile d'exposer en classe des notions de sciences et de techniques sans aborder du même souffle les doutes, les divergences de vues, les réticences d'une partie de la population à propos du téléphone mobile (p. 135); du réchauffement climatique (p. 138); ou sur la place des éoliennes dans le paysage (p. 144). Or, la recherche de Virginie Albe réalisée à partir de questionnaires auprès de divers groupes de jeunes élèves et à la suite de rencontres d'enseignants français démontre que ceux-ci mobilisent en réalité très peu de notions scientifiques et techniques pour "se faire une opinion" à propos des enjeux scientifiques, mais qu'ils restent généralement ouverts pour en apprendre davantage sur ces sujets (p. 146).

L'approche interdisciplinaire contenue dans Enseigner des controverses est richement documentée, proposant à la fois des stratégies pédagogiques destinées aux enseignants mais aussi des avenues théoriques et conceptuelles de pointe pour les didacticiens (à la fin du 3e chapitre et au 4e chapitre). En somme, Enseigner des controverses est un ouvrage stimulant et nuancé qui intéressera particulièrement les enseignants (actuels et futurs) en sciences et technologies désireux de connaître les tendances actuelles de la recherche didactique en France. On devine que certains de ces aspects existent déjà dans les institutions canadiennes ou pourraient y être transposés.

Yves Laberge, Ph.D.
Québec

PHYSICS IN DARWINISM AND ITS DISCONTENTS, Michael Ruse, Cambridge University Press, 2006; pp. 316; ISBN: 0-521-82947-X (hc); Price: $30.00.

Michael Ruse is a well-known historian and philosopher who has been prominent in defending Darwin in the creation/evolution debates. The preface states the purpose of this book: "Many people told me...that they could not see how any right-thinking person could be a Darwinian. This [book] is my answer to those people". The aim of this book, then, is to defend natural selection against not only the proponents of creationism and Intelligent Design, but also against other biologists like Gould and Lewontin who propose non-Darwinian modes of evolution. Thus, according to Ruse, it is natural selection – not genetic drift, not mass extinctions, not evo-devo, and certainly not supernatural intervention – which is the chief causal process in biology. In this book, Ruse aims to take on all pretenders.

Surprisingly, on page 2, Ruse even directs his invective against (some) physicists: "At the other end of the scientific spectrum, we now have physicists who tell us that their science can do it all for us—that there is no real need of natural selection. The laws of physics, unaided, can produce and explain everything worth knowing about organisms." Much later in the book (pg 159) we learn which physicists he is talking about. It is theoretical biologists like Brian Goodwin and Stuart Kauffman, who advocate that there are fundamental physical principles that determine the basic forms that organisms can take. In this sense, form is not merely adaptive, but is what it is because some underlying physical laws dictate the possible forms. As a physicist myself, I feel that Ruse is too dismissive of the importance of this approach. Darwinism (natural selection on variation) is merely a process that navigates the configurational landscape, analogous to a Monte-Carlo search algorithm. Darwinism in itself does not define what forms can exist to populate that landscape, so that it is at best half the story. Saying that it's all natural selection, there's nothing more to explain in biology is like saying that it's all Monte Carlo, there's nothing more to explain in high energy physics. There must be other principles that define the landscape that natural selection navigates and the forms that populate that landscape. Does thermodynamics not matter? Are the stable biological configurations not local minima of free energy in configuration space? Why is there a configurational landscape that is smooth enough to navigate in the first place? Worthwhile reading on these ideas can be found in Goodwin's book How the Leopard Changed Its Spots: The Evolution of Complexity and in Kauffman's book At Home in the Universe: The Search for the Laws of Self-Organization and Complexity.

My most serious criticism of this book is that I found it tedious to read, because Ruse frequently writes in a long-winded, meandering fashion, distracting the reader by leading him onto tangents of questionable relevance. This is especially true in the first seven chapters, which contain most of the scientific discussion. He would do better to just focus the reader's mind on a small number of simple, crisp arguments. For example, on page 38, when bio-geographical distribution is introduced as evidence for evolution, Ruse could have asked a few pointed questions such as “Why are marsupials and not mammals found in Australia, if it were not for an ancestral marsupial first reaching Australia and populating that continent in isolation from the others? Why do New Zealand and Madagascar, which are geographically isolated, have unique life-forms found nowhere else? Why is geographical isolation so strongly correlated with biological uniqueness, if evolution were not true?” Instead, we are treated to a long, boring quote from Darwin's book from the 19th century, which may be of historical interest, but is not in itself the best presentation of the biogeographical evidence for evolution. In far too many places, there are secondary asides inserted into the middle of already too-long sentences to further confound the reader. At the bottom of page 99, for example, we read this convoluted sentence: “Even if we agree that much of the classificatory procedure is not evolutionary – although today, surely, in many branches (especially those with some fossil record) it is going to be difficult to separate out what is not evolutionary from what is – this does not mean that classification has no relevance to evolution, or that evolution has no relevance to classification.” Stronger editorial oversight is badly needed to prune away the extraneous details and to just cut to the chase! If reader is seeking a clear presentation of the scientific evidence for evolution, there are more lucid books available.

The best part of the book is to be found in chapters 8 to 12, where the content is more philosophical rather than scientific. Here, Ruse the philosopher comes to the fore. Chapter 8, “Fact or Fiction” tackles some of the alleged implications of biological Darwinism: the inevitability of progress, social Darwinism and the moral implications of Darwinism. Chapter 9 deals with honesty and dishonesty in science. The discussion of Darwin vs. Wallace regarding the credit for the theory of natural selection, Haeckel's inaccurate pictures of embryonic development, and the hoax of Piltdown man, make for entertaining reading. In Chapter 10, Ruse pursues his stance that “if we humans are an end product of a long, slow, law-governed process of natural selection rather than the favored of God created miraculously on the Sixth Day, Darwinism simply has to be relevant to philosophy” (pg. 237). Chapter 11, entitle “Literature” explores how the views of several literary figures relate to Darwinism. Samuel Butler, George Bernard Shaw, H.G. Wells, Herbert Spencer and Ian McEwan are some of the authors critiqued. Issues of social Darwinism and determinism are addressed here. Chapter 12, “Religion”, deals with the religious implications of Darwinism. I found this to be a fair-minded, respectful treatment of the interface between Darwinism and Christian faith; as a former Christian himself, Ruse obviously retains respect for those of faith, in contrast to other writers like Richard Dawkins.

In summary, this book will be of greatest interest for readers of a more philosophical bent who want to read one philosopher's defense of Darwinism and his views on its social and philosophical implications.

Stanley Yen
TRIUMF

FUNDAMENTALS OF PLASMA PHYSICS, Paul M. Bellan, Cambridge University Press, 2008; pp. 609; ISBN: 978-0-521-52800-9 (pbk); Price: $75.00.

As a natural product of his graduate course at Caltech, Professor Paul Bellan wrote this elegant textbook. He employed powerful, but as simple as possible, mathematical techniques in the book to help readers get deeper insights into plasma behaviours relevant to diverse plasma applications in fields of, e.g., controlled fusion, cosmic and space plasmas, and experimental plasmas.

The book contains 17 chapters and three appendices. The first three chapters (1-3) introduce basic plasma concepts, equations from Vlasov, two-fluid, and MHD models, and classical theories on single particle motion with particular attention to adiabatic invariance. The next five chapters (4-8) examine types of plasma waves and the issue of Landau damping, including elementary plasma waves, streaming instabilities and the Landau problem, cold plasma waves in a magnetized plasma, waves in inhomogeneous plasmas and wave energy relations, and the Vlasov theory of warm electrostatic waves in a magnetized plasma.

Chapters 9 to 12 focus on fundamental magneto-hydrodynamic (MHD) theories and hot topics, such as, MHD equilibria, stability of static MHD equilibria, magnetic helicity, self-organization, and magnetic reconnection. In particular, chapter 13 exposes the Fokker-Planck theory of collisions. After that, all the following chapters (14-17) provide an extensive picture to readers about modern topics in plasma physics, e.g., wave-particle / wave-wave nonlinearities, non-neutral and dust plasmas. The appendices list vector calculus identities, vector calculus in orthogonal curvilinear coordinates, and frequently used physical constants and formulae.

However, I would like to mention a few shortcomings found in reading the book. Firstly, there is a lack of time-dependent MHD theories in the text, though relevant experiments are mentioned. Secondly, an important concept, the magnetic Reynolds number is missing, though this parameter is indispensable in dealing with the effects of magnetic advection and diffusion. Lastly, a popular subject, nonlinear solitary waves in a cylindrical geometry, is not included, even a word.
In general, this book can be used as a good reference for undergraduates and graduates.

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GEOMETRY AND TOPOLOGY, Miles Reid and Balazs Szendroi, Cambridge University Press, 2005; pp. 196; ISBN: 0-521-61325-6 (pb)0-521-84889-X (hc); Price: $45/95.

This introductory undergraduate level book actually dedicates more than half of its chapters towards geometry. The authors start with a thorough introduction on Euclidean and non-Euclidean geometry, including spherical and hyperbolic geometry, affine and projective linear geometries. As a side, you will learn some basics of group theory as the authors utilized the Erlangen program to unify geometry and group theory. The Erlangen program simply studies the invariant properties of a geometric system under a certain set of transformations, i.e. a group of transformations. This is important as special relativity utilized the same idea of invariance to study geometric system properties that are invariant under the Lorentz transformation group.

Building on that, topology is introduced as the study of some invariant properties of a certain mathematical space. Topics on topology are elementary and scratch the surface of how topology applies to physics, in particular there is a big chunk on particles and spin.

Geometry and Topology uses a typical mathematically rigorous language for theorems and proofs but is made very easy to understand with copious graphical illustrations, examples and exercises at the end of each chapter, with hints for the readers. This book is based on years of teaching experience, mostly on a second year module taught at Warwick with an informal writing style similar to Introduction to Quantum Mechanics by David J. Griffiths., with words in the book like “I” referring to an imaginary teacher, and “you” referring to you as the student. You will find this fun and will hardly get lost at any page.

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PHYSICS FOR DUMMIES, Steven Holzner, John Wiley & Sons, 2009; pp. 360; ISBN: 0-764-554-336 (pbk); Price: $25.99.

'Physics for Dummies' by Steven Holzner, PhD, aspires to be your 'plain-English guide to everything from relativity to supernovas'. It's written in the clear, familiar voice characteristic of the For Dummies series. There are three audiences in particular that may appreciate such an approach: a senior high school or first year college /university student (particularly, a non-physics major) to consider as a nice assist; for the general interest, pleasure reading public, as either first contact with the material or to help brush up on old lessons; and the third group was my own position, an instructor looking for tips, tricks, and insight into presenting material to students and getting back into a beginner's frame of mind.

Holzner presents his assumptions that his readers have no previous physics knowledge, but are versed in at least some algebra and trigonometry. However, he does provide the uninitiated with a very brief introduction to algebra, trigonometry, and vector basics.

There are twenty-two chapters in all covering the range of topics in kinematics, work-energy, thermodynamics, electricity and magnetism, and bonus chapters such as "ten amazing insights on relativity". Conservative vs. non-conservative forces, Hooke's Law, specific heat capacity, the laws of thermodynamics, Lenz's Law; it's all here, in small digestible bits with humorous examples.

Holzner has done an exceptional job at summarizing concepts neatly and with pleasant prose. The strength of the book is in the ease of the explanations; a student struggling with lessons in a textbook may find Physics for Dummies a nice, light, easy read to help them process some basic ideas and relationships. Each 'Big Idea' is presented with usually just one or two examples. These explanations and examples are far from rigorous; however, neither are they cursory or trivial. The odd subtlety is explored, along with tips and cautionary remarks for things that normally trip people up.

Someone who hasn't had their head in the subject matter for some years might find this a compact little refresher of introductory level physics. If everyone who studied first-year university physics understood and remembered this much, it would be truly impressive! They might even like to try and tackle the additional problems in the companion workbook available. As for myself, personally I was left unsatisfied with the brevity and simplicity, but this treatment of the material did well to emphasize what are the main ideas that I would like my students to know, and it gave me a few cute examples to help explain them.

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PHYSICS OF SPACE PLASMA ACTIVITY, Karl Schindler, Cambridge University Press, 2006; pp. 508; ISBN: 978-0-521-85897-7 (hc); Price: $80.00.

This monograph presents studies of more than 30 years in the past on space plasma activities pioneered by the author and his colleagues, along with a substantial body of relevant results drawn from the work of others. It provides a thorough insight into the physics of large-scale plasmas beyond the scope of our Solar System. The text is concise and easy to read, and a lot of references are cited.

In the book, there are four main parts following an introductory chapter 1: Part I. Setting the scene; Part II. Quiescence; Part III. Dynamics; and Part IV. Applications. At the end, there are three appendices.

Part I contains two chapters. Chapter 2 introduces sites of activity in geospace, the solar atmosphere, and other places. Chapter 3 describes basic plasma models, such as kinetic models, fluid models, and discusses the validity of MHD models, electron MHD, conservation laws, and discontinuities. Part II consists of four chapters: Chapter 4. Introduction; Chapter 5. Magnetohydrostatic states; Chapter 6. Particle picture of steady states; Chapter 7. A unified theory of steady states; Chapter 8. Quasi-static evolution and the formation of thin current sheets.
In Part III, efficient background materials are chosen to elucidate the dynamic processes. It is comprised of four chapters. Chapter 9 introduces non-ideal effects, including generalized Ohm's law, resistivity, micro-turbulence, and non-turbulent kinetic effects. Chapter 10 emphasizes several macro-instabilities, e.g., the ideal MHD stability, resistive tearing instability, collisionless tearing, etc. Chapter 11 is dedicated to 2D and 3D magnetic reconnection models. Chapter 12 demonstrates aspects of bifurcation and nonlinear dynamics. It deserves to mention that an important topic, self-organized criticality, is also covered in this chapter.

By contrast to previous Parts, Part IV is easy to read because it contains few mathematical derivations. To some extent, it looks like a series of physical review articles divided into three chapters. Chapter 13 and 14 discusses magnetospheric and solar activities, respectively, whereas Chapter 15 points out the problem of the reconnection model and depicts a general eruption scheme. Finally, the appendices describe the derivations of the unified theory, the principle for collisionless plasmas, and fundamental constants and symbols.

The book contributes to readers an exhaustive resource about the fundamentals of activity in space plasmas. However, in my view, it is not a reference for beginners without basic mathematical techniques and some knowledge of plasma physics, but is intended for high-level graduate students, professors, and scientists.

John Z. G. Ma
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PRINCIPLES OF MAGNETOHYDRODYNAMICS WITH APPLICATIONS TO LABORATORY AND ASTROPHYSICAL PLASMAS, Hans Goedbloed and Stefaan Poedts, Cambridge University Press, 2003; pp. 613; ISBN: 0-521-62607-2 (pbk); Price: $70.00.

Professors Goedbloed and Poedts offer an excellent and classic textbook on the magnetohydrodynamic (MHD) theory in plasma physics at all levels from laboratory to astronomical sites. The contents are extremely comprehensive, coherent, and rigorous with sufficient, well-knitted physical analyses, mathematical methods, and typical examples.

The book includes two parts: introduction to fundamental plasma physics, and MHD theories and their applications. In the first part, the authors used three chapters to guide readers into necessary preliminaries of plasma physics, such as, basic concepts of plasmas (chapter 1), elements of plasma physics (chapter 2), and the origin of macroscopic equations (chapter 3). In the second part, they made use of the following 8 important chapters to exhibit a comprehensive picture of MHD theories, along with applications in studies of both laboratory thermo-nuclear fusion and cosmic plasma processes happening in our universe.

These chapters are categorized as follows: Chapter 4 exposes MHD models under various conditions. The conservation laws are discussed in great detail. Chapter 5 derives basic MHD waves and instabilities in homogeneous plasmas, and describes their properties. Phase and group diagrams are treated using the dispersion equation of wave phenomena. Chapter 6 continues to treat these waves and instabilities in view of spectral theory. The force operator of formulation and the energy principle are extensively discussed. Chapter 7 develops the spectral approaches to inhomogeneous plasmas. In particular, equations for gravito-MHD waves are solved under various limits. Chapter 8 illustrates enormous magnetic structures and bulk magnetic phenomena and their dynamics in astrophysics, especially in the solar system. Chapter 9 treats waves and instabilities in a cylindrical geometry, and presents the stability analysis of diffuse plasmas from the spectral perspective. Chapter 10 concentrates on one-dimensional initial value problems and related wave damping in inhomogeneous plasmas. Finally, Chapter 11 introduces resonant absorption and phase mixing, linked to the wave heating in solar and stellar coronae. At the end of the book, vector identities, coordinate systems, and the usual physical quantities are listed in two appendices.

This book provides effective methods and insights in the interpretation of MHD phenomena on all scales. It is an extraordinary reference for undergraduates, graduates, and professors in physics, space/planetary physics, and astrophysics.

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THE TROUBLE WITH PHYSICS, Lee Smolin, Thomas Allen Publishers, 2007; pp. 392; ISBN: 978-0-618-91868-3 (pbk); Price: $19.95 Cdn.

Smolin's book on `The Trouble with Physics' makes some bold claims on how string theory is stagnating theoretical physics and how, in fact, string theory isn't really science at all!

Smolin begins by dividing the current state of theoretical physics into five main problems: (1) quantizing gravity; (2) making sense of quantum mechanics; (3) unify the forces and particles of nature; (4) explain the constants of nature; and (5) explain dark matter/energy. He summarizes in an accessible fashion the previous century in physics leading to these questions. From there, he presents his personal, and arguably biased, account of the development of string theory and how it addresses these five fundamental problems of physics. He attempts to explain how a field could attain such widespread acceptance while devoid of experimental verification. He introduces the very uncomplimentary notion of `groupthink' and suggests an overly hierarchical structure amid string theorists, and theorists in general. Their combined effects quickly discourage incoming scientists from introducing fresh innovative ideas and, instead, if they're to advance in physics, they're forced to work on the very same problems as their superiors and therefore everyone else.

The last part of the book follows an interesting analysis of "what is science" starting with a firm basis in the theories of Popper (science must be falsifiable) and progressing into, for instance, the theories of Feyerabend who "attacks the whole idea that method is the key to scientific progress, by showing that at critical junctures scientists will make progress by breaking the rules". As a young scientist myself, I found discussion nicely refreshing.

Smolin closes the book with suggestions for reversing the degenerative trends of theoretical physics. He criticizes the peer review system in place in large funding agencies and hiring committees; but without a good alternative, I suspect that there is no hope of replacing it. He notes that academia has systematically preferred strong `craftsman' over the so-called `seers' of physics, those who may be slower at straight computation but will offer startling ideas and advances. I find it hard to accept when he suggests that to find such `seers' we should in fact turn to the older generation to choose them after he has spent the book exposing the dangers of always pleasing the older generation, as in string theory.

Overall, I must conclude that the book remains a fascinating read. A summary of the developments within a field is extremely difficult to write, particularly when the story is far from finished, and yet, Smolin's exposition is well done and interesting. But perhaps more importantly, it may serve to guide further developments within string theory and related fields, and as a lesson to other fields in science. It keeps us accountable to the general public and to our fellow scientists. The book has met with much skepticism, and downright outrage in a few cases, but at the very least it has generated some much needed discussion on the deeper ideas and workings of theoretical physics.

Lara Thompson
University of British Columbia

THERE'S STILL TIME

IL Y A ENCORE DU TEMPS

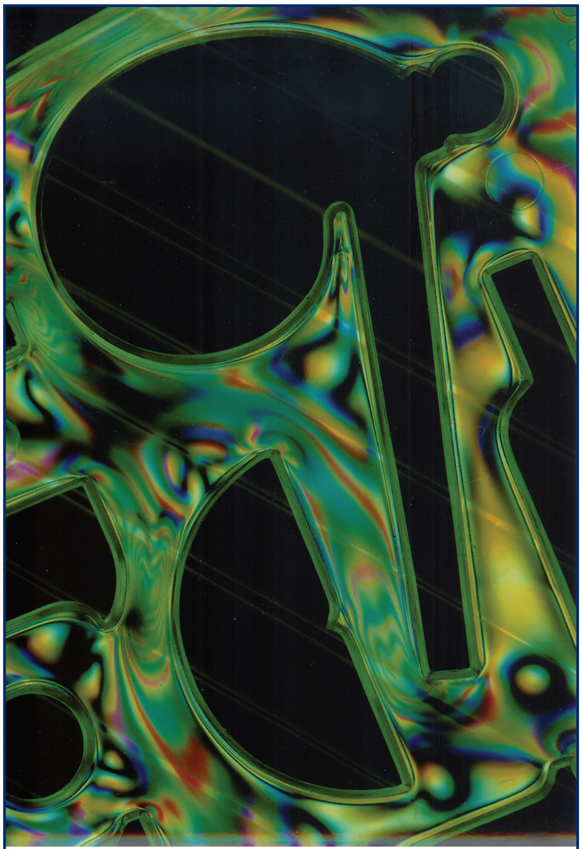
ART OF PHYSICS COMPETITION

You are invited to enter the competition by capturing in a photograph a beautiful or unusual physics phenomenon and explaining it in less than 200 words in terms that everyone can understand.

The emphasis of the contest is not so much on having a high level of physics comprehension as it is on being able to explain the general principle behind the photograph submitted. Individual (open and high school) and high school class entries are invited up untilApril 30, 2010 (see http://www.cap.ca /en/activities/art-physics for entry form/rules). Please note that all entries must be original artwork produced by the participant.

Winning entries will form part of our Art of Physics exhibition which will be on display at the Canada Science and Technology Museum, and may appear as a cover on our publication, *Physics in Canada.* They will also be posted on our Art of Physics website at http://www.cap.ca.

We hope you will take advantage of this opportunity to explore the art of physics by submitting entries for the 2010 competition.



2nd Prize (Open Category) , 2005 competition
by Jean-Luc Riendeau, Québec, QC

CONCOURS L'ART DE LA PHYSIQUE

Vous êtes invités (es) à participer en photographiant un phénomène physique magnifique, ou particulier, et en rédigeant un court texte explicatif de moins de 200 mots, en termes simples et à la portée de tous.

L'accent de ce concours est de pouvoir expliquer le principe général de la photo soumise plutôt que de démontrer un niveau élevé de compréhension de la physique. L'échéance pour les inscriptions individuelles (ouvert et école secondaire) et scolaires (voir formulaire d'inscription/règlements à http://www.cap.ca/fr/activites/lart-de-physique) est fixée au 30 avril, 2010. Notez bien que toutes les inscriptions doivent être des oeuvres originales du participant ou de la participante.

Les articles gagnants feront partie de notre exposition L'Art de la physique au Musée des sciences et de la technologie du Canada et auront une chance de paraître sur la couverture d'un numéro de *La Physique au Canada*. Ils seront également affichés sous la rubrique L'Art de la physique du site web de l'ACP à l'adresse suivante: http://www.cap.ca.

Nous espérons que vous profiterez de cette occasion d'explorer l'art de la physique en faisant de cette inscription un travail pour l'année 2010.

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