Chalk River Laboratories

NRCan and DFAIT Visit

2000 August 31

National Research Council Canada
Conseil national de recherches Canada

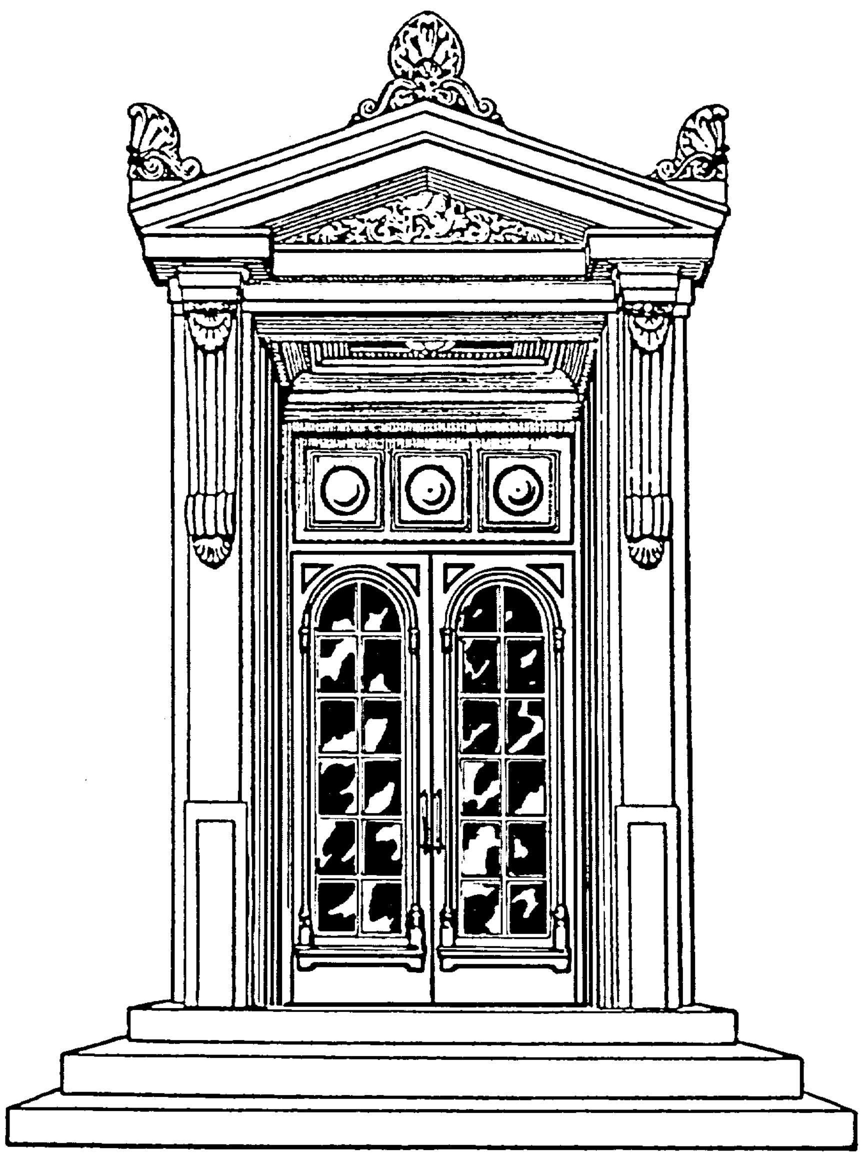
.b3576796(E)

NRC · CNRC

Steacie Institute for Molecular Sciences
Institut Steacie des sciences moléculaires

The fundamental things apply

Un rôle fondamental



Steacie Institute for Molecular Sciences

Institut Steacie des sciences moléculaires

National Research Council Canada | Conseil national de recherches Canada

NRC · CNRC

Canada's leading research organization

Canada

Canada's leading research organization

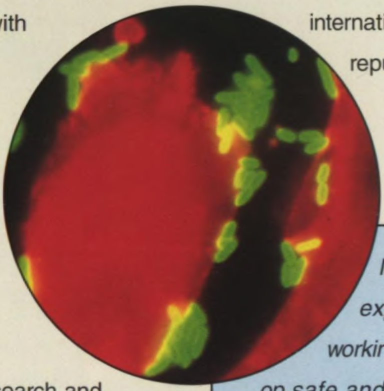
The National Research Council, Canada's pre-eminent national research and development organization, is a major force in the Government of Canada's drive to build a strong national system of innovation and a vibrant knowledge-based economy. In laboratories and offices from coast to coast, NRC's specialized staff works with partners from industry, government, and universities to explore new ideas and find new answers.

Our vision is to help create wealth, jobs and prosperity for Canadians by linking NRC's outstanding research capabilities with S&T, business and finance to forge a powerful national system of innovation.

Since its creation in 1916, NRC has sought to improve life for Canadians by performing and supporting research and development in the national interest. This proud history includes critical contributions to canola, the Canadarm, the world's first heart pacemaker, radar, cancer treatment, the development of new energy sources, revolutionary advances in transportation technology, agriculture, and many of our country's greatest scientific and technical achievements.

Today NRC's 16 research institutes provide Canada with the resources needed to explore strategic technologies by forging alliances for collaborative research, and by creating consortia, partnerships and special interest groups. New NRC Technology Centres operate like businesses, earning revenue and working with industrial clients seeking national and international business.

NRC's research and technology programs are linked to Canada's innovation priorities and respond to the identified needs of industrial, academic and public sector clients and partners. They focus on key and strategic technologies needed for Canada's current and future economy such as biotechnology, construction, manufacturing and information technologies. These are areas where NRC has distinctive competencies, recognized research leadership and international reputations.



NRC experts are working to develop safe and effective anti-infective agents to block bacterial pathogens from invading human cells and causing infectious diseases.

NRC researchers work with major Canadian high-technology firms to develop ultra-fast semi-conductors that will run the computers and telecommunications devices of the future.

These capabilities are delivered by NRC's institutes in partnership with firms, universities, public institutions and governments across Canada in its regions and communities. NRC is a focal point for innovation and a carrier for technology, creating new and more internationally-competitive firms, economic growth and jobs in Canada's community innovation systems.

In addition, NRC provides expertise, technical advice, testing and calibration services; maintains facilities crucial to research in astrophysics, ocean engineering, and the aerospace industries; establishes national standards; and provides vital expertise in the fundamental field of molecular sciences.

Canada's top source of industrial technology assistance

In addition to facilities, and the expertise, licensing and collaborative research opportunities offered by its research institutes, NRC provides Canadian firms with on-site technology assistance and access to funding through its national network of over 250 Industrial Technology Advisors delivering NRC's highly acclaimed Industrial Research Assistance Program (IRAP).

The IRAP Network

IRAP helps small and medium-sized Canadian firms improve their operations and bring new products to market by putting them in touch with appropriate sources of technology and expertise in Canada and abroad. IRAP advisors are located in almost 100 organizations across the country and collectively offer clients a remarkable range of professional skills, expertise, and experience.

The network of public and private organizations linked through IRAP represents a powerful resource that not only delivers valued service to more than 10,000

More than 250 advisors in NRC's Industrial Research Assistance Program work in communities from coast to coast.

firms each year, but also ties together most of Canada's technological resources in a coherent national system.

Linking with CTN — the Canadian Technology Network

IRAP helps ensure that its clients have access to the full range of services needed to increase their competitive edge by linking them to the Government of Canada's Canadian Technology Network — an easily accessible alliance of people who help small and medium-sized businesses solve technology and innovation problems.

Canada's largest S&T information service

NRC's Canada Institute for Scientific and Technical Information (CISTI) is one of the world's leading sources for scientific, technical and medical information. Information specialists, a range of electronic products, and a vast collection of published information make it an invaluable resource for Canada's R&D community — a national system of scientific information unequalled anywhere.

CISTI Services

CISTI provides a wide range of services including

- information searches to provide precise information on any scientific or technical topic
- copies of articles, reports, conference proceedings or books from around the world
- electronic information tools that increase efficiency and productivity.

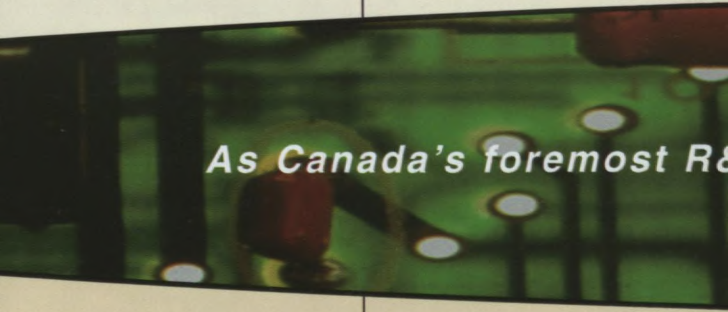
NRC Research Press

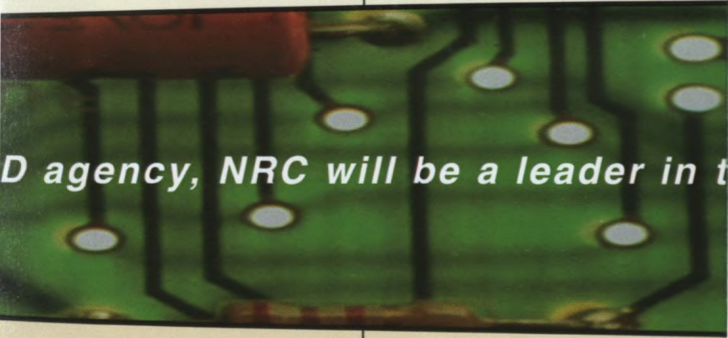
CISTI is also Canada's leading publisher of scientific and engineering journals with 14 internationally renowned titles in science and engineering.

Making an Impact

Thawing and repairing frozen water service lines can cost Canadian municipalities millions of dollars annually. Working with the Regional Municipality of Ottawa-Carleton, NRC researchers have come up with a simple solution: the lines can be protected by covering them with an insulating layer of plastic chips made from recycled yogurt and margarine containers. Not only does the municipality save money on maintenance, but it is able to reuse a material readily available through its consumer recycling program.

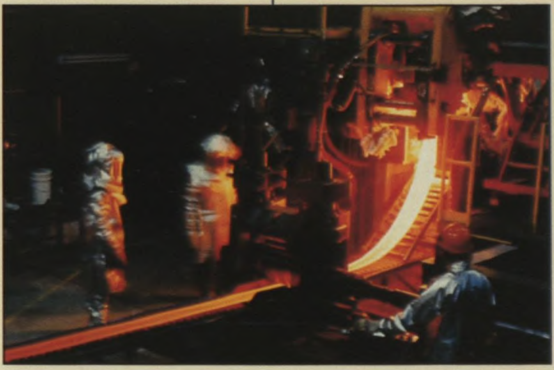
NRC is working with Spar Aerospace Ltd., Atomic Energy Canada Ltd. and the Canadian Space Agency to develop computer software that will create digital images of heavy equipment and the work sites where they operate — in full, three-dimensional detail. This emerging technology, known as a virtual environment for remote operations (VERO), uses a 3D laser camera invented and patented at NRC. With VERO, remote operations like hazardous waste site inspections will be made simpler, safer and more cost-effective.

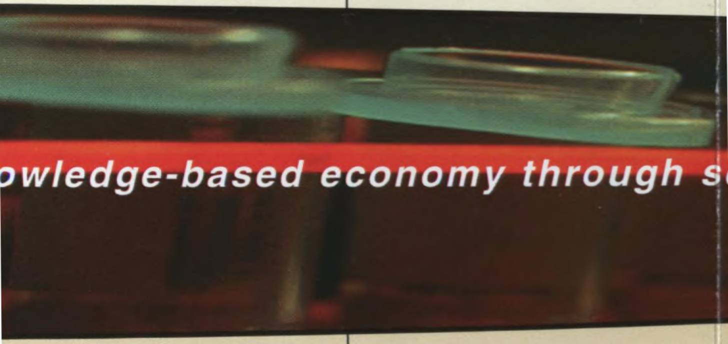




Throughout the 20th century NRC researchers have played a key role in Canada's major scientific successes. One example is NRC's role in canola, an edible food crop and now a multi-billion-dollar industry. An important breakthrough in the development of canola came when NRC successfully applied gas-liquid chromatography to the analysis of seed oils. Plant breeders were then able to work on reducing erucic acid in rapeseed to eliminate any health risks. Today, NRC scientists are adding value to canola using new biotechnology techniques that create plant strains resistant to herbicides and diseases.

NRC is working with a consortium of Canadian steel companies to develop a new method for manufacturing flat rolled products like steel sheets. This strip casting process, which produces a thin strip directly from liquid metal, has the advantage of partially, if not completely, eliminating hot rolling. With lower operating costs, this process will allow mills to offer high-quality semi-finished steel products at a very competitive price and tailor production to client or market needs.





NRC's expertise in aerospace research recently helped a Windsor-based business refine its technology for detecting barely visible defects on the surfaces of aircraft. Diffracto Ltd. now markets D Sight™ Aircraft Inspection Systems (DAIS) to major civil and military carriers. The greatest advantage of DAIS is its speed: inspections of typical transport jet aircraft exteriors that used to take over 250 hours can now be done in about 25 hours. Thanks to NRC's support, Diffracto entered the aerospace industry with a technology that will enhance safety and lower maintenance costs.

NRC's Canada Institute for Scientific and Technical Information

In recent years, CISTI has enhanced its services through innovative uses of the Internet and a number of national award-winning initiatives. These include *Romulus*, a ground-breaking CD-ROM that includes a novel telecommunications system as well as an electronic catalogue of serial publications in Canadian libraries, and *Intellidoc*, an integrated, electronic document ordering and delivery system that responds to some 1500 document requests from around the world each day.

NRC's Industrial Research Assistance Program

Fulcrum Technologies Inc. of Ottawa controls about 30 per cent of the world market in text retrieval software, a powerful search engine that gives fast and accurate access to massive amounts of information. Many major corporations have chosen Fulcrum products for their speed and ease of use. The company credits much of its success to advice and support from NRC's Industrial Research Assistance Program (IRAP). In the words of Fulcrum CEO Eric Goodwin: "IRAP deserves a lot of credit for helping us when we needed it."

NRC Research Institutes

Biotechnology Research Institute
Herzberg Institute of Astrophysics
Industrial Materials Institute
Institute for Aerospace Research
Institute for Biodiagnostics
Institute for Biological Sciences
Institute for Chemical Process and Environmental Technology
Institute for Information Technology
Institute for Marine Biosciences
Institute for Marine Dynamics
Institute for Microstructural Sciences
Institute for National Measurement Standards
Institute for Research in Construction
Integrated Manufacturing Technologies Institute
Plant Biotechnology Institute
Steacie Institute for Molecular Sciences

NRC Technology Centres

Canadian Hydraulics Centre
Centre for Fluid Power Technology
Centre for Surface Transportation Technology
Thermal Technology Centre

For more information, please contact
National Research Council of Canada
Corporate Communications
Ottawa K1A 0R6

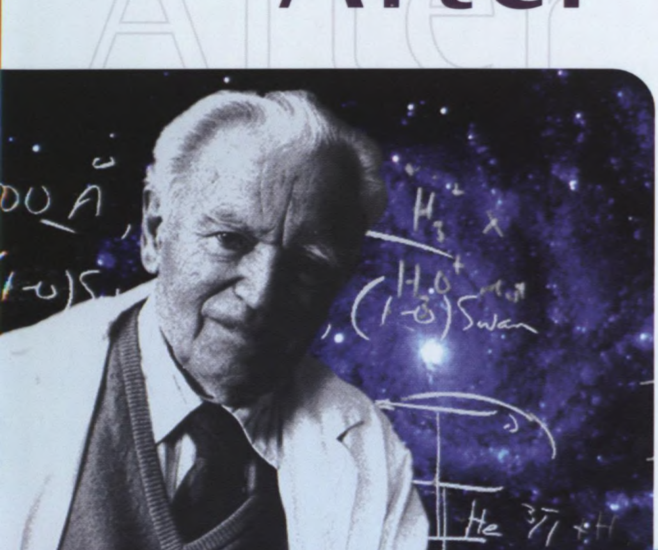
Telephone (613) 993 3041
E-mail: R&D@NRC.CA
Internet: WWW.NRC.CA

National Research Council Canada
Conseil national de recherches Canada

NRC · CNRC

Made in Canada, thanks to NRC

Time After Time



Canada

1916-2000+

NRC Takes its Place

1916-27

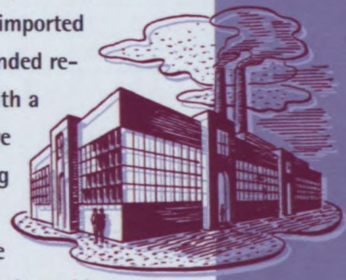
IN 1916, CANADA IS 49 YEARS OLD. WORLD WAR I (1914-18) IS RAGING, AND MANY CANADIANS ARE SERVING OVERSEAS.

Since 1916, NRC has worked with governments, universities and industry to push the limits of science and technology for the benefit of Canadians and people around the world. NRC has done amazing things. NRC still does.

Here are just a few examples.

Heavy Metal

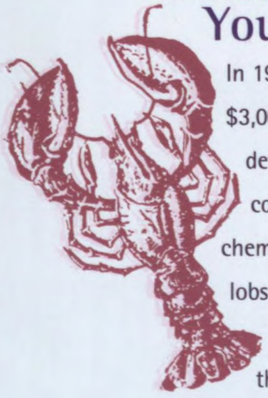
Magnesite, used as a lining in high-temperature steel furnaces, was imported for years. NRC-funded researchers came up with a simple and inexpensive way of eliminating impurities from domestic magnesite ore, so that Canada could cut its dependence on imports.



Steam Saves Concrete

In the early 1920s, concrete structures in western Canada were falling apart. Two researchers at the University of Saskatchewan knew that chemicals in ground water were weakening the concrete. In 1926, with NRC support, they developed a steam curing technique that made the concrete more resistant to ground water damage. The discovery saved millions in construction and repair costs.

What Colour's Your Lobster?



In 1920, scientists used about $3,000 in grants from NRC to devise a method that used a combination of heat and chemicals to stop canned lobster meat from discolouring. Their research saved the lobster canning industry at least $75,000 a year.

Talented Canadian scientists and engineers have done a lot to make Canada a great place to live. The National Research Council has given many of them the chance to turn their ideas into new products or processes that help make life better.

milestones

- Substitute fuels
- Improved fog signals for ships
- Better grading of dairy products
- Cold-weather research
- Studies of infrared, ultraviolet and ultrasonic rays

New Home, Dark Times

1928-32

NRC MOVES INTO ITS NEW LABS. THE 1929 STOCK MARKET CRASH LEADS TO THE GREAT DEPRESSION.

It's a Gas

In the early 1930s, NRC researchers did important work on converting waste natural gas from western Canada into new and useful products such as antifreeze, synthetic rubber, and benzene, a chemical used to make such things as insecticides, detergent, and motor fuels.

TB Research

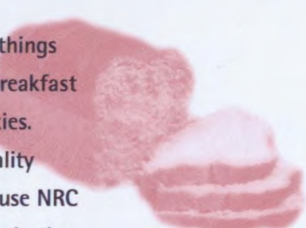
From 1924 to 1938, some of the best medical researchers in the country worked with NRC to find a vaccine against tuberculosis (TB). Their work helped make the BCG vaccine the main weapon against a disease that for years was one of the leading causes of death for people aged 20 to 50 in Canada.

Super Inventor

George Klein (1904-1992), a Canadian inventor and a longtime NRC employee, produced an almost endless list of inventions. He designed NRC's first wind tunnels, and invented such useful things as aircraft skis, an electric wheelchair for quadriplegics, a microsurgery staple gun, and a retractable antenna that is still standard equipment on satellites.

M-m-m Good!

Many of the good things we eat are made from wheat, like bread, spaghetti, breakfast cereal, muffins and cookies. Canada has the best quality wheat in the world because NRC brought experts together in the 1920s and 1930s to develop wheat varieties that would resist "rust", a disease that sometimes used to wipe out entire crops.



milestones

• Improved food storage techniques • Tastier maple syrup • First edition of Canadian Journal of Research

The Road to War and Beyond

1933-45

DROUGHT MAKES BAD TIMES WORSE. DICTATORS IN EUROPE AND ASIA PUSH THE WORLD TOWARD THE SECOND WORLD WAR (1939-1945).

NRC played an important part in the development of radar during the Second World War. Radar ("radio distance and ranging") helped win the war for the Allies. Today, radar is still in use to make travel safer by air, land and sea.

Scanning the Skies

Medical Miracles

Before World War II began, NRC enlisted Sir Frederick Banting, the discoverer of insulin, to lead research on combat-related medicine. Banting's team did important work on wound infections, shock, penicillin, a typhus vaccine, blood substitutes, and plastic surgery.

NRC Streamlines Locomotive

In 1936, Canadian National Railways introduced a stream-lined steam locomotive that used one third the energy, and kept the engine cabin clear of smoke. Many of the design improvements were suggested by NRC engineers from results of scale-model tests that began in 1931 in NRC's wind tunnels.

Bringin' Home the Bacon

Bacon shipped to wartime Britain used to be preserved in a mix of salt and borax, which made it barely edible. NRC biologists and engineers produced a unique refrigeration system for ships carrying bacon and other meats. It is estimated that more than one-fifth of the meat shipped to Britain was refrigerated in the NRC-designed units.

milestones

- New explosives
- Wartime food substitutes for eggs and bacon
- Transport ship refrigeration
- Improved cold weather jet performance

Baby and Other Booms

1946-52

POST-WAR ECONOMIES TAKE OFF, AND SO DOES THE BABY BOOM.

In 1951, Canadian scientists first used cobalt-60 supplied by NRC to treat cancer. The apparatus used in the treatment, nicknamed the cobalt bomb, was soon in operation in cancer clinics around the world. Today, Canada produces about 85 per cent of the world's supply of cobalt-60.

The Cobalt "Bomb"

They Found Us!

NRC's Harry Stevinson spent many years developing a reliable emergency locator beacon for downed aircraft. In 1957 the Crash Position Indicator was introduced for military use, and by 1960 was available for commercial aircraft. The CPI breaks free on impact, and sends a distress signal even if buried in snow, lying upside down or floating on water.

Hi Grandpa,

good to see you again. Grandpa wears a heart pacemaker. The technology that made it possible was developed by NRC in the late 1940s by Dr. Jack Hopps. That means millions of people like Grandpa can now live better, longer lives.

A Boost to Research

Rapid postwar economic expansion had a major impact on science and technology research in Canada. In 1951, NRC's investment in research grants and fellowship programs was more than five times what it had been in 1945. The NRC funding programs supported research that helped build a stronger Canadian economy.

milestones

- Safe nuclear energy • Better wheat varieties • Codes and standards for safer buildings
- Arthritis research • Blood research, including the effects of cholesterol
- NRC's Arthur Covington brings radio astronomy to Canada

Discovery and Prosperity

1953-63

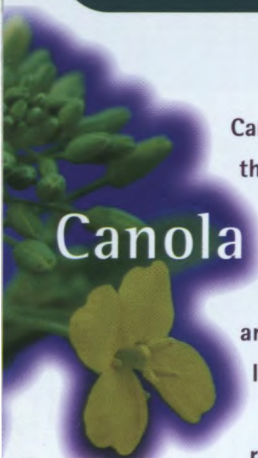
THE COLD WAR GETS CHILLIER, AND THE FRONTIERS OF SPACE BECKON.

It's About Time

NRC designed one of the world's earliest cesium beam atomic clocks in 1958. It was one of the most precise clocks known in history, accurate to a few millionths of a second per year. By the 1970s, NRC time was being used to set official time scales and clocks around the world.

Radio to the Stars

In 1960, NRC built a research station at Lake Traverse in Algonquin Park, Ontario for its new radio telescopes, which were rated among the best in the world. Using what looked like huge satellite TV dishes, NRC experts picked up radio signals from stars, gas clouds and other objects many millions of light years away.



Canola

Canola oil sometimes takes the place of butter on popcorn. It's also used to make margarine, cooking oils, lubricants, and non polluting inks. In the 1940s, NRC worked with other researchers to develop a hybrid canola plant, and today canola is one of Canada's leading cash crops.

Breakthrough in Breakwaters

In 1962, a breakwater that looked like a huge piece of Swiss cheese was built to protect the harbour at Baie Comeau, Québec. Designed by NRC, the breakwater absorbed up to 85 per cent of wave energy by letting water flow through holes in its walls.

- Studies of the upper atmosphere using satellites
- Aircraft de-icing technology
- Cultivation of sea plants as food sources
- Method of reducing silt accumulation in harbours
- National Science Library established in 1957
- Industrial Research Assistance Program (IRAP) established in 1961

Change and Excitement

"FLOWER POWER" MAKES ITS MARK. CANADA CELEBRATES ITS 100TH BIRTHDAY IN 1967. ASTRONAUTS WALK ON THE MOON IN 1969.

Versatile Choppers

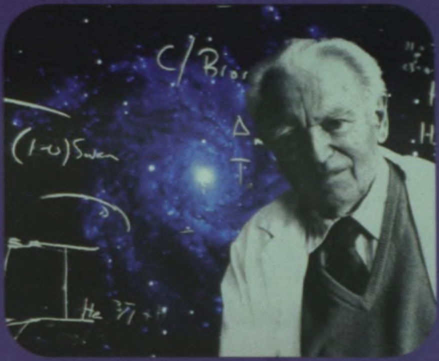
In 1966, NRC converted two helicopters into airborne simulators to explore the flight and control system characteristics required in Vertical/Short Take-Off and Landing (V/STOL) aircraft.

A bomb sniffer small enough to fit in an attaché case and able to detect explosives in parts per trillion was developed by NRC in 1966. Improved versions are still used today by police, customs, airports, air lines and embassies.

A Hi-tech Nose

Nobel Winner

In 1971, Dr. Gerhard Herzberg of NRC won a Nobel Prize in chemistry for his work in identifying molecules in space.



Have you ever played a synthesizer? Did you know the first one in the world was invented in 1945 by NRC's **Hugh Le Caine?**

NRC research has given Canada some of the best loudspeakers in the world. Among them are "smart" units that give you the same sound quality no matter where you are in a room!

Smart Sound

milestones

• Heat exchanger for blood to reduce risk in brain surgery • NRC defines characteristics of red colour on Canada's new flag • NRC builds 9 metre wind tunnel to improve airplane, automobile and bridge designs

New Energies

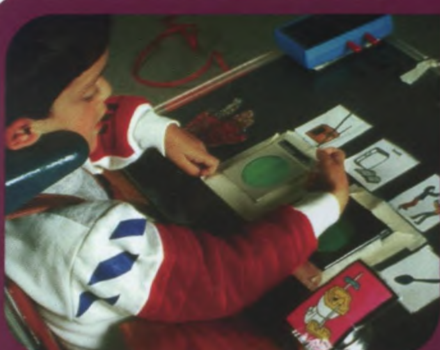
THE ENERGY CRISIS DRIVES OIL PRICES UP, WAY UP. MONTREAL HOSTS THE 1976 SUMMER OLYMPICS.

Seaweed in your double-dip cone?

Sure! Carageenan, a thickener in ice cream, chocolate sauce and other foods, comes from the seaweed called Irish Moss. NRC experts were instrumental in helping develop improved methods of growing and harvesting Irish Moss on Canada's Atlantic coast.

Oil be Darned!

In response to the skyrocketing cost of oil, NRC experts developed a number of alternative ways to generate and store energy, including windmills, solar cells, underground heat exchangers, and biomass generators.



A Helping Hand

Through the 1970s and 1980s, NRC developed many aids for the handicapped or injured, such as braille calculators for the blind, specially designed walkers, ultrasound therapies, electronic speech-generating devices, and methods for cooling the spinal cord to reduce or eliminate back injuries.

"Black box" gets a rewind

In 1973, NRC opened a centre to retrieve and analyse data from flight recorders – more commonly known as black boxes. By gathering information on aircraft crashes and other incidents, the centre has helped improve air safety.

Some bicycle frames

contain magnesium, a strong and super light metal. In the 1930s, NRC found a much faster and safer way to make magnesium. The method is still used today.

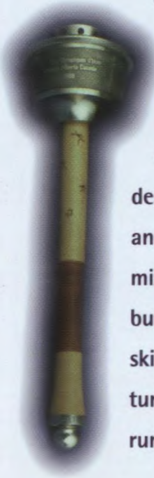
milestones

- Canada-France Hawaii Telescope opens in Hawaii in 1979
- Advanced computers
- High pressure water jets to cut steel and weaken rock
- Canada Institute for Scientific and Technical Information (CISTI) established in 1974

Breakthroughs and Breakdowns

1981-89

THE EASTERN BLOC AND THE COLD WAR DISAPPEAR. CALGARY HOSTS THE 1988 WINTER OLYMPICS.



NRC has some interesting connections with the Olympics. For instance, before the 1988 Winter Olympics in Calgary, NRC designed the Olympic torch and provided a special fuel mixture to keep the flame burning, helped the Canadian ski team train in its wind tunnels, and improved the runners on Canadian bobsleds.

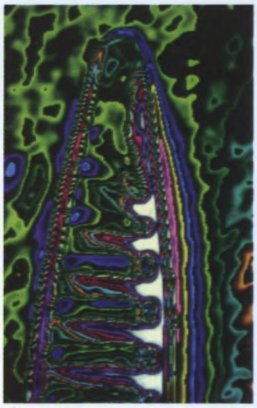
Bogus bucks Banished

NRC developed an optical security patch, made of super-thin ceramic layers, that changes colour in different lights. The patch is used on such things as paper money and drivers' licences to prevent counterfeiting or fraud.

Virtualizing reality

A laser scanning camera developed by Marc Rioux and others at NRC can make accurate 3-dimensional digital copies of objects in full colour and store them in a computer database. With this new technology, it is now possible to scan and store rare or fragile objects for use in virtual museums, and for scientific studies.

Mussel mystery solved



Eating shellfish has been safer than ever since 1987, when a team of NRC researchers quickly tracked down a poison called domoic acid that is found in some mussels. Dr. Jeffrey Wright, who led the NRC research team, was named to the Order of Canada in 1993.

NRC's Dr. Saran Narang

made a major medical breakthrough when he produced synthetic human insulin for use by diabetics. For his work Narang was awarded the Order of Canada in 1985.

milestones

- Improvements to design of ocean drilling platforms
- Advances in telecommunications technology
- Canadian Astronomical Data Centre established in 1986 to capture data from Hubble Space Telescope
- Excimer laser technology for improved heart surgery

Our Shrinking World

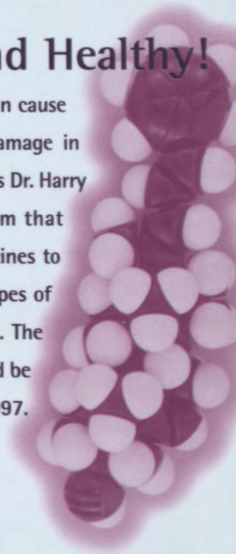
1990-2000+

THE INTERNET BRINGS EVERYONE TOGETHER. KNOWLEDGE IS WEALTH.

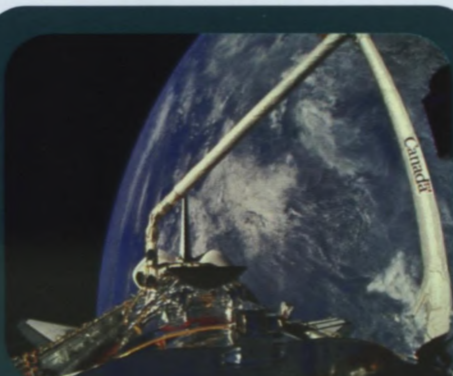
In the early 1990s, NRC experts introduced various fingerprint detection methods that included superglue, a vacuum chamber, a fluorescent dye, and an ultraviolet light. The RCMP and other police forces continue to use the techniques.

Criminals Beware!

Young and Healthy!



Infant meningitis can cause permanent brain damage in small children. NRC's Dr. Harry Jennings led a team that developed new vaccines to prevent different types of this terrible disease. The first products should be on the market in 1997.



On a NASA space shuttle mission In May 1996, Canadian astronaut Marc Garneau retrieved a satellite in flight using the Canadarm. He did it with the help of the Space Vision System, a technology developed by NRC that helps astronauts guide the Canadarm with pinpoint accuracy.

Nice Catch!

How do we know

what time or temperature it really is? In its measurement labs, NRC maintains Canadian and international standards for time, temperature, length, mass, luminous intensity, electrical resistance, X-ray radiation, and many other things.

We've only started

Canada and NRC are both going in the same direction: ahead. A new century is just down the road, and NRC is drawing the map to get us there. Who will help NRC meet the challenges? Canadian universities, industry, governments ...and you!

Contact us for more information:

Tel.	(613) 993-9101
E-mail	r&d@nrc.ca
WWW	http://www.nrc.ca
Mail	NRC, Montreal Road, Ottawa, Canada K1A 0R6

milestones

- Transgenic wheat • Bone-building therapy for osteoporosis • Biotreatment of contaminated soils
- Stroke therapy • Improvements to newsprint production • Designer antibodies for cancer therapy
- New rail grinding technique

NRC·CNRC

INFORMATION

Neutron Program for Materials Research
Applied Neutron Diffraction for Industry (ANDI)

Applied Neutron Diffraction for Industry (ANDI)

Component Design
Manufacture
Failure Analysis
Regulatory Issues
Materials Processing

Neutron diffraction is the most versatile non-destructive probe of materials and industrial components. Industry can gain access to neutron scattering technology through a fee-for-service contract with the NRC. Contracts are handled by the Applied Neutron Diffraction for Industry (ANDI) group, at Chalk River Laboratories. This group has over twelve years of experience in providing neutron diffraction services to clients from nuclear, aerospace, automotive, materials and energy-sector industries.

Residual Stress Scanning

Residual stress-scanning is a major component of the ANDI business, with projects that have included:

- The effectiveness of post-weld stress-relieving treatments.
- The relaxation rate of residual stresses in rolled joints and bent pipes at operating temperatures.
- The residual stresses in landing gear (advanced aluminum alloys).
- The stress-concentration effects near a notch or crack, under load.

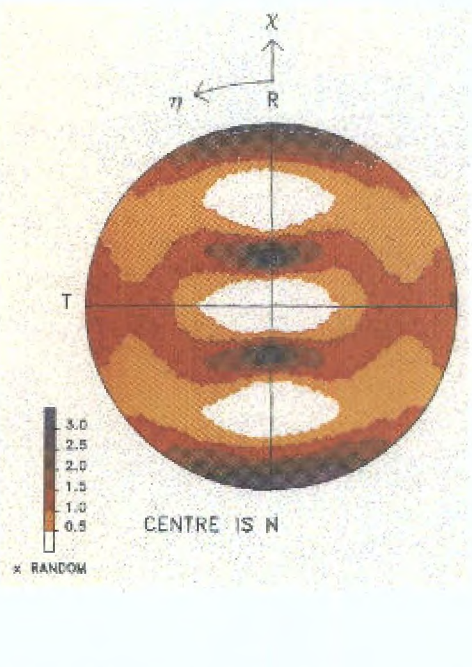
Information on residual stresses at the design stage can help to optimize the performance and reliability of new products. Prototypes can be evaluated and compared against calculations. Scanning is non-destructive, so components can be returned to a client for subsequent treatment or testing.

Measuring the residual stresses near the fusion zone of a sleeve-welded pipeline.

National Research Council Canada
Conseil national de recherches Canada
Steacie Institute for Molecular Sciences
Institut Steacie des sciences moléculaires

Analysis of Texture

The preferred orientations of crystallites in industrial materials can influence the properties of manufactured objects, adding a directional dependence to such quantities as corrosion resistance, yield strength, creep resistance, elastic stiffness and thermal expansion. Neutron diffraction averages over the bulk of a specimen to obtain a quantitative analysis of the distribution of crystallite orientations, also called the crystallographic texture. Texture is a key measurement for evaluating the effects of process parameters on industrial materials, such as rolled plates, extruded tubes and forgings.



Volume-fraction Analysis

Complete neutron diffraction patterns are analyzed to determine the volume fractions of components in composite materials, such as graded ceramics, metal-matrix composites and precipitates in alloys. Volume fractions as low as 0.5% can be evaluated quantitatively. Data can be acquired as a volume-average of bulk material, or as a non-destructive spatial scan of the interior of a component. Volume fraction data serve as indicators of process-control. This analysis method can be exploited to monitor precipitation, reactions and phase transformations at realistic material-processing temperatures.

New Techniques

The versatile nature of neutron diffraction makes it an ideal tool to undertake novel inquiries into industrial issues. Developing techniques include non-invasive thermometry, real-time tracking of oxidation, monitoring of electrochemical reactions, and large-volume-scanning of microstructural homogeneity.

Texture is determined from the variation of diffracted neutron intensity versus direction in material, plotted here as a stereographic pole figure.

- Aerospace
- Automotive
- Shipping and Rail
- Oil and Gas
- Nuclear
- Pressure Vessels
- Piping
- Steel
- Aluminum
- Advanced Alloys
- Ceramics
- Composites

For more information or to arrange measurements contact Dr. John Root:
National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3974
1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

NRC·CNRC

INFORMATION

Neutron Program for Materials Research

The Centre of Neutron Scattering in Canada

National Facility
User Program
Industry Support
Applied Research
Fundamental Science

Introduction

The Neutron Program for Materials Research (NPMR) provides access to Canada's primary neutron scattering facility located at Chalk River Laboratories. Canada has an outstanding tradition in neutron scattering that began with the Nobel prize winning research of Dr. B.N. Brockhouse. Today, this national facility provides Canadian and foreign researchers in universities, national laboratories and industry access to the myriad of neutron scattering techniques that reveal so much about the materials properties and help scientists and engineers develop and improve materials. Applied neutron diffraction is also available as a service to Canadian and foreign industry to improve the quality and safety of engineering materials and components. The six neutron spectrometers at the NRU reactor are operated in support of the two principal functions of the NPMR:

Figure 1: *DUALSPEC*, these state-of-the-art neutron scattering instruments were partly funded by NSERC.

National User Facility

Beam time is available to all researchers who need to use neutron scattering techniques. The research is often carried out through collaborations between NPMR scientific staff and university, industrial and government scientists. Research programs are classified into three broad categories, Materials Science, Physical Sciences, and Biomaterials.

Materials Science

Neutron diffraction is a uniquely versatile probe for the study of material response to temperature, load and a wide range of thermomechanical treatments. Because many experiments can be performed on specimens that are held in realistic conditions (high temperature, reactive environments, applied stresses), the measured information provides direct insight about the physical processes that occur during the manufacture of materials. This information can lead to refinements of material processing routes and the development of improved materials, including metals, alloys, ceramics and composites.

Physical Sciences

The physical sciences program encompasses measurement of the structures and the excitation spectra of newly discovered materials and of materials exhibiting novel or unusual properties. Crystalline, magnetic and amorphous structures are determined and related to the physical properties of the material. The spectrum of excitations is measured to investigate the fundamental atomic and molecular dynamics. This structural and dynamical information will advance our understanding of the responses and phases that occur in materials as a function of parameters such as temperature, pressure, magnetic field etc.. Neutron scattering is an essential tool for such investigations.

Biomaterials

The program for biomaterials research explores topics of current interest to biology using neutron diffraction, small-angle scattering and reflectometry. Unlike x-rays, neutrons scatter equally well from low- and high-atomic number elements making them an ideal probe for the study of biological materials which are naturally rich in hydrogen and other low-atomic number elements (e.g. carbon, oxygen and nitrogen). The biomaterials program focuses on structural studies of model membrane systems and the development of techniques to study aligned biological materials under physiologically relevant conditions.

Applied Neutron Diffraction for Industry (ANDI)

Neutron beams are exploited to obtain experimental information that bears directly on the quality and reliability of industrial materials and engineering components. This information is delivered as a commercial service to industrial clients who need to solve industrial problems. For more details see the ANDI fact sheet.

Analyze Failures
Processing Problems
Benchmark Models
Qualify New Supplier
Meet New Protocols

Facilities

The six neutron scattering instruments are (clockwise in Figure 2):

- C2: DUALSPEC, High Resolution Powder Diffractometer
- C5: DUALSPEC, Polarized Beam Triple Axis Spectrometer & Reflectometer
- E3: Materials Science Diffractometer
- L3: Strain Scanning Diffractometer
- N5: Triple Axis Spectrometer
- T3: Biomaterials Diffractometer

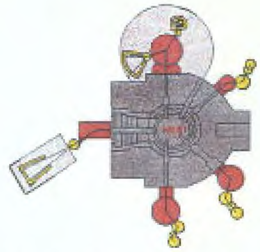


Figure 2: Instrument layout around NRU Reactor.

For more information or to arrange measurements contact, Dr. John Root:
National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3974
1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

NRC·CNRC

INFORMATION

Neutron Program for Materials Research

Magnetism

Magnetic Structures
Spin Waves
Local Correlations

The application of neutron scattering techniques to the study of condensed matter has resulted in immense gains in our understanding of cooperative phenomena. Magnetic materials, by virtue of their relative simplicity and the short-range nature of magnetic interactions, have served as prototypical cooperative systems.

The magnetism and superconductivity program provides users with a variety of environments (see list below) in which their sample can be mounted while performing elastic and/or inelastic neutron scattering measurements. The range of wavelength and energy possessed by thermally moderated neutrons allows us to study not only the nuclear long-range, *static*, nature of solids but also the dynamics (phonons). Similarly, the neutron's magnetic moment (S=1/2) allows it to couple well to the magnetism in solids, allowing unparalleled scrutiny of both the magnetic structure (short- and long-range) and the excitations (magnons) of magnetic materials. Neutron scattering techniques are presently considered as the most powerful probe of magnetic materials.

The 7 Tesla vertical and 2.5T horizontal field magnets. Both pieces of equipment can be mounted on our triple axis spectrometers.

The field of magnetism and superconductivity has not only produced some of the most exciting pieces of neutron scattering work, (determination of antiferromagnetic structures (Shull and Wollan), spin dynamics in High Tc (Rossat-Mignod), etc.) but it has also advanced the development of neutron scattering techniques, such as the triple axis spectrometer (Brockhouse), polarisation analysis (Moon, Riste and Koehler) and Neutron Spin Echo (Mezei). At the NRU, the magnetism program utilises the two triple axis spectrometers (N5 and C5) and the high resolution diffractometer (C2). C5 has the capability of performing polarised experiments and with its velocity selector we have a tunable filter for neutrons between 2.37 and 4Å.

Current ancillary equipment allows us to apply magnetic fields up to 2.5T in the scattering plane and 7T perpendicular to the plane. We can reach 1.8 K in the horizontal field magnet and our bath cryostat and we have several closed cycle refrigerators.

National Research Council Canada | Conseil national de recherches Canada
Steacie Institute for Molecular Sciences | Institut Steacie des sciences moléculaires

For experiments above room temperature we have several furnaces one of which can reach 2000°C.

In-house Research

In Collaboration with scientists from England and the United States we are studying the excitations in low dimensional quantum antiferromagnets. Detailed studies of the excitations in one dimensional spin systems such as NENP, $CsNiCl_3$ and $CsCoBr_3$ are helping to clear up several questions that recent theories have introduced to the field.

In a large collaboration with many Canadian scientists (TRIUMF, McMaster, Waterloo and Toronto) we have studied the affect of geometric frustration on magnetic systems. Unusual groundstates are brought about by the inability of these systems to uniquely minimise their energy. Neutron scattering, μSR, low temperature bulk properties and NMR experiments are allowing us to investigate the true nature of these magnetic systems. Several detailed studied on $Tb_2Ti_2O_7$ [see Phys. Rev. Lett., **82**, 1012 (1999)] and $Y_2Mo_2O_7$ [see Phys. Rev. Lett., **83**, 211 (1999)] were performed within the past year. Neutron scattering experiments have shown that although $Tb_2Ti_2O_7$ has a Curie-Weiss temperature of -20K, the 9.4 μ_B spins on the Tb ion are still fluctuating and are only spatially correlated over nearest neighbours at 10K (see figure 2).

User Program

Apart from our in house collaborations we also perform experiments where the visiting researcher is the driving force of a project. Two such projects are the study of the many magnetic phases of elemental holmium and the materials that exhibit colossal magneto-resistance. In these materials the competition between charge, lattice and spin degrees of freedom in these materials have led to very interesting transport and magnetic properties. The magnetic structure and temperature dependence of these materials have been investigated on C2 (see figure 3).

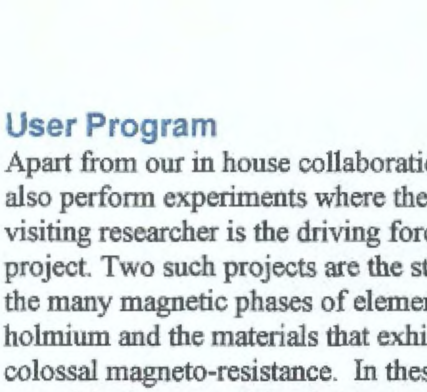


Figure 2: Diffuse magnetic scattering from the geometrically frustrated antiferromagnet, $Tb_2Ti_2O_7$, at 10K. A nuclear component has been subtracted.

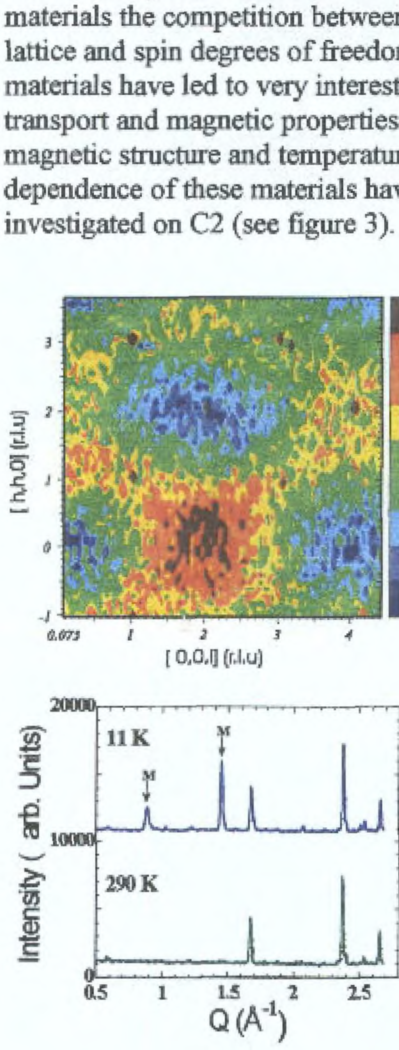


Figure 3: Upon decreasing the temperature new Bragg peaks appear (M) that can be shown to be magnetic in origin with a simple structure similar to the nuclear room temperature structure.

For more information or to arrange measurements contact Dr. John Root:
National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3974
1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

NRC·CNRC

INFORMATION

Neutron Program for Materials Research
Applied Neutron Diffraction for Industry (ANDI)

Near-Surface Stress Mapping

Non-destructive Measurement of Residual Stress

Materials Research
Process Evaluation
Failure Analysis
Residual Stress
Laser Ablation
Shot Peening

The Need

The stresses introduced by surface treatments such as shot peening and laser ablation, extend to several millimetres below the surface, with the greatest variations occurring within the first millimetre of the surface.

The accurate determination of residual strain by diffraction has traditionally fallen into two spatial regimes:

- surface measurements, using highly attenuated x-rays (typically 1-100 μm)
- measurements at depth, using highly penetrating neutrons (typically 1-30 mm)

A new **non-destructive** neutron diffraction technique, called *Near-Surface Stress Mapping*, has been developed to probe continuously from 0.1 mm below the surface to well inside the specimen. Labor-intensive layer removal and re-measurement is not needed.

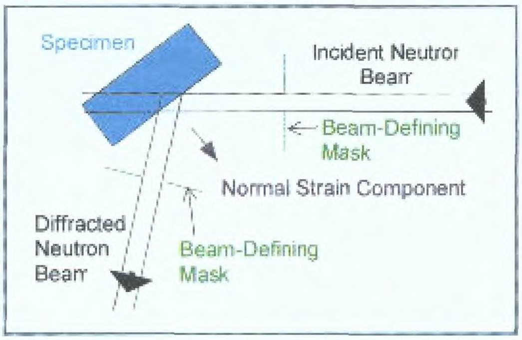


Figure 1: The normal strain component (as indicated by the arrow) is measured at the position of the intersecting beams.

The Technique

When an incident neutron beam impinges upon a crystalline specimen, neutrons are diffracted at an angle that depends on the spacing between planes of atoms, *d*. With accurate measurement of the diffraction angle, the *d*-spacing between the lattice planes can be calculated, to determine whether the planes are being pushed together (compression), or pulled apart (tension).

Neutron-absorbing masks define the incident and diffracted beams. Information about the plane spacing is obtained from the material contained within the intersection volume of the beams. The specimen is positioned with respect to the intersection volume using a suitable combination of precise, computer-controlled translations and rotations (see figure 1).

The basis of the technique is the same as standard neutron diffraction strain scanning. However, special operational modes and specially designed hardware are required to perform accurate strain measurements within 1 mm of the surface.

Test Measurements

Measurements were performed on a heavily peened Waspaloy plate. The in-plane and normal strains were measured as a function of position from the surface to 4 mm inside the sample. The calculated stress as a function of position is shown in figure 2. The stresses were calculated directly from the measured in-plane and normal strains.

Measurements have also been made on other Waspaloy plates peened to various intensities. As well, peening stresses have been successfully measured in mild and carbon steel specimens.

The ANDI group has over 10 years of experience in residual stress mapping in a variety of industrial components of varying shapes and sizes, manufactured from many different industrial materials. The recently developed technique for *Near-Surface Stress Mapping* is now available to industry as part of the ANDI portfolio of applied neutron diffraction techniques.

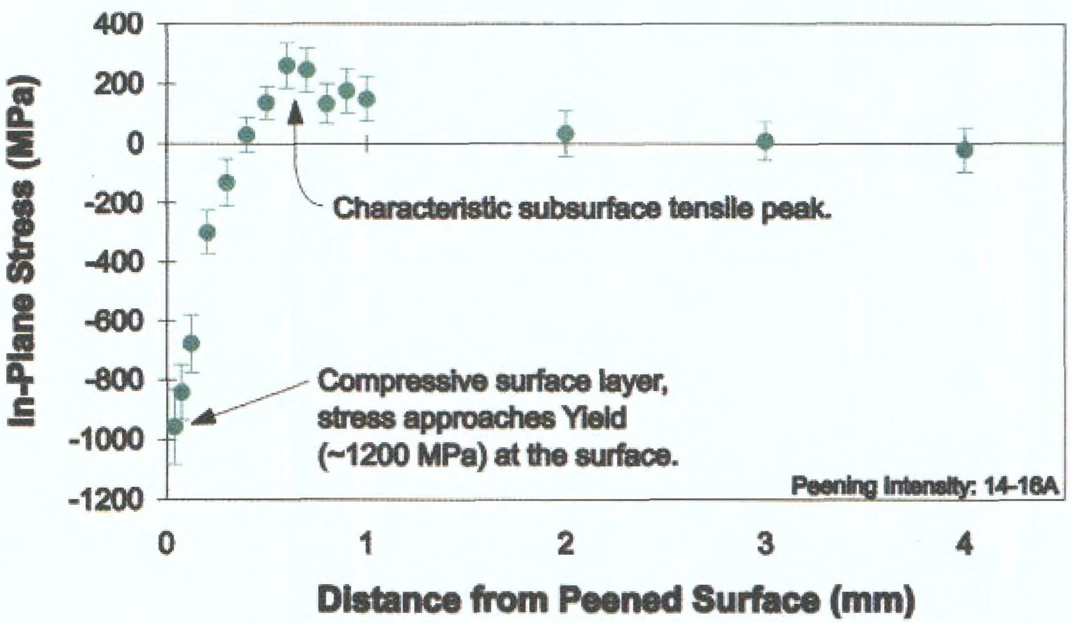


Figure 2: In-plane component of stress calculated from measured strains in a Waspaloy test sample. The stress profile is typical of shot peening.

For more information or to arrange measurements contact Dr. John Root:

National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3974
1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

NRC·CNRC INFORMATION

Neutron Program for Materials Research
Applied Neutron Diffraction for Industry (ANDI)

Phase Analysis

Quality Assurance
Product Development
Process Evaluation
Non-Destructive Test
***In-Situ* Measurement**

The Need

Certain products (e.g. ceramics, welds, metal-matrix composites) may consist of many crystalline *phases*. The identification of these phases, and the proportion of each in the product can be very important in determining its usefulness or reliability.

The Technique

Neutrons can pass through centimetres of most materials and are diffracted from every phase they encounter. Each phase has a characteristic unit cell and interatomic spacings, *d*.

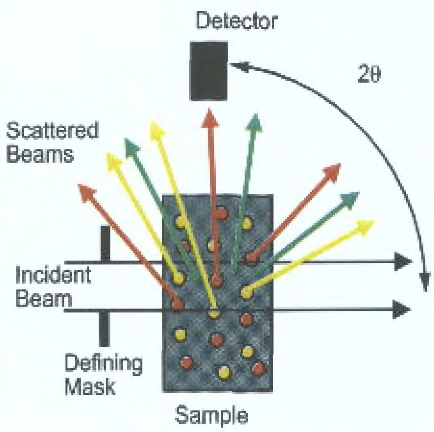


Fig 1. Scattering from a multiphase sample gives a composite diffraction pattern, with lines characteristic of each phase

Bragg's Law, predicts exactly the angles of scattering, 2θ, at which diffraction peaks occur.

The result is a composite diffraction pattern, consisting of peaks characteristic of each phase in the sample. The ratio of the intensity of the diffraction peaks can directly yield the volume and weight fractions present. Using this information **Quantitative Phase Analysis** can be performed.

Due to the great penetrating ability entire specimens of product can be examined *without* the need to grind the sample into a powder, completely **non-destructively**, and complex sample environments can constructed around the sample.

Depending on the requirements, either the *bulk* composition can be examined by bathing the entire sample in the beam, or the *composition as a function of depth* can be examined, by masking the incident beam and detector.

National Research Council Canada
Conseil national de recherches Canada
Steacie Institute for Molecular Sciences
Institut Steacie des sciences moléculaires

Product Evaluation

Information on what happens to a product if a process, or starting material changes can be vital. Batch samples at various stages of processing can be examined. Alternatively, measurements can be made *in-situ* with special furnaces, e.g. for testing the response of materials to high temperatures and/or oxidizing gases, without the need for quenching.

Quality Assurance (QA)

For well established processes, the technique can be used to check compliance with a quality standard. Quantitative phase analysis using neutron diffraction is a leading QA method for ensuring the correct proportion of fissile phases in nuclear fuels in Canada.

- Ceramics
- Metal-matrix composite
- Welds
- Alloys
- Nuclear fuels
- Oxidation phases
- Minority phases
- Retained austenite
- Bulk compositions
- Compositional profiling

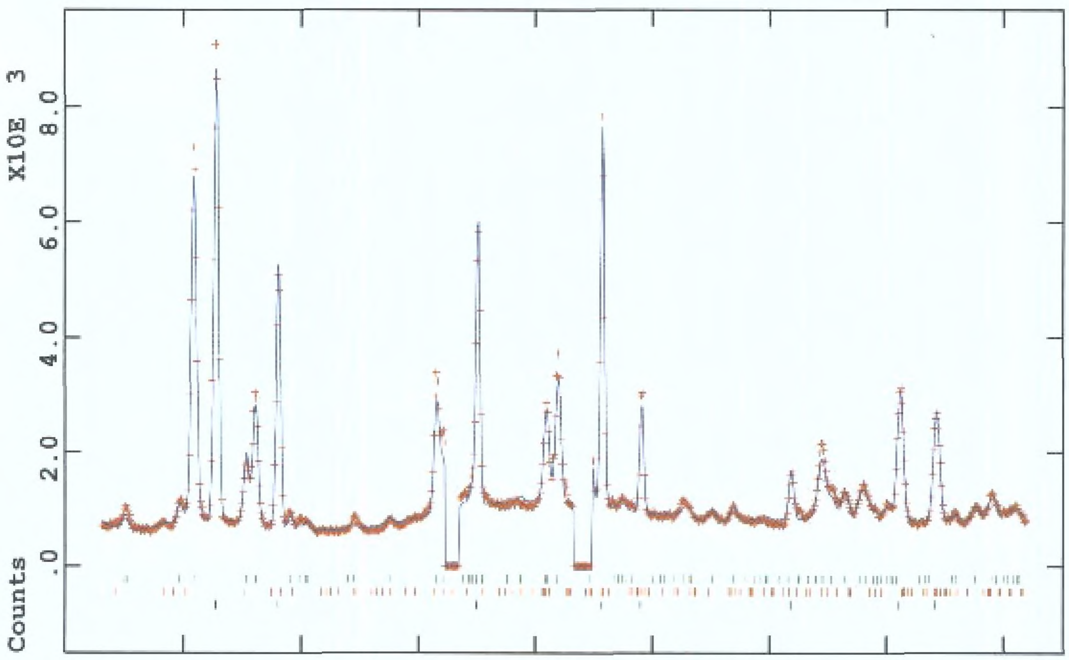


Fig 2. The composite diffraction pattern from a three-phase metal-matrix composite, showing the observed (+), and fitted (line) diffraction pattern. The tic marks, define contributions from each phase.

For more information or to arrange measurements contact Dr. John Root:
National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3974
1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

NRC·CNRC

INFORMATION

Neutron Program for Materials Research
Applied Neutron Diffraction for Industry (ANDI)

Non-destructive Stress Mapping

Product Development
Process Evaluation
Failure Analysis
Residual Stress
Non-destructive

Completely non-destructive and highly accurate: neutron diffraction is used to determine internal residual stresses in crystalline materials (e.g. metals, alloys, ceramics and composites). Neutrons can probe several centimeters beneath the surface—well into joints, internal components and other critical sub-surface regions vital to the performance of materials and engineering components. The spatial resolution (defined by a volume element) ranges from 0.2 to 1,000 mm^3. The resolution in lattice strain is of the order 0.01%.

New Product Development

Information on residual stresses at the design stage can help to optimize the performance and reliability of new products. Prototypes can be evaluated and compared against calculations.

Process Evaluation

Knowledge of the development of residual stress in components at various stages of production—extrusion, rolling, machining, welding and heat-treating—can be used to optimize processes and improve product reliability and performance.

Problem Solving

Residual stress data can help in determining the causes of failures so that appropriate remedial action can be taken. With neutron diffraction, accurate measurements can be obtained deep within a joint or below highly corroded or fouled surfaces. Neutrons penetrate right through the surface region, no surface preparation is needed).

Determining the thermal evolution of stress in a 3-component (Inconel, Zr-2.5%Nb, & Stainless Steel) rolled joint

National Research Council Canada
Conseil national de recherches Canada
Steacie Institute for Molecular Sciences
Institut Steacie des sciences moléculaires

The Technique

When an incident neutron beam strikes a specimen it is diffracted at an angle that depends on the distance between the planes of atoms. This angle is measured with a neutron diffractometer and the distance calculated.

The technique requires an intense neutron source and precise alignment of the neutron beam. At Chalk River, neutrons are provided by the high-flux NRU research reactor.

Measurement locations are defined by precise, computer-controlled specimen translations and rotations. Specimens can range in size from a few grams to 500 kg.

Applications

The depth to which neutrons will penetrate depends on the type of material, but is approximately 30 mm in steel and 300 mm in aluminum. This allows the technique to be applied to a wide range of important engineering materials and full-scale critical components.

- aircraft components
- steel-forgings
- weldments
- pipe steels
- rail steels
- ceramics
- composites
- turbine blades
- pressure vessels
- reactor components
- heat-exchanger tubes

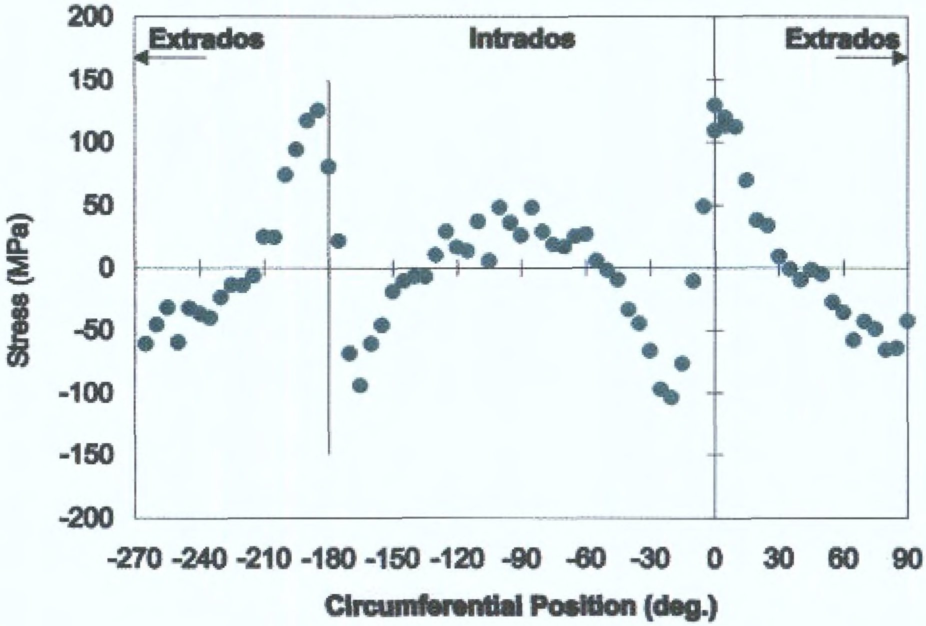


Figure 2: Residual stress variation (in MPa) measured around the circumference of a bent tube. The nominal flank position is at 0°.

For more information or to arrange measurements contact Dr. John Root:
National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3974
1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

NRC·CNRC

INFORMATION

Neutron Program for Materials Research
Applied Neutron Diffraction for Industry (ANDI)

Neutrons as a Surface Probe

Neutron Reflectometry

Surface Composition
Roughness
Multilayers
Buried Interfaces
Bio-membranes

Non-invasive and non-destructive, neutron reflectometry can determine area-averaged chemical composition and roughness of a surface. In addition, the technique is sensitive to variation of chemical composition with depth. If the sample consists of layers of different materials it gives chemical composition and thickness of each layer, as well as the roughness of the interfaces between the layers.

With suitable samples, researchers can acheive excellent resolution: within the overall sensitive depth of up to 300 nm one can often see layers that are only a few atomic layers thick.

Sample Requirements

Samples for reflectometry must be very flat but do not need to be atomically flat. Samples with large surface area generally give better results but those as small as 10 ∞ 10 mm can be studied.

Since many metals and alloys can be deposited on to a flat Si or sapphire substrate, the technique is applicable to a wide variety of R&D topics.

Research Topics

Neutron reflectometry is often applied to the study of metallic films, polymer films and biological membranes. Since neutrons are sensitive to magnetism, it is also used to study surface magnetism and artificial magnetic/non-magnetic multilayers. It is a powerful research tool for probing solid/liquid interfaces such as an electrode in contact with an aqueous solution.

In-situ neutron reflectometry to study hydrogen ingress into metal films

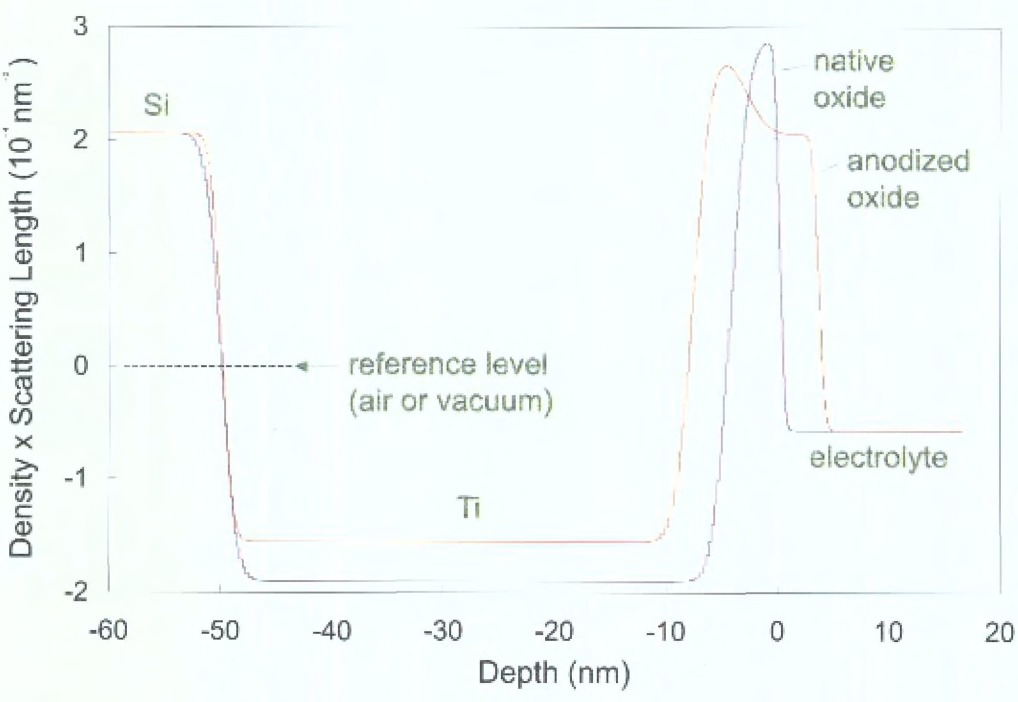
National Research Council Canada
Conseil national de recherches Canada
Steacie Institute for Molecular Sciences
Institut Steacie des sciences moléculaires

For many problems, it is often possible to design a special sample environment for *in-situ* studies. The figure overleaf, for example, shows an electrochemical cell used to observe, in-situ, the ingress of hydrogen into metal under an applied cathodic potential.

What do We Actually Learn?

Result from a typical reflectometry experiment is shown in the figure below. The x-axis of the figure is depth. The quantity along the y-axis is the density of the material at a particular depth, times its "neutron scattering length". The latter is a measure of how strongly a given material scatters neutrons, a known quantity and signature of each material.

This particular result shows how the natural oxide layer on the surface of Ti thickens when the metal is anodized to –2 volt. From this result one can deduce the type of oxides present after anodization and percentages of cation and anion migration during the anodization process.



Chemical changes produced by anodization of a Ti film deposited on a Si substrate.

For more information or to arrange measurements contact Dr. John Root:
National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3974
1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

NRC-CNRC
INFORMATION

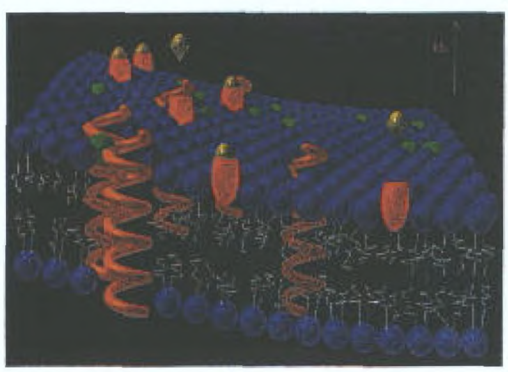
Neutron Program for Materials Research

Biomaterials Program

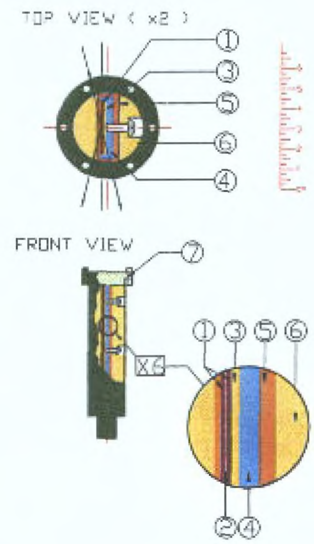
Model Membranes
Biologically Relevant Conditions
Aligned Lipid Bilayers
Sample Environments

Background

The Biomaterials program focuses primarily on the study of lipid/water systems using a variety of scattering techniques particularly neutron diffraction. Furthermore, we attempt to study orientationally aligned systems since the experimental information is greatly enhanced when compared to liposomal or "powder" preparations. Although we have traditionally aligned bilayers using rigid substrates (e.g., glass, silicon, quartz, mica etc.), recently we have studied a "biologically relevant membrane" which is highly alignable in the presence of an applied magnetic field (**B**) [(1)]. Such a system promises to be an excellent "substrate" for orienting membrane associated peptides and proteins irrespective of the macromolecules intrinsic magnetic properties.



Magnetically alignable bicelle containing the peptide gramicidin A. [Prosser et al., Biophys. J. 75, 2163 (1998)]

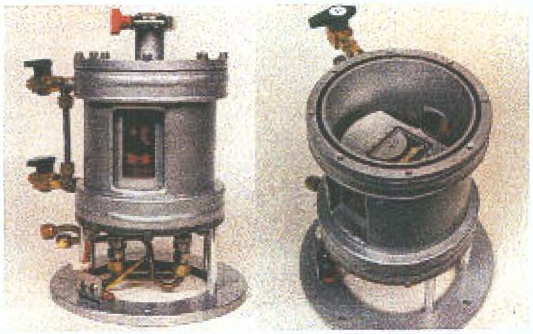


Schematic of aluminum sample holder for neutron diffraction studies capable of producing samples under physiologically relevant conditions. (1) Silicon/teflon assembly containing the aligned lipid bilayers. (2) Lipid multibilayers. (3) Aluminum pressure plate. (4) Water reservoir. (5) Removable aluminum cassette that retains the silicon/teflon assembly and the pressure plate. (6) Aluminum billets. (7) Indium seal. [Katsaras, Biophys. J. 73, 2924-2929 (1997)]

Recent Developments

Using rigid substrates, we have developed novel and simple methods of aligning model membrane systems under conditions of excess water, and which will enable a variety of techniques (e.g., neutron and x-ray diffraction, nuclear magnetic resonance, electron spin resonance, attenuated total reflection infrared spectroscopy, etc.) to study such systems under physiologically relevant conditions (e.g., relevant pH and ionic strengths, excess water conditions, L_α phase lipid bilayers).

Another development has been the hydration, using sample ovens capable of reaching ~ 100% relative humidity, of fully hydrated samples using water vapour. Previously, lipid multibilayers hydrated from water vapour exhibited repeat-spacings much smaller than their liposomal counterparts in contact with liquid water.



Full elevation and partial top view of neutron or x-ray sample holder capable of achieving humidities approaching 100%.

Since the chemical potential of water in the liquid and vapour phases, under equilibrium conditions, is the same this phenomenon became known as the "vapour pressure paradox". This perennial problem was recently resolved using neutron diffraction [2].

Diffraction pattern from aligned, fully hydrated lipid multibilayers in the ripple, $P_{\beta'}$ phase hydrated from water vapour.

REFERENCES:

(1) J. Katsaras et al., Phys. Rev. Lett. 78, 899 (1997).

(2) J. Katsaras, Biophys. J. 75, 2157 (1998).

For more information or to arrange measurements contact: John H. Root
National Research Council Canada
Steacie Institute for Molecular Sciences
Neutron Program for Materials Research
Chalk River Laboratories
Chalk River, Ontario
Canada, K0J 1J0

Phone: 613-584-8811, Ext. 3973
or 1-888-243-ANDI
FAX: 613-584-4040
E-mail: NPMR@nrc.ca
WWW: http://neutron.nrc.ca

Canadian Neutron Facility (CNF) – Key points

Background – The current neutron beam laboratory

- The CNF neutron beam laboratory builds on a historic foundation that extends from Nobel prize-winner Bertram Brockhouse to the present Neutron Program for Materials Research (NRC) at Chalk River. Canada's neutron beam expertise is highly regarded worldwide.
- The neutron beam laboratory generates knowledge that is exploited by the full spectrum of science and technology, from academic exploration and student education to problem-solving for industry.
- Industrial clients of current neutron beam services are from all materials intensive sectors: aerospace, automotive, manufacturing, nuclear, oil & gas and materials producers.
- The neutron beam laboratory is presently used by university and industry researchers located across Canada (over 20 universities, over 60 projects for Canadian companies).
- The neutron beam laboratory is used by many foreign universities, companies and institutions, enabling reciprocal Canadian access to an extensive array of research facilities worldwide.
- The Canadian neutron beam laboratory and Canada's base of expertise is threatened by the imminent closure of the NRU research reactor at Chalk River Laboratories. The reactor is not expected to operate beyond 2005.

Current Proposal - The Canadian Neutron Facility

- Since 1994, there has been a serious effort to replace the NRU reactor with a modern neutron source. The most recent push to obtain funding for a Canadian Neutron Facility has been led jointly by the National Research Council of Canada and AECL, beginning in 1998.
- The total construction cost of the CNF will be $466M (escalated over 6 years of construction). Worldwide, such projects are funded entirely by national governments as strategic investments in their research infrastructure.
- Over 20,000 researchers from across Canada will use the neutron beam laboratory at the CNF during its 40 year lifetime.
- The neutron beam laboratory at the proposed CNF will extend Canada's ability to generate knowledge applicable to industry sectors such as pharmaceuticals, foods, biomaterials, electronics and computing devices.

- The knowledge generated by the CNF will pertain to the materials and components required by Canadian industries that support 400,000 jobs.

- Unlike other big science facilities that focus on single subjects, such as astronomy or particle physics, the CNF's neutron beam laboratory will support research in many science areas, including: physics, chemistry, biology, materials science and engineering.

- The world-class CNF neutron beam laboratory will attract talented young researchers and keep them in Canada.

- As a multi-disciplinary educational environment, the CNF will enhance the capabilities and outlook of students who will graduate to positions in knowledge-intensive, high-technology industries.

- The CNF will be one of a small number (about 20) of such facilities worldwide. Companies that exploit the unique knowledge obtained by neutron beam measurements can achieve a competitive advantage in a global arena.

The Urgency

- It will take 6 years to construct the CNF, and commission the first neutron instruments. Even if the CNF is funded today, there will be a 2-year gap in the availability of neutrons for the Canadian research community.

- The "neutron gap" disrupts the continuity of training required to exploit neutron beam technology. The training of young researchers will decline in the 4 years prior to the gap and will not recover for a number of years after the CNF starts up.

- The "neutron gap" disrupts the continuity of the research and development projects presently underway. The academic and industrial user community will begin to dissipate prior to the gap.

- The research staff at the laboratory are key to the effective exploitation of neutron beam methods by the user community.

- Exciting and well-funded neutron beam projects are presently underway in the US, the UK, Germany, Australia and China. Attractive opportunities offshore may draw the essential Canadian expertise away during this time of funding uncertainty for the Canadian Neutron Facility.

Dr. John Root, Program Leader
Neutron Program for Materials Research
National Research Council of Canada
Chalk River Laboratories
(613) 584-8811 ext. 3974

AECL EACL

Visit of
NRCan
&
Nuclear, Non-Proliferation and Disarmament Implementation Agency of the Department of Foreign Affairs and International Trade Officials

to Chalk River Laboratories
2000 Thursday, August 31

FINAL AGENDA

9:30	**Arrival at Outer Gate**	
9:30-9:45	**Delegation will be escorted to Visitors' Centre by CRL staff**	
9:45-10:00	**Registration and badging**	CRL Protective Services
10:00	**Welcome & Site Introduction (20 min)** **Overview of Refurbishment Activities (10 min)** **Pre-Tour Discussion(Two Thom mini-buses will pick up at Visitors' Centre for tour)**	P.J. Fehrenbach D.F. Weeks Visitors' Centre
10:30	**Divided group to board 2 buses** **Driving Tour of site with stops at:** **BLUE TOUR** **1. NRU (25 min)** **W.R. Shorter * Bldg. 150** **2. Fuel Development Lab (20 min)** **J.D. Sullivan * Bldg. 300** **3. Waste Management Area "B" (25 min)** **D.K. Raman** **Thom bus to deliver to Private Dining Room**	 **GOLD TOUR** **1. Waste Management Area "B" (25 min)** **D.K. Raman** **2. NRU (25 min)** **W.R. Shorter * Bldg. 150** **3. Fuel Development Lab (20 min)** **J.D. Sullivan * Bldg. 300** **Thom bus to deliver to Private Dining Room**
1:00-2:00	***4. L U N C H*** ***(18 visitors, P. Fehrenbach, J.P. Labrie, A. Vikis, D. Weeks, B. Shorter, J.D. Sullivan, D. Raman, R. Drouin, J. Bond, D. Taylor)***	***Buffet in Private Dining Room***
2:00	**NRCan Depart** **(Thom bus will pick up visitors from Private Dining Room entrance and deliver to Visitors' Centre for departure.)**	
1:30-2:30	**DFAIT visitors:** **MAPLE Reactor and NPF Tour** **(CRL driver with van will pick up for tour and deliver to Visitors' Centre for departure.)**	J.P. Labrie, J.A. Bond, D.B. Taylor
2:30	**DFAIT Depart**	

* 2000 August 29

List of AECL Personnel

Paul Fehrenbach, General Manager, CANDU Technology Development (CRL)
Jean Pierre Labrie, General Manager, Research and Isotope Reactor Business (SP)
Dale Weeks, Deputy General Manager, Facilities and Nuclear Operations (CRL)
Andy Vikis, Director, Health, Chemistry & Environment (CRL)
Jim Bond, Manager, Isotope Processing Facility (CRL)
Don Taylor, Manager, MAPLE Operations (CRL)
Bob Drouin, Facilities and Nuclear Operations (CRL)
Dave Raman, Waste Management and Decommissioning (CRL)
Bill Shorter, Manager, NRU Operations (CRL)
Jim Sullivan, Fuel Development (CRL)

	Blue Tour Narrators	Gold Tour Narrators
SD&E	Andy Vikis	Ron Mitchel
FNO	George Dolinar	Bob Drouin
CTD	Andrew White	Paul Fehrenbach

List of Visitors

NRCan

Minister's Office:

Pat Breton, Press Secretary
John Embury, Director of Communications
Dan Seekings, Policy Advisor, Energy Sector
Marjolaine Rocheleau, Secretary

Deputy Minister's Office:

Robert Laframboise, Executive Assistant (TBC)

Communications Branch:

Mary O'Rourke, Associate Director General
Tracy Thiessen, A/Account Executive, Energy Sector
Alice Barnabé, Communications Officer, Energy Sector
Cathy McRae, Account Executive, Climate Change Sector
Jean-Guy Dégagné, Chief, Editorial Services
Ellen Charette, A/Director, Public Affairs (TBC)

Energy Resources Branch:

Dan Whelan, Director General (TBC)

Nuclear Energy Division:

Arlene Brunke, Public Information Officer
Martin Lamontagne, Analyst

DFAIT

Nuclear, Non-Proliferation and Disarmament Implementation Agency:

Mark Gwozdecky, Director
Maria Raletich-Rajicic, Deputy Director, Nuclear Safety, G-7 & Eastern Europe, CTBT, Bilateral Relations
Terry Wood, Deputy Director, Non-Proliferation, Bilateral Co-operation, Export Controls
Ché van Haastrecht, Nuclear Cooperation Officer

Check point	Blue Tour	Gold Tour		Narrator
1	10:30	10:30	Depart Visitor Centre (Blue Tour to Check Point 2, Gold Tour to Check Point 12)	
2	10:35	11:15	Buildings 513, 524 Radiological sciences support to government policy, environmental protection, protection of staff working at nuclear sites	SD&E
			Hospital/Clinic - required for initial screening of radiation incidents	FNO
			Cafeteria - used by all staff, required for staff from active area	FNO
			Fire Department - required to protect assets and staff	FNO
			Bldg. 412 - manufacturing services	FNO
			Quonsets - used for storage, need replacement	FNO
3	10:45	11:25	Bldg. 456 - houses support and R&D staff, slated for retirement	CTD
			Waste treatment centre - basic requirement for an industrial site	FNO
4	10:50	11:30	Active Area Gate - security check	
			Power house - another basic requirement for an industrial site	FNO
5	10:55	11:35	Stop at NRU: used for isotope production, CANDU R&D (fuel, materials, safety, chemistry), basic R&D (neutron beam materials studies)	
5	11:20	12:00	Depart NRU	
			Active Drain Project - necessary refurbishment to active site infrastructure	FNO
			Bldg. 234 - Universal Cells, required to support Isotopes, CANDU business, site operations	FNO
6	11:25	12:05	MTF/loops - thermalhydraulics studies fundamental to water reactors, mix of new and old facilities	CTD
			Active machine shop - key support to active site	FNO
			ZED-2 - provides basic physics data for CANDU reactors, required to support Canadian nuclear utilities and the CNSC (e.g. data fundamental to analysis of large Loss-of-Coolant accidents)	CTD
			Bldg. 469 & 145 - relocating reactor safety R&D programs from Whiteshell Laboratories	CTD
7	11:30	12:10	Bldg. 320/330 - active chemistry, "modern" 20-year old buildings	CTD
			Bldg. 107 - building due for decommissioning, requires extensive characterization/decontamination	FNO
			Bldg. 250 - houses tritium/heavy water/reactor chemistry R&D, older building requiring alternatives for programs/staff and decommissioning	SD&E
			Bldg. 210 - decontamination, support required for an active site	FNO
8	11:35	12:15	Building 215 CECEUD: demonstration of key CANDU technology - cheaper and more environmentally friendly. investment payoff - recycling used heavy water	SD&E
9	11:40	12:20	MAPLE and NPF: successful spinout business, requires infrastructure of an active site; important to world health industry	CTD
			NRX and associated buildings - decommissioned reactor	FNO
			Building 375 - Fuel and materials cells - key facility for nuclear laboratory and to support domestic nuclear industry, modernization required. Surface science labs - important instruments for materials studies in support of nuclear industry	CTD
10	11:45	12:25	Stop at Bldg. 300: Fuel development lab - essential technology, simplicity eases technology transfer, important spinout business for Canada	CTD
10	12:10	12:50	depart Building 300	
~~11~~	12:15	12:55	exit Active Area - personnel monitoring	

* 2000 August 29

Check point	Blue Tour	Gold Tour		Narrator
			Bldg. 114 - restored, now being used for FNO	FNO
			Bldg. 137 - decommissioned, now being considered for other uses	FNO
12	12:20	10:35	Stop at Waste Management area"B": important infrastructure for active site and for Canadian nuclear waste (historic and current); essential facility for a nuclear laboratory	FNO
			Waste Management area "G" - canisters for dry spent fuel storage	FNO
			low-level waste "D" - support public policy, expense of accepting waste from formerly unregulated sites	FNO
13	12:55	11:05	Depart Waste Management Area (Blue Tour for Cafeteria, Gold Tour for Check Point 2)	
14	13:00	13:00	Private Dining Room for Lunch	

National Research Council Canada | Conseil national de recherches Canada

Steacie Institute for Molecular Sciences | Institut Steacie des sciences moléculaires

John H. Root

Senior Research Officer
Neutron Program for Materials Research
Chalk River Laboratories, Building 459, Stn. 18
Chalk River, Ontario, Canada K0J 1J0

(613) 584-8811 Ext. 3974 Docufax (613) 584-4040
E-mail: john.root@nrc.ca http://neutron.nrc.ca

Canada NRC·CNRC

Functional Materials Program

Programme des matériaux fonctionnels

Molecular Spectroscopy Program

Programme de spectroscopie moléculaire

Neutron Program for Materials Research

Programme neutronique pour la recherche sur les matériaux

Femtosecond Science Program

Programme de recherche femtoseconde

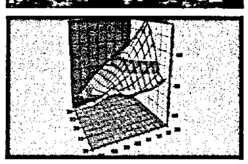
Chemical Biology Program

Programme de biologie chimique

Molecular Interfaces Program

Programme des interfaces moléculaires

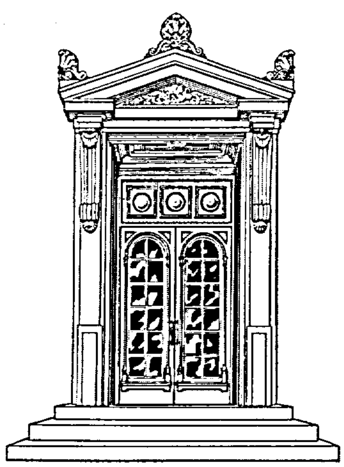
Theory and Computation Program



Programme de théorie et calcul

Contact:

Lise Hughes
Liaison Officer
NRC's Steacie Institute for Molecular Sciences
Ottawa, Canada K1A 0R6
Tel.: (613) 990-0970
Fax: (613) 954-5242
E-mail: Lise.Hughes@nrc.ca
Visit our Web site at
http://www.nrc.ca/sims



Information :

Lise Hughes
Agente de liaison
Institut Steacie des sciences moléculaires du CNRC
Ottawa, Canada K1A 0R6
Téléphone : (613) 990-0970
Télécopieur : (613) 954-5242
Courrier électronique : Lise.Hughes@nrc.ca
Visitez notre site Web à
http://www.cnrc.ca/issm

Canada

Agenda

Visit of

NRCan
&
Nuclear, Non-Proliferation and Disarmament Implementation Agency of the Department of Foreign Affairs and International Trade Officials

to Chalk River Laboratories

2000 Thursday, August 31

FINAL AGENDA

9:30	**Arrival at Outer Gate**	
9:30-9:45	**Delegation will be escorted to Visitors' Centre by CRL staff**	
9:45-10:00	**Registration and badging**	CRL Protective Services
10:00	**Welcome & Site Introduction (20 min)** **Overview of Refurbishment Activities (10 min)** **Pre-Tour Discussion(Two Thom mini-buses will pick up at Visitors' Centre for tour)**	P.J. Fehrenbach D.F. Weeks Visitors' Centre
10:30	**Divided group to board 2 buses** **Driving Tour of site with stops at:** **BLUE TOUR** **1. NRU (25 min)** **W.R. Shorter * Bldg. 150** **2. Fuel Development Lab (20 min)** **J.D. Sullivan * Bldg. 300** **3. Waste Management Area "B" (25 min)** **D.K. Raman** **Thom bus to deliver to Private Dining Room**	 **GOLD TOUR** **1. Waste Management Area "B" (25 min)** **D.K. Raman** **2. NRU (25 min)** **W.R. Shorter * Bldg. 150** **3. Fuel Development Lab (20 min)** **J.D. Sullivan * Bldg. 300** **Thom bus to deliver to Private Dining Room**
1:00-2:00	***4. L U N C H*** ***(18 visitors, P. Fehrenbach, J.P. Labrie, A. Vikis, D. Weeks, B. Shorter, J.D. Sullivan, D. Raman, R. Drouin, J. Bond, D. Taylor)***	***Buffet in Private Dining Room***
2:00	**NRCan Depart** **(Thom bus will pick up visitors from Private Dining Room entrance and deliver to Visitors' Centre for departure.)**	
1:30-2:30	**DFAIT visitors:** **MAPLE Reactor and NPF Tour** **(CRL driver with van will pick up for tour and deliver to Visitors' Centre for departure.)**	J.P. Labrie, J.A. Bond, D.B. Taylor
2:30	**DFAIT Depart**	

* 2000 August 29

List of AECL Personnel

Paul Fehrenbach, General Manager, CANDU Technology Development (CRL)
Jean Pierre Labrie, General Manager, Research and Isotope Reactor Business (SP)
Dale Weeks, Deputy General Manager, Facilities and Nuclear Operations (CRL)
Andy Vikis, Director, Health, Chemistry & Environment (CRL)
Jim Bond, Manager, Isotope Processing Facility (CRL)
Don Taylor, Manager, MAPLE Operations (CRL)
Bob Drouin, Facilities and Nuclear Operations (CRL)
Dave Raman, Waste Management and Decommissioning (CRL)
Bill Shorter, Manager, NRU Operations (CRL)
Jim Sullivan, Fuel Development (CRL)

	Blue Tour Narrators	**Gold Tour Narrators**
SD&E	Andy Vikis	Ron Mitchel
FNO	George Dolinar	Bob Drouin
CTD	Andrew White	Paul Fehrenbach

List of Visitors

NRCan

Minister's Office:

Pat Breton, Press Secretary
John Embury, Director of Communications
Dan Seekings, Policy Advisor, Energy Sector
Marjolaine Rocheleau, Secretary

Deputy Minister's Office:

Robert Laframboise, Executive Assistant (TBC)

Communications Branch:

Mary O'Rourke, Associate Director General
Tracy Thiessen, A/Account Executive, Energy Sector
Alice Barnabé, Communications Officer, Energy Sector
Cathy McRae, Account Executive, Climate Change Sector
Jean-Guy Dégagné, Chief, Editorial Services
Ellen Charette, A/Director, Public Affairs (TBC)

Energy Resources Branch:

Dan Whelan, Director General (TBC)

Nuclear Energy Division:

Arlene Brunke, Public Information Officer
Martin Lamontagne, Analyst

DFAIT

Nuclear, Non-Proliferation and Disarmament Implementation Agency:

Mark Gwozdecky, Director
Maria Raletich-Rajicic, Deputy Director, Nuclear Safety, G-7 & Eastern Europe, CTBT, Bilateral Relations
Terry Wood, Deputy Director, Non-Proliferation, Bilateral Co-operation, Export Controls
Ché van Haastrecht, Nuclear Cooperation Officer

Welcome & Site Introduction

Introduction to AECL's Chalk River Laboratories

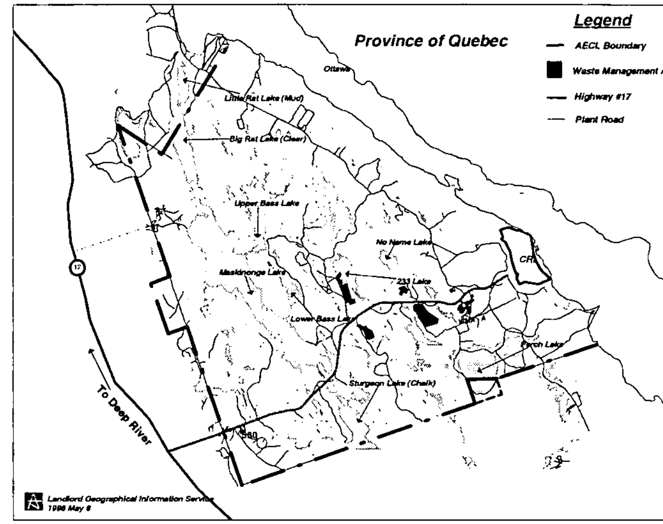
P.J. Fehrenbach

CRL Site Head &

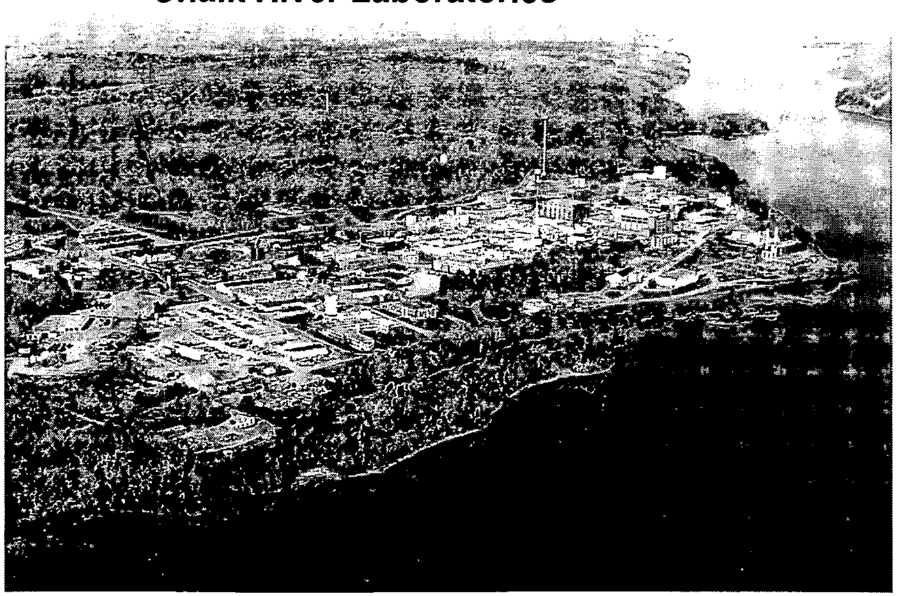
General Manager

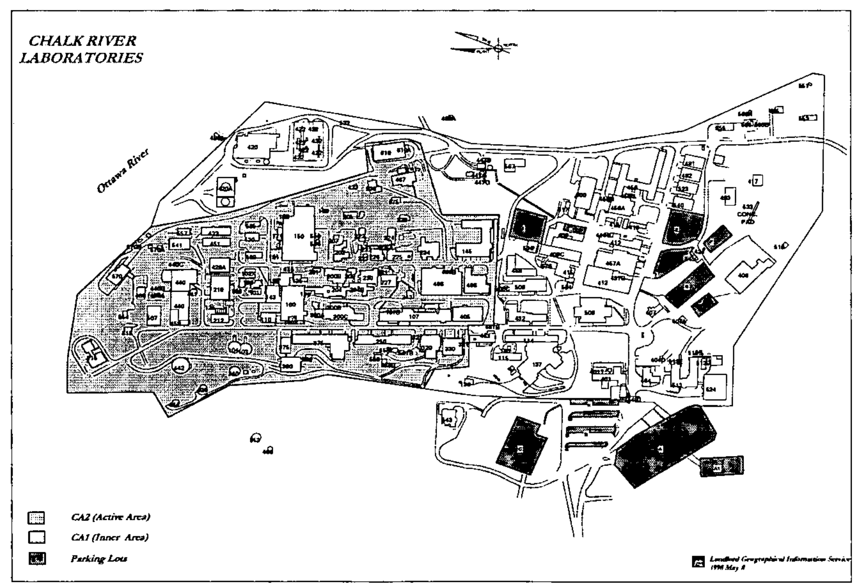
CANDU Technology Development

2000 August 31



Chalk River Laboratories





How We Began

- Canada's nuclear program born at Chalk River Laboratories
- First sustained fission reaction outside USA achieved 1945 Sept. 5 in ZEEP (Zero Energy Experimental Pile)
- From those early days came larger and more powerful research reactor designs:
- 1947 NRX (National Research EXperimental)
- 1957 NRU (National Research Universal)
- NRX and NRU key facilities in development of CANDU design--and other nuclear technology
- NRU produces ~70% of world radioisotope supply for medical and industrial applications
- NRU continues to be used by AECL and NRC for CANDU fuel and materials testing and for advanced materials research

Some Notable Achievements

- 1962: First CANDU prototype, Nuclear Power Demonstration (NPD), feeds nuclear-generated electricity to the Ontario grid
- 1967: A larger prototype, the 208 MW Douglas Point reactor, supplies electricity to the Ontario grid
- 1971: The first of the Pickering A 520 MWe commercial scale CANDU reactors in operation
- 1987: CANDU nuclear power system cited as one of Canada's 10 most significant accomplishments of the first 100 years of engineering in Canada.
- 1994: Dr. Bertram Brockhouse shares Nobel Prize in Physics for work on the applications of neutron beams performed at Chalk River in the 1950's

Wealth & Job Creation of Canadian Nuclear Industry

- $5 billion in electricity/goods/services annually

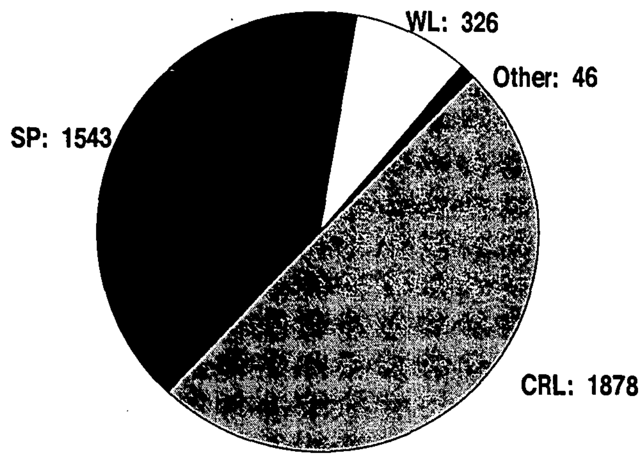
Ernst & Young (1993):

- 30,000 direct/10,000 indirect jobs (150 Co.)
- $700M income and sales tax annually
- $500M trade surplus in 1991
- OH estimate: $17 billion in FX savings ('65 to '89)
- Two CANDU sales to Korea: single largest export order in 1992
- Two CANDU 6 units sold to China in 1996

AECL-CRL Economic Impact on Region 1998/99

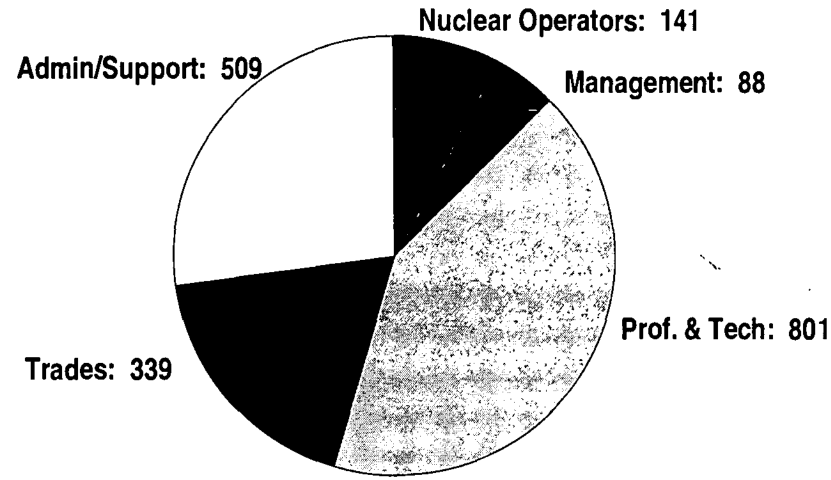
Salaries		$104,000,000
Local Goods & Services		
Contracts	$14,000,000	
Transportation	1,500,000	
Accommodation	200,000	
	$15,700,000	
Grant-in-Lieu of Taxes	~ 2,500,000	
No. of visitors/year	~ 30,000	

AECL Staff Distribution (2000 August)



Total Staff: 3793

CRL Staff Profile

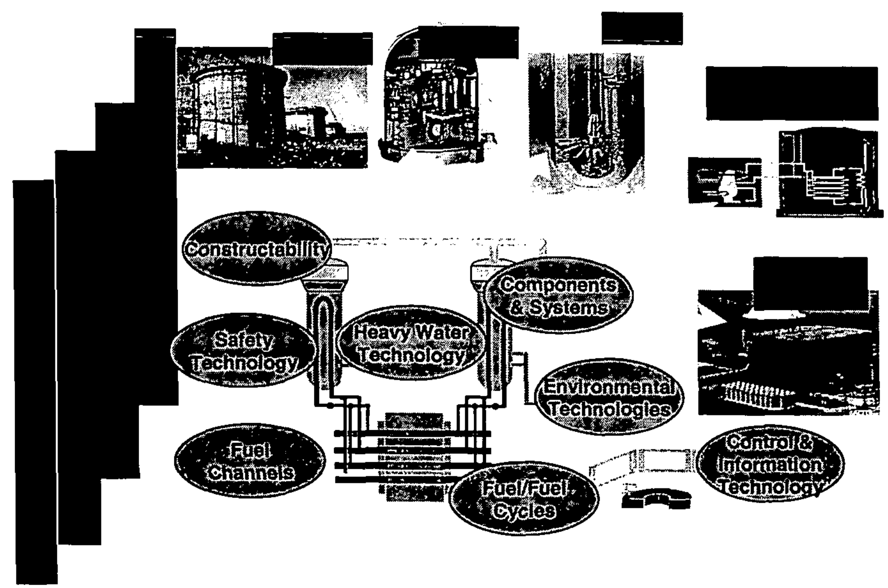


Total Staff: 1878

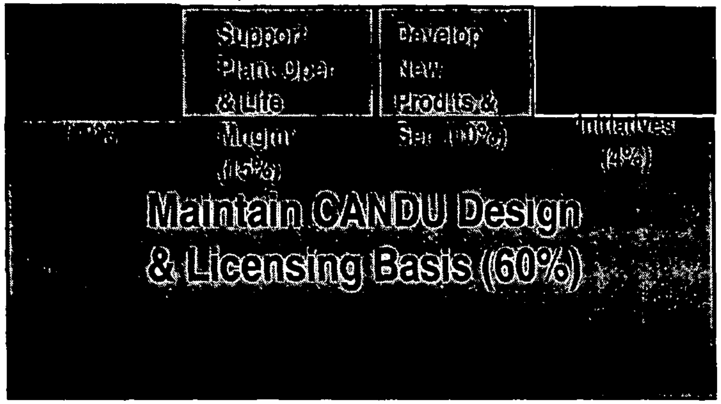
Current CRL Activities/Responsibilities

- **CANDU Technology R&D**
  - Maintain Design & Licensing Basis,
  - Advance CANDU Designs, Products & Services
  - Support Operating Stations - COG (CNSC Stakeholder)
- **Public Policy Support, e.g.**
  - Pu disposition project - "MOX"
  - Radioactive Waste Storage/Management (historic + current)
  - International technical representation (IAEA, NEA, etc.)
- **Commercial Activities**
  - Research Reactor Fuel Fabrication
  - Commercial R&D
- **Neutron Scattering for Materials Science (NRC)**
- **Medical Isotope Production (MDS NORDION)**
- **Facilities and Nuclear Operations**

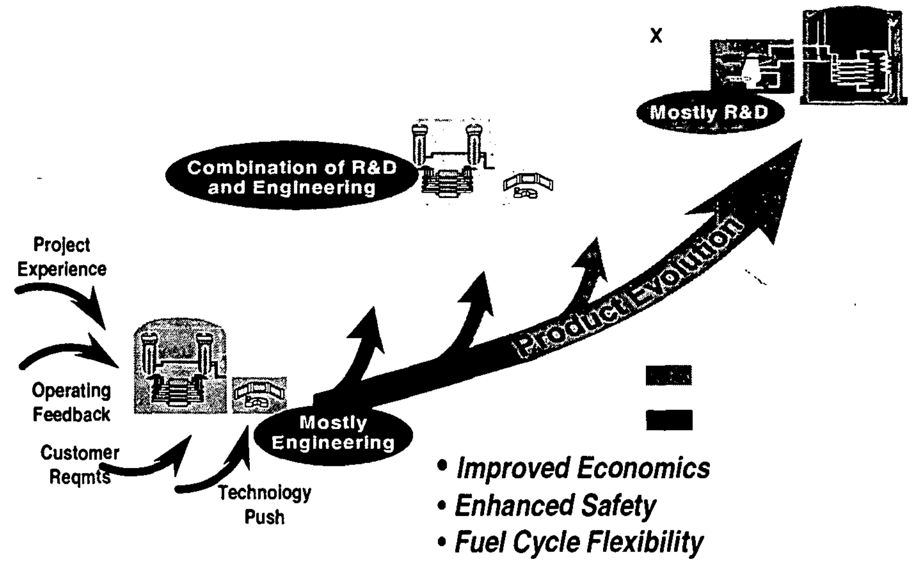
AECL's Range of R&D Activities



CANDU R&D Objectives:



Evolution of CANDU Reactors



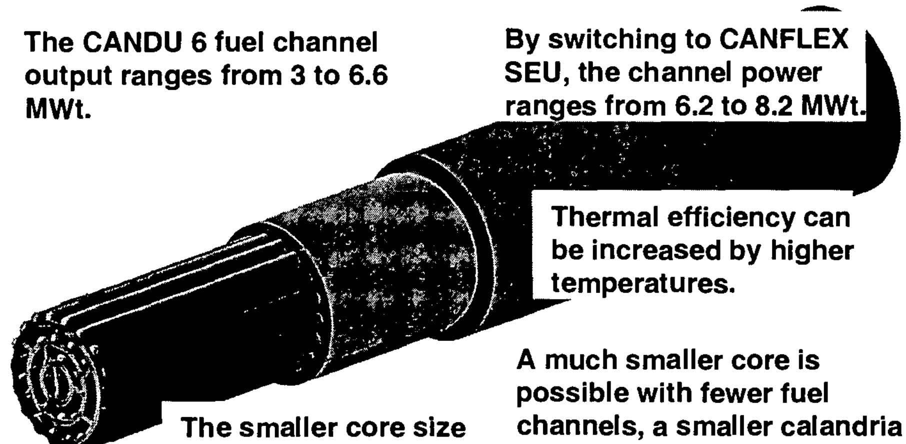
Next Generation CANDU Features

- Significant capital cost reduction - competitive with natural gas
- Higher thermal efficiency - increase coolant outlet temperature (330°C) & pressure
- 600 MWe from smaller core
- Slightly enriched fuel
- Light water coolant - less heavy water
- Enhanced passive safety
- Simplify all other components & systems

NG CANDU - Optimizing the Reactor Core

The CANDU 6 fuel channel output ranges from 3 to 6.6 MWt.

By switching to CANFLEX SEU, the channel power ranges from 6.2 to 8.2 MWt.

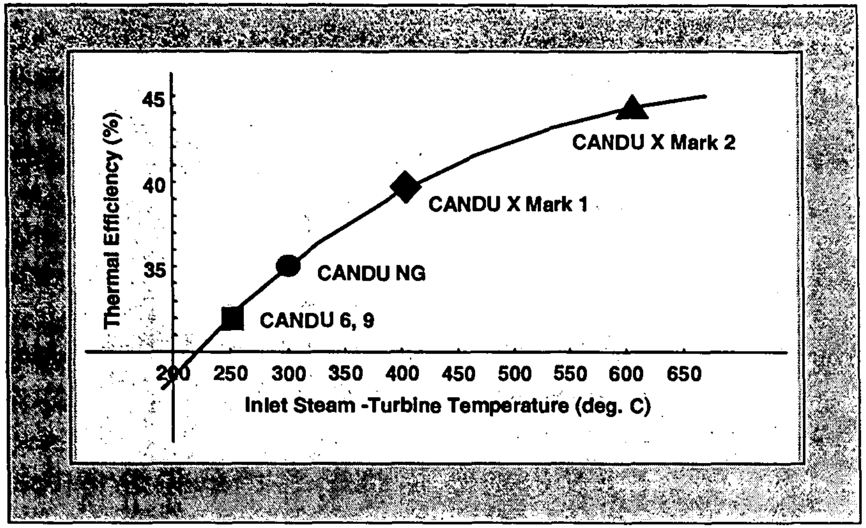


Thermal efficiency can be increased by higher temperatures.

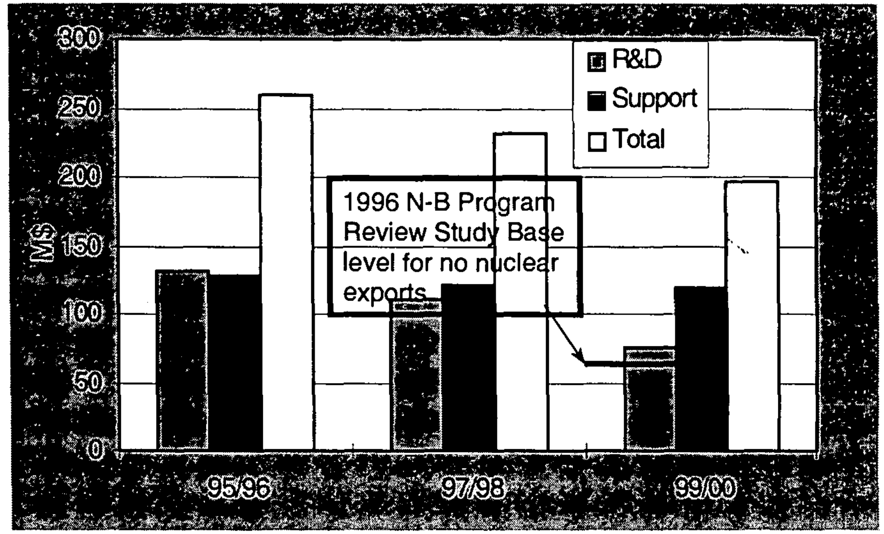
A much smaller core is possible with fewer fuel channels, a smaller calandria and less heavy water.

The smaller core size drives down the cost of many other systems.

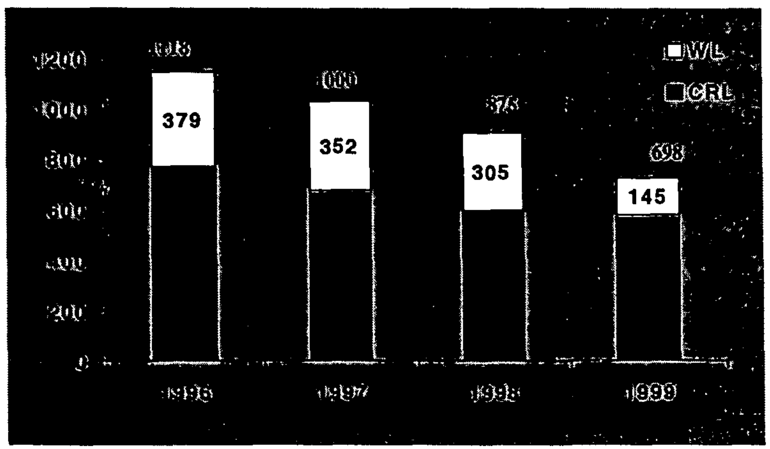
Enhancing Thermal Efficiencies



Canadian Nuclear R&D Funding Trends



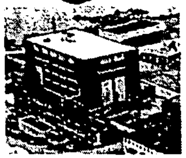
Number of R&D Staff at CRL/WL (R&PD)



Notes:
(1) Includes staff in SD&E, CTD, and PE at CRL & WL
(2) Excludes staff in Engineered Products and Services, Safety & Licensing

New Initiatives at Chalk River

- Two MAPLE reactors and an isotope processing facility for isotope production by NORDION
- Site infrastructure being refurbished and updated
  - site master plan
  - active drain system
  - building consolidation
- New waste management facilities
  - liquid waste treatment plant
  - above ground storage (MAGS)
- Planning underway for Canadian Neutron Facility to replace NRU



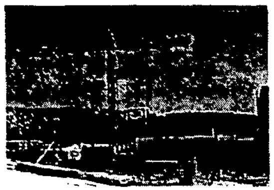
National Research Universal (NRU)
1957-2005

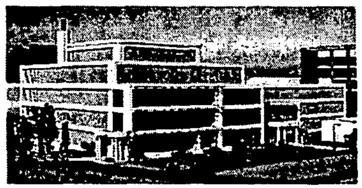
Isotope production
60-70% of world market
50,000 medical procedures daily

Research
CANDU® research & development
NRC materials research

Medical Isotope Reactor
MDS Nordion facilities to take over isotope production
In service by end of 2000

Canadian Neutron Facility
Proposed to take over CANDU® and NRC materials research currently done in NRU





Summary

- CRL is a multi-tenant site
- CRL, as a national nuclear laboratory, is a key element of R&D infrastructure in Canada
  - essential for CANDU development
  - essential for NRC/Canadian university neutron scattering
  - essential for medical isotope production
- A research reactor (CNF to replace NRU) is a key facility for a national nuclear laboratory
- Nuclear industry R&D capability study by COG recommended more R&D spending on CANDU

Overview
Refurbishment
Activities

Natural Resources Canada Visit to CRL

"Facilities & Nuclear Operations"

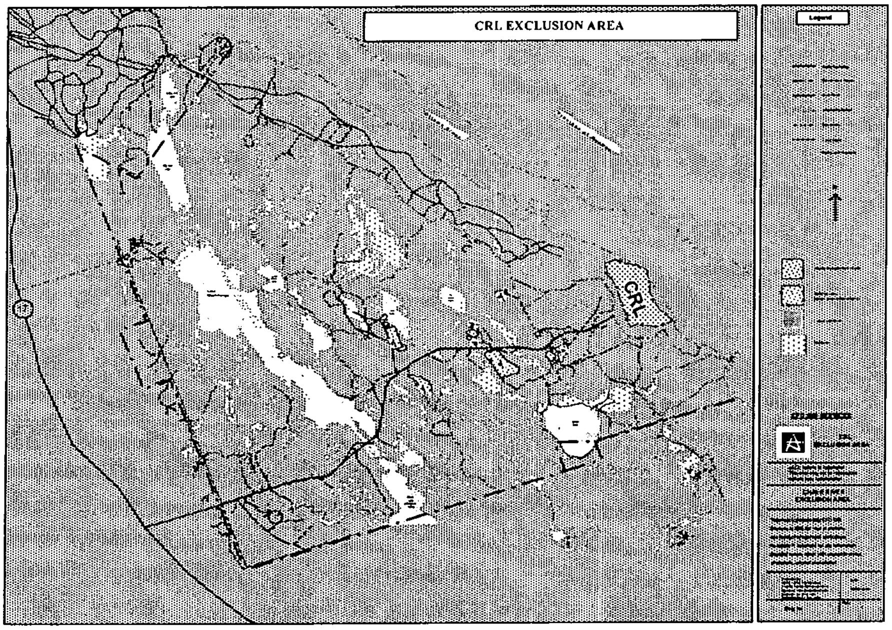
2000 August 31

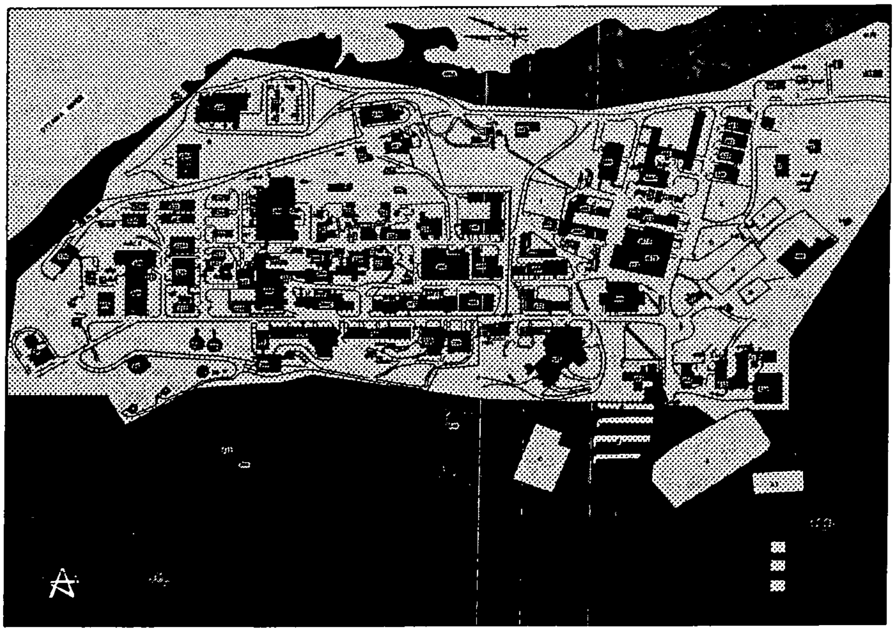
Dale F. Weeks
Deputy General Manager

FNO Mission

We are a valued business partner, relied upon to provide:

- process-integrated facility management and nuclear operations;
- innovative products and services.


CRL EXCLUSION AREA
CRL



FNO Mandate

1. Responsible for safe operation of facilities
   - site licence holder for AECL (CRL & WL)
   - compliance with Nuclear Safety Act
   - monitoring & control of emissions
   - radiation monitoring of personnel
   - emergency preparedness
2. Decommissioning of nuclear facilities
   - safe shut-down and storage with surveillance
   - ultimately achieve end state

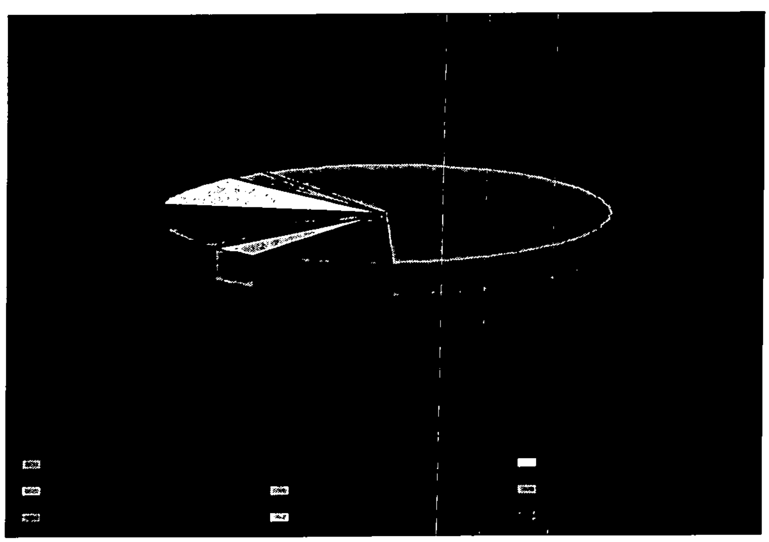
FNO Mandate ... con't.

3. Provision of operating and landlord services:
   - 172 site buildings;
   - diverse tenants; offices, machine shops, and research laboratories,
   - electrical distribution & other services equivalent to a small town,
   - heating, ventilation & air conditioning loads equivalent to University of Ottawa,
   - processes systems and equipment range from conventional to nuclear
   -

FNO Mandate .... con't

4. Provision of general services:
    - road, grounds and vehicle maintenance;
    - building structure maintenance and renewal
    - food & cafeteria services;
    - sewage treatment;
    - fire protection and response;
    - manufacturing.
5. Radioactive & non-radioactive waste management:
    - treatment, segregation, storage, disposal.

FNO Human Resources - Total People CRL: 877



CRL Site - "Layered" View

City Services

- Municipal services and utilities (taxes, sewerage, heat, electricity)

Industrial Site & Services

- Basic industrial site and services (bldg. maint, envir monitoring, etc.)

Nuclear Licensed Site

- Permission to conduct nuclear activities

Waste Management Capability

- Ability to manage nuclear waste

Operating Nuclear Site

- Services to conduct nuclear operations

License Listed Facilities

- Specific nuclear facilities to conduct nuclear work

KEY ISSUES & FUTURE CHALLENGES

➪ **Regulatory:**

- Highly regulated site (e.g. Cdn. Nuclear Safety Commission)
- increasing regulatory scrutiny

➪ **CRL Infrastructure:**

- Old and complex site with attendant maintenance/refurbishment needs

➪ **Waste & Liabilities:**

- Risk and liabilities from past waste practices

➪ **Business Climate:**

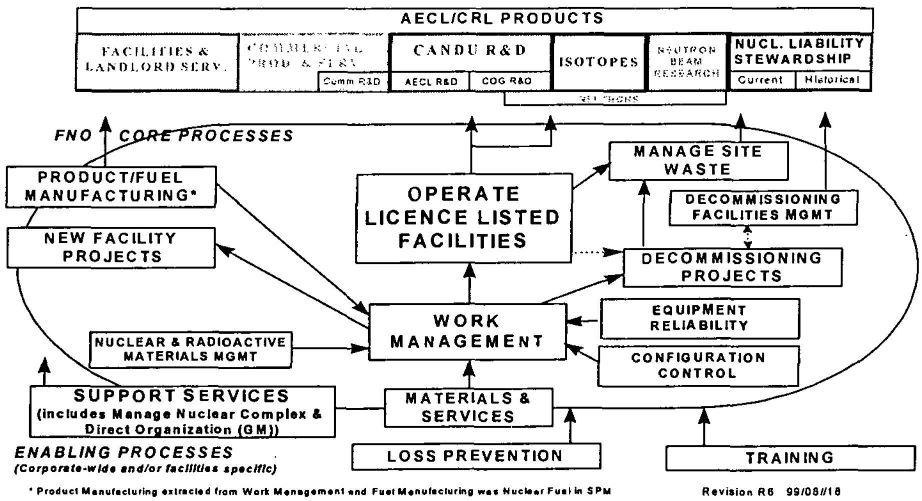
- Adopting contemporary business tools to site operations including business planning, activity based management, process focus

➪ **Partnerships**

- Developing partnering business relationships, a new era for AECL (e.g integrating DIF to AECL operations; NRC; Health Canada)

KEY ISSUES & FUTURE CHALLENGES

FNO BUSINESS PROCESS MODEL



KEY ISSUES & FUTURE CHALLENGES

CRL Infrastructure Refurbishment:

Major projects completed since 1994:

- e.g. 2 new boilers for powerhouse; new security and monitoring gatehouses; decontamination centre upgrades; life safety and fire protection upgrades; Waste Treatment Centre upgrades; refurbishment of 32,000 sq'; demolition of 55,000 sq'

Major projects in progress:

- e.g. Active Drain System replacement (in excess of 6000 feet of buried line) ; Modular Above Ground Storage (MAGS); NRU upgrades; B107 and B430 Transfer to Decommissioning

KEY ISSUES & FUTURE CHALLENGES

CRL Infrastructure Refurbishment → Site Master Plan:

- Vision and a road map for decision making
- Comprehensive site plan linked to strategic business plans
- Integrate industry standard facility management principles:
  - Maintenance funding model for campus style facilities based on Present Replacement Value (PRV)
  - Establishes a Life Cycle Index (LCI) for all buildings
  - Establishes a deficiency listing program

Key Objectives of Site Master Plan:

- Match space with business needs - consolidation resulting in space reduction of 269,000 sq'
- Refurbish Valued Assets
- Reduce Long Term Liabilities

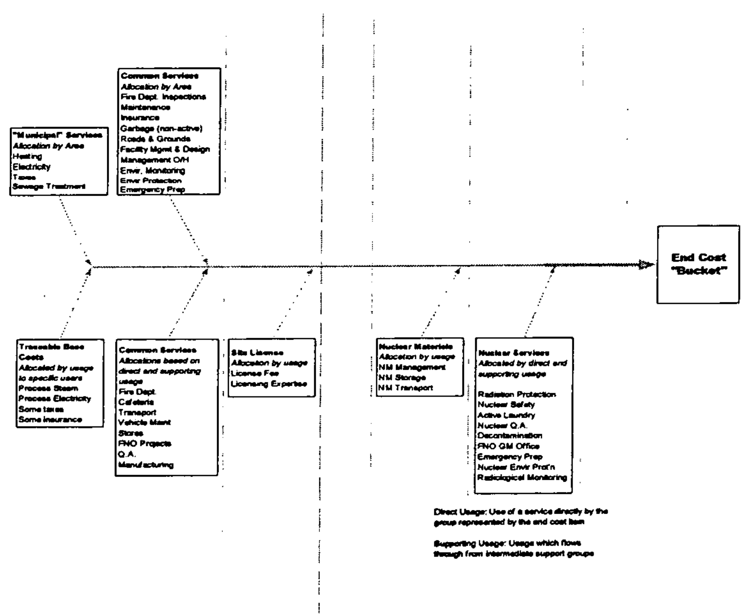
Impact on CRL Real Estate

Use Category (sq ft)	Existing	Post SMP
• Building Services	93,593	64,365
• Labs	221,291	178,865
• Offices	212,084	185,659
• Process Services	173,305	148,824
• Workshops	84,962	53,185
• Storage	245,934	202,361
• Common Areas	310,221	238,913
• Total	1,341,390	1,072,172

•

FNO Cost Attribution

FNO - Cost Attribution



Direct Usage: Use of a service directly by the group represented by the end cost item

Supporting Usage: Usage which flows through from intermediate support groups

Research and Decommissioning Costs 1998/99 Actuals

Research		87
Indirects -		
Facilities		
Chalk River	75	
Whiteshell	11	
	86	
Common services	29	
Amortization	2	
Total indirects		117
Total costs before		204
Decommissioning		16
Capital		13
Total		233

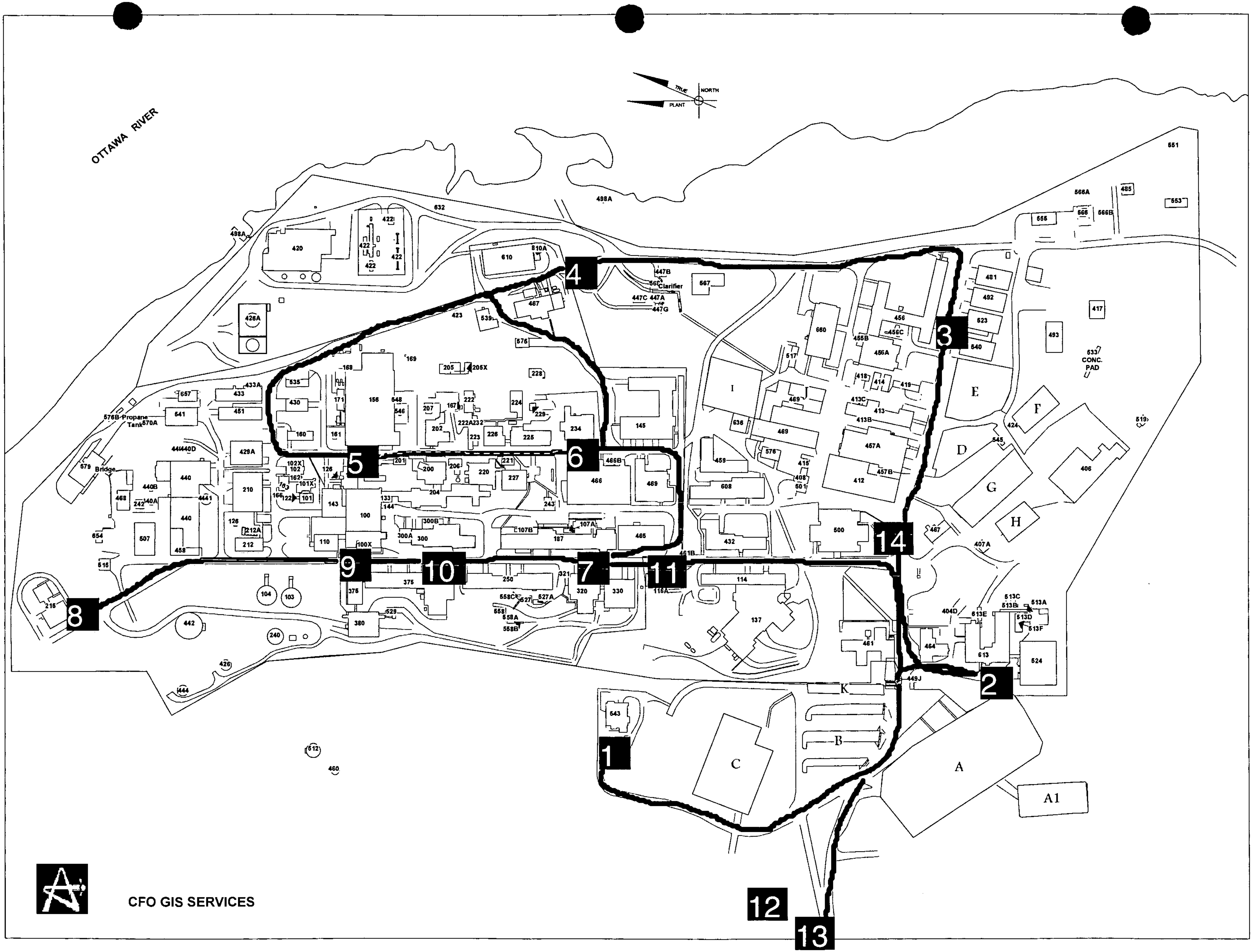
Facilities and Nuclear Operations

*** Estimated Base Cost to Meet Minimum Requirements Exclusive of Research**

$ Millions

	1999/00 Sept Frcst (Inclusive of Research)	Estimated Portion	Estimated Base * Cost (Exclusive of Research)
CRL			
GM	(2.1)	0.3	(1.8)
Admin Business Centres	(0.4)	0.1	(0.3)
Licensing SPOC	(1.7)	0.0	(1.7)
QA	(0.9)	0.1	(0.8)
Planning	(1.0)	0.4	(0.6)
Nuc Safety	(0.8)	0.0	(0.8)
Safety & Radiological Protection	(5.4)	0.2	(5.2)
Facility Maintenance Resourcing	(4.7)	2.3	(2.4)
NRU	(20.2)	0.0	(20.2)
Waste Management	(3.8)	(1.1)	(4.9)
Nuclear Facility Operations	(2.8)	0.5	(2.3)
Common Facility Operations **	(22.4)	3.3	(19.1)
Manufacturing Services	(0.2)	0.0	(0.2)
IRP	(0.4)	0.4	0.0
Projects	(5.8)	1.8	(4.0)
Projects (M&A)	(0.7)	0.4	(0.3)
MMIR interface project	(0.3)	0.3	0.0
Total CRL	(73.6)	9.0	(64.6)

Map & Tour



OTTAWA RIVER
TRUE
NORTH
PLANT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
A
A1
B
C
D
E
F
G
H
I
K
420
422
426A
610
810A
447B
Clarifier
447C
447A
447G
567
423
539
467
576
660
456
456C
455B
456A
481
492
523
540
417
493
533
CONC.
PAD
551
566A
485
553
555
566
566B
498A
632
498A
535
430
160
161
171
156
548
546
169
168
205
205X
228
207
167
202
222
222A
232
223
226
224
225
229
234
145
636
469
459
576
415
408
501
608
418
414
419
413C
413
413B
457A
412
457B
424
545
406
519
433A
433
451
657
641
576B Propane
Tank
570A
429A
440
440D
579
Bridge
440
440B
468
242
140A
4441
210
102X
102
162
163
101X
166
122
101
126
143
201
200
206
220
221
227
466B
466
469
204
243
133
144
100
300B
300A
300
107A
107B
187
465
432
500
467
407A
126
212A
212
507
458
654
110
100X
461B
515
215
104
103
378
375
250
321
320
330
116A
114
137
380
529
558C
527
527A
558
558A
558B
442
240
426
444
461
464
404D
613E
613
513C
513B
513A
513D
513F
524
449J
543
512
460
CFO GIS SERVICES

Check point	Blue Tour	Gold Tour		Narrator
1	10:30	10:30	Depart Visitor Centre (Blue Tour to Check Point 2, Gold Tour to Check Point 12)	
2	10:35	11:15	Buildings 513, 524 Radiological sciences support to government policy, environmental protection, protection of staff working at nuclear sites	SD&E
			Hospital/Clinic - required for initial screening of radiation incidents	FNO
			Cafeteria - used by all staff, required for staff from active area	FNO
			Fire Department - required to protect assets and staff	FNO
			Bldg. 412 - **for site support, R&D and commercial deliverables**	FNO
			Quonsets - used for storage, need replacement	FNO
3	10:45	11:25	Bldg. 456 - houses support and R&D staff, slated for retirement	CTD
			Waste treatment centre - basic requirement for an industrial site	FNO
4	10:50	11:30	Active Area Gate - security check	
			Power house - another basic requirement for an industrial site	FNO
5	10:55	11:35	Stop at NRU: used for isotope production, CANDU R&D (fuel, materials, safety, chemistry), basic R&D (neutron beam materials studies)	
5	11:20	12:00	Depart NRU	
			Active Drain Project - necessary refurbishment to active site infrastructure	FNO
			Bldg. 234 - Universal Cells, required to support Isotopes, CANDU business, site operations	FNO
6	11:25	12:05	MTF/loops - thermalhydraulics studies fundamental to water reactors, mix of new and old facilities	CTD
			Active machine shop - key support to active site	FNO
			ZED-2 - provides basic physics data for CANDU reactors, required to support Canadian nuclear utilities and the CNSC (e.g. data fundamental to analysis of large Loss-of-Coolant accidents)	CTD
			Bldg. 469 & 145 - relocating reactor safety R&D programs from Whiteshell Laboratories	CTD
7	11:30	12:10	Bldg. 320/330 - active chemistry, "modern" 20-year old buildings	CTD
			Bldg. 107 - building due for decommissioning, requires extensive characterization/decontamination	FNO
			Bldg. 250 - houses tritium/heavy water/reactor chemistry R&D, older building requiring alternatives for programs/staff and decommissioning	SD&E
			Bldg. 210 - decontamination, support required for an active site	FNO
8	11:35	12:15	Building 215 CECEUD: demonstration of key CANDU technology - cheaper and more environmentally friendly. investment payoff - recycling used heavy water	SD&E
9	11:40	12:20	MAPLE and NPF: successful spinout business, requires infrastructure of an active site; important to world health industry	CTD
			NRX and associated buildings - decommissioned reactor	FNO
			Building 375 - Fuel and materials cells - key facility for nuclear laboratory and to support domestic nuclear industry, modernization required. Surface science labs - important instruments for materials studies in support of nuclear industry	CTD
10	11:45	12:25	Stop at Bldg. 300: Fuel development lab - essential technology, simplicity eases technology transfer, important spinout business for Canada	CTD
10	12:10	12:50	depart Building 300	
11	12:15	12:55	exit Active Area - personnel monitoring	

Check point	Blue Tour	Gold Tour		Narrator
			Bldg. 114 - restored, now being used for FNO	FNO
			Bldg. 137 - decommissioned, now being considered for other uses	FNO
12	12:20	10:35	Stop at Waste Management area"B": important infrastructure for active site and for Canadian nuclear waste (historic and current); essential facility for a nuclear laboratory	FNO
			Waste Management area "G" - canisters for dry spent fuel storage	FNO
			low-level waste "D" - used to accept contaminated waste from other Canadian sites	FNO
13	12:55	11:05	Depart Waste Management Area (Blue Tour for Cafeteria, Gold Tour for Check Point 2)	
14	13:00	13:00	Private Dining Room for Lunch	

CANDU Life Sciences

CANDU Life Sciences Centre

The CANDU Life Sciences Centre, to your right as you enter the Chalk River Laboratories (CRL) plant gate, houses AECL's program in Environmental and Radiological Sciences. These programs develop the knowledge and technologies to measure and control CANDU power emissions and assess their radiological impact on man and the environment.

The Environmental program includes R&D to identify CANDU waste and emission sources, and technologies for reducing releases at the source. R&D is also conducted to assess the dispersion of potential releases to the environment via various pathways and to assess the impact of such releases on plant and animal life. In addition, the program carries out all the radiological and non-radiological environmental monitoring for the CRL site.

The Radiological Sciences program includes R&D funded jointly by the CANDU Owners Group utilities and AECL to develop improved technologies to measure radiation and radiation dose to workers in a CANDU power reactor environment. In addition, the Radiological Sciences program includes a component of radiation biology research aimed at understanding the interactions of radiation with living systems and the role of genetic and environmental factors in in determining cancer risk. The latter program focuses on low radiation dose and dose-rates relevant to exposures of atomic radiation workers and the public as a result of nuclear fuel cycle activities. The research includes *in vivo* experiments with mice using a state-of-the-art Biological Research Facility.

The AECL program in Radiological Sciences traditionally served the national needs benefiting several customers (AECL, CNSC, Canadian nuclear utilities, Canadian uranium industry, Health Canada, et al.). Program cutbacks, as a result of the changing focus of AECL and the Canadian nuclear utilities, have placed the future of this program at risk and necessitated a new structure to enable the program to access research funds to supplement those of the nuclear industry. Presently, the program has been transferred to Health Canada's Radiation Protection Bureau, on an interim basis, as a first step towards the establishment at CRL of an independent institute, the **National Centre for Radiological Sciences (NCRS)**, with a mandate to:

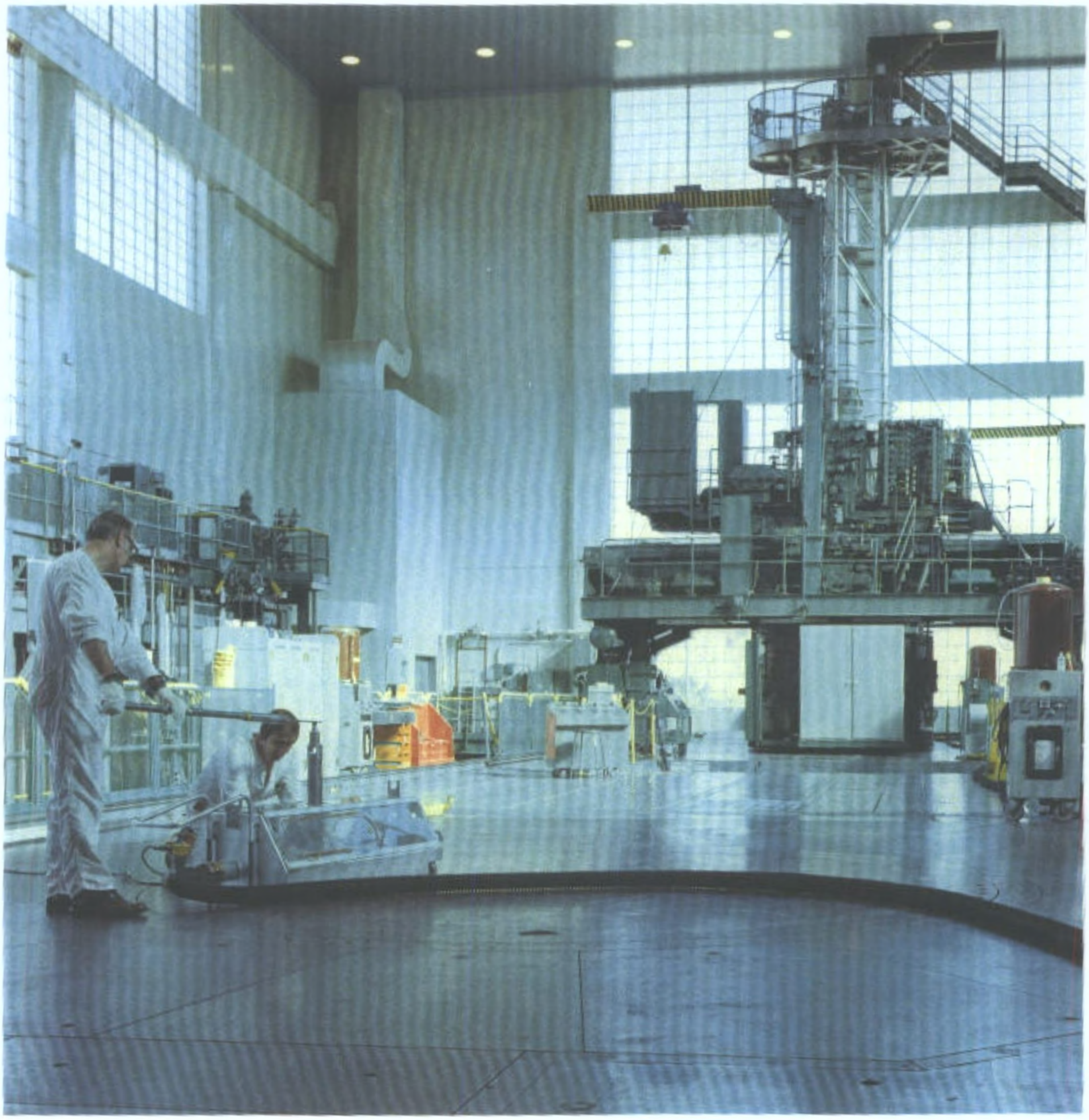
- Carry out R&D in radiological sciences
- Offer R&D on a commercial basis to the nuclear industry
- Provide dosimetry services to AECL and other customers on a commercial basis
- Inform and advise government and industry, and participate in formulating national / international radiological standards.

It is expected that NCRS would network with other government departments and universities across Canada to provide as broad a level of technical expertise as possible and to leverage industrial funding with government research grants.

NRU

NRU Research Reactor

Irradiation Facilities and Services



AECL

Chalk River Laboratories

The National Research Universal (NRU) Reactor at Chalk River Laboratories is one of the largest and most versatile research reactors in the world. In operation since 1957, it was built for three (3) main purposes: to provide engineering research and development support for the CANDU® power reactor program; as a major Canadian facility for basic neutron physics research; and as a supplier of medical (which includes sixty percent (60%) of the world's Molybdenum-99 supply) and industrial radioisotopes.

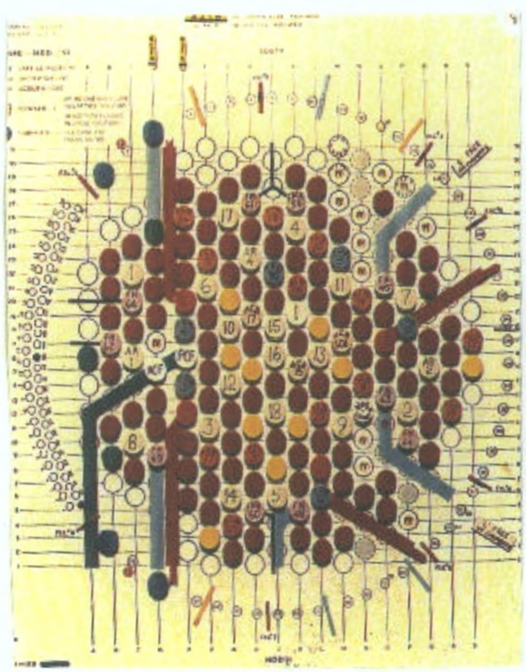
The NRU Reactor is one of the few research reactors in the world available for a wide variety of commercial irradiations. The applications include:

- fuels and materials testing for all types of nuclear reactors;
- fuel testing under accident conditions;
- testing of fusion blanket materials, and
- research sample irradiations.

The NRU Reactor also provides facilities for neutron scattering, not only for the study of structure and dynamics of solids and liquids, but also for the determination of residual stress, texture and temperature inside engineering components.

Reactor Specifications

The NRU Reactor operates at power levels up to 135 megawatts (thermal) and is heavy-water-moderated and cooled. The reactor is refuelled at power. The core consists of an aluminum cylinder approximately 3.7 m (12.1 ft) high and 3.5 m (11.5 ft) in diameter. It is made up of 227 vertical lattice sites arranged in a hexagonal array with a pitch of 19.7 cm (7.75 in). Control rods and enriched uranium fuel rods occupy about half of the lattice sites; the remainder of the sites are for low-temperature/low-pressure experiments and irradiations. Two high-pressure/high-temperature experimental loops and eight beam tube facilities are also available.



Experimental Facilities

Loops

CANDU® and full-length Light Water Reactor (LWR) fuel strings can be tested in the U-1 and U-2 high-temperature, high-pressure, light-water-cooled loops. Typical neutron fluxes at these loop sites are 2×10^{17} n/m²/s (fast) and 3×10^{18} n/m²/s (thermal). The U-1 and U-2 Loops are used extensively for:

- development and testing of fuel cycles and designs;
- materials tests;
- accident transient (Loss-Of-Coolant-Accident (LOCA) and Severe Fuel Damage) tests, and
- thermalhydraulic studies.

NRU Reactor Loop Specifications

	U-1	U-2
In-core Tubes	2	2
Configuration	parallel	series
Location	L-8, E-12*	E-20, O-17
Coolant	light water	light water
Max. Operating Pressure (MPa)	10.7	10.7
Normal Operation Flow (kg/s)	17 (L-8) 1 (E-12 †) 0.7 (E-12 ††)	20
Normal Operation Temperature (°C)	310† 354††	310
Heat Removal Capacity	4.5 MW	8 MW
In-core Dimensions: Diameter (mm)	103.4	103.4
Length (mm)	3000	3000

* The E-12 site is for the Blowdown Test Facility which has a stainless steel pressure tube, re-entrant from the bottom.

† pressurized water

†† steam

"Inspection of Test Fuel Prior to Irradiation in U-1 & U-2 Loops"

Blowdown Test Facility (BTF)

The Blowdown Test Facility, connected to the U-1 Loop, is available in the NRU Reactor to support AECL's program on fuel behaviour and fission product release under accident conditions. The facility will allow simulations of loss-of-coolant accidents (LOCAs) with or without additional impairment of emergency cooling. Data on fuel performance, fission product release and transport, and decontamination, is used for benchmarking codes and providing a more reliable estimate of the consequences of severe fuel damage.

"Installing the BTF Fuel Test Assembly"

Fusion Test Facility

A fusion test facility has been designed and installed to evaluate solid fusion blanket materials. The facility is used for vented capsule tests, designated Chalk River In-Reactor Tritium Instrumented Capsule (CRITIC), which simulate a miniature segment of a fusion blanket. On-line tritium analysis is performed in a dedicated control centre.

"CRITIC Fusion Test Facility"

Fast Neutron Rods

The fast neutron (FN) rod is a fuel rod with a cylindrical central cavity in which test specimens are irradiated. The central cavity is 7.2 cm in diameter, 7.89 m long and is open at the top. Annular bundles surround the cavity. Most of the material irradiations are performed in MK 4 natural uranium FN rods which produce a fast neutron flux up to 2.3×10^{17} n/m^2/s, (E > 1 MeV). A MK 7 enriched uranium FN rod is also available which gives a fast neutron flux up to 6.0×10^{17} n/m^2/s, (E > 1 MeV).

Test specimens are contained in inserts which are suspended inside the FN rod cavity. Helium cooled inserts are used for performing single and multi-specimen constant load uniaxial and biaxial stress creep tests. Containment tubes are used for wet insets where specimens are cooled by low pressure light water at about 55°C. These wet inserts are used for static irradiations which include bent-beam stress relaxation tests, irradiation growth tests, and pre-irradiation of fracture toughness, tensile and metallographic specimens.

"Final Inspection of the Specimen Capsule Assembly of the Uniaxial Creep Insert for a MK-IV FN Rod"

Hydraulic and Pneumatic Capsule Facilities

The Hydraulic Capsule Facility (HCF) uses re-circulating heavy water to insert and remove material contained in aluminum capsules from the NRU Reactor core. A string of up to twenty (20) capsules can be hydraulically transferred to and from the core. The heavy water, and the capsules are maintained at about 55°C.

The HCF has several features which are attractive for materials testing. First, since the HCF is located in an "unfuelled" reactor site, it has a high thermal neutron flux (about 2×10^{18} n/m^2/s and a correspondingly high thermal to fast neutron flux ratio. The HCF is therefore used to study the effects of neutron energy on the microstructural irradiation damage and mechanical properties of fuel channel materials. Second, the hydraulic capsule transport system allows specimens to be loaded and removed from the core while the reactor is operating at full power. Therefore, short irradiations are possible with the HCF. Aluminum capsules have been constructed for static irradiation of zirconium alloy and steel specimens. The capsule has an internal cavity (8 mm x 8 mm x 29.3 mm) in which four (4) flat tensile bars can be contained. The capsule can also contain several transmission electron microscopy specimens or metallic wireflux monitors by reducing the number of tensile specimens. In recent irradiations the capsules have contained cadmium or steel shielding around the specimens to further filter out neutrons of specific energy levels.

Isotope Production

Medical and industrial isotopes are produced in the NRU Reactor for MDS Nordion and Theratronics International Ltd. Facilities allow for the irradiation of both single and bulk samples under many different neutron fluxes. Irradiation times of a few seconds to several weeks are common, although some isotopes may be in the core for several years prior to processing. Many isotopes are produced, such as, Molybdenum-99, Xenon-133, Iodine-125 Cobalt-60 and industrial isotopes such as Iridium-192.

Water Bays

Water bays in the reactor building are available for disassembly and examination of fuels and materials experiments. Examination equipment includes a portable field-model Questar telescope and remote video and 35 mm cameras.

Neutron Beam Facilities

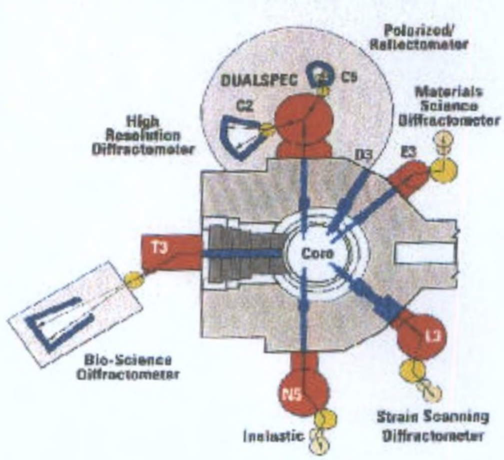
The neutron beam holes in NRU are a source for thermal neutrons that are used to investigate the properties of materials at the atomic level. Six beam holes are in use and they access a core flux as high as 3×10^{18} n/m^2/s. Thermal neutrons are the single most versatile probe of materials and neutron scattering is able to provide unique information for a broad range of scientific and engineering fields. The technique is used in materials science and engineering, in biology and chemistry, in physics and geology and many other scientific and engineering disciplines. It can be used to study solids and liquids, alloys and minerals, ceramics and composites, magnetic systems and thin films, disordered materials and amorphous systems, biological systems and polymers. Applications range from the most basic research studies to the inspection and development of applied industrial products and processes.

The neutron scattering experiments are carried out on instruments called neutron spectrometers. These are large, computer-controlled devices at each beam hole that permit the researcher to measure the characteristic pattern and energy of the neutrons scattered from the sample under investigation. This data enables the scientist to learn about the atomic arrangements and the atomic motions in the material. Materials can be examined under many different conditions; at temperatures ranging from near absolute zero to 1400°C, at pressures up to 20,000 atmospheres, in magnetic fields as high as 8 Tesla, under loads up to 5 tonnes and in the presence of hostile environments. More than 80 scientists from university and industrial laboratories in Canada and other countries come to Chalk River to carry out their neutron measurements on the neutron beam facilities at NRU.

Neutrons are non-destructive and penetrate deeply into many materials. They are used to probe deep inside engineering components, measuring stress and texture within industrial structures and qualifying new materials and fabrication processes. A successful commercial contract business, Applied Neutron Diffraction for Industry (ANDI), carries out such measurements for many Canadian and foreign industrial customers.

The enormous impact neutron scattering has had in advancing our understanding of materials and the fundamental information it can provide, was recognized in 1994 by the award of the Nobel Prize in Physics to B.N. Brockhouse of McMaster University and C.G. Shull of the Massachusetts Institute of Technology, the two founders of neutron scattering. The pioneering work of Professor Brockhouse was carried out at NRU in the 1950s. It led him to invent a new, highly sophisticated neutron instrument known as a triple-axis spectrometer. These are now standard instruments at every neutron laboratory throughout the world. Professor Brockhouse was the founder of the neutron scattering group at Chalk River. His seminal experiments at NRU paved the way for neutron scattering to develop into a key, strategic investigative tool for the examination of materials.

NRU Reactor, Chalk River



Beam Hole	Spectrometer Type
C2	DUALSPEC, High Resolution Powder Diffractometer Structure determination, phase composition/transitions, time dependencies.
C5	DUALSPEC, Polarized Beam Triple-Axis Spectrometer/Reflectometer Magnetic structures and dynamics, structure of surfaces and interfaces.
E3	Materials Science Diffractometer Texture analysis, precipitation kinetics, radiography, stress scanning.
L3	Strain-Scanning Diffractometer Stress scanning, tensile testing, effects of applied loads.
N5	Triple-Axis Spectrometer Atomic and molecular structure and dynamics.
T3	Bioscience Diffractometer Structures and phases of large biomolecular systems.

Experience

The NRU Reactor operates consistently at an annual capacity factor of 80%. An experienced operating staff of more than 120, provides year-round, quality assured service. Chalk River Laboratories as a whole employs approximately 2 000 staff with a wide range of skills available for the support of research and commercial programs carried on in the NRU Reactor. Related expertise includes fuels and materials testing, design, project management, construction, commissioning, decontamination, and radiation and industrial safety. The laboratories' Hot Cell Facility offers comprehensive post-irradiation examination and analysis of fuel from all reactor types, reactor components and other materials requiring remote-handling, including accelerator-activated materials.

The high neutron flux, large core size, and varied facilities of the NRU Reactor attract a wide range of projects, including:

- fuel development and testing;
- neutron diffraction examination of residual stresses, texture and temperature in pipes, welds, jet turbine blades, ceramic composites and other industrial materials;

- neutron determination of structure and dynamics of crystalline, amorphous, liquid, superconducting, magnetic and plastic inorganic and organic materials;

- irradiation and examination of fusion blanket materials;

- CANDU® pressure tube irradiations;

- remote tooling work and decommissioning associated with reactor vessel changes; and

- neutron activation analysis of forensic samples.

NRU has undertaken a program of seven major safety upgrades designed to enhance the reactor's defenses against external events consistent with modern standards. This work is integrated into the regular operating cycles of the reactor and is scheduled for completion in 1999, enabling the NRU Reactor to continue its significant contribution to science, medicine, and the CANDU power reactor program world-wide.

For more information, contact:

~~J.M. Mark~~ W.R. SHORTER
Manager, NRU Operations
AECL
Chalk River Laboratories
Chalk River, Ontario
KOJ 1JO Canada
Telephone: (613) 584-3311
Ext. 3021
Fax: (613) 584-1178

MAPLE & NPF

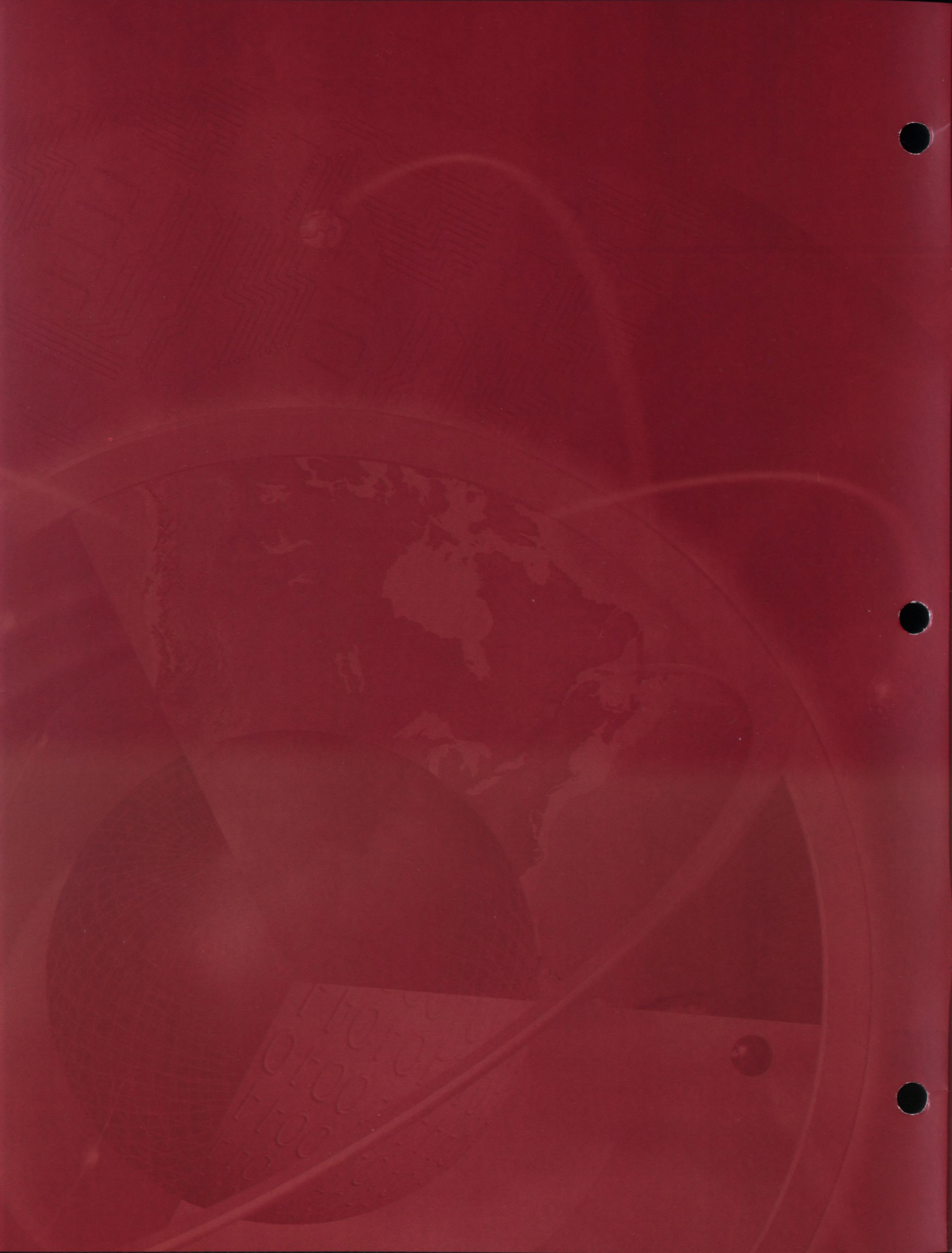
The MAPLE Research Reactor

Proven Technology

Global Experience

Canada

AECL
Atomic Energy of Canada Limited



The MAPLE Research Reactor

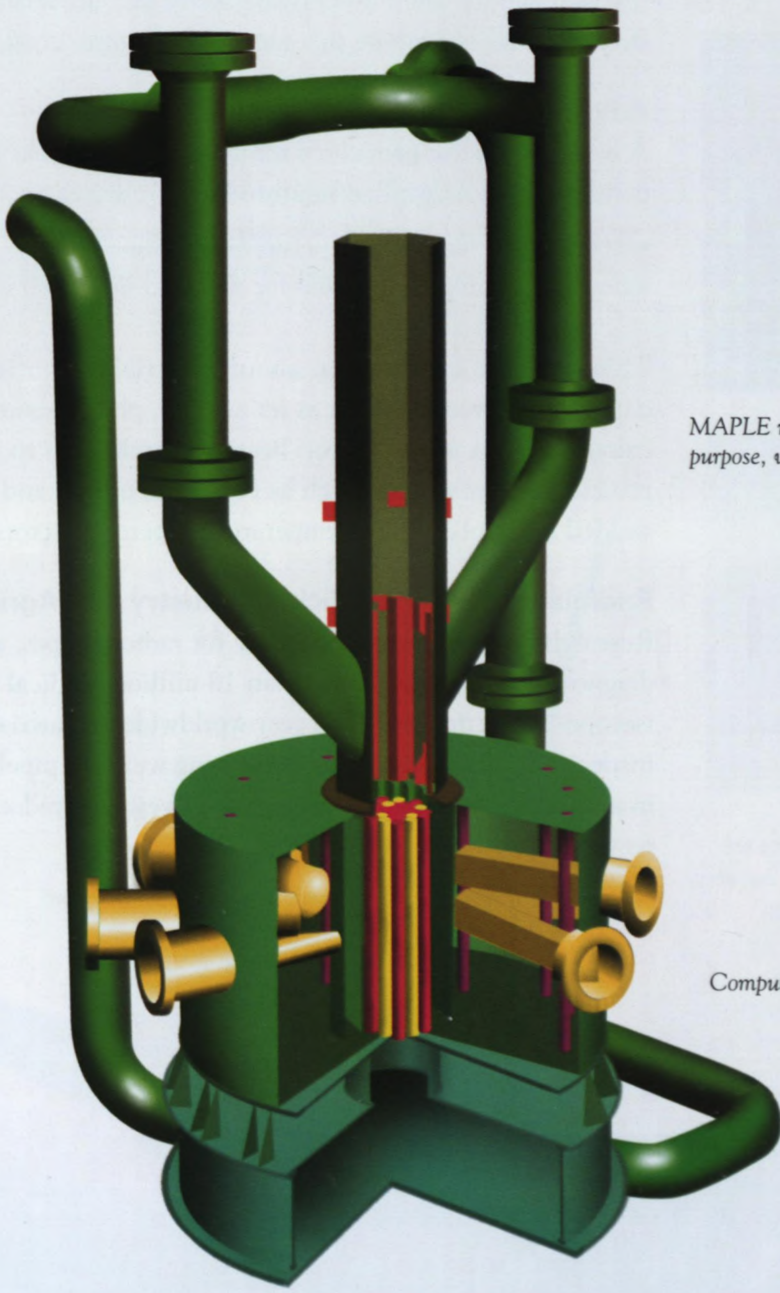
The MAPLE research reactor, developed by Atomic Energy of Canada Limited (AECL), is one of the most advanced research reactor technologies available today.

The MAPLE design is flexible and able to accommodate each user's individual requirements.

MAPLE reactors are multi-purpose, with many applications. Their flexible design is able to accommodate each user's individual requirements. Options include a major facility for neutron beam research, a source of radioisotopes for medical and industrial purposes, a facility for nuclear fuel and materials testing, as well as a source for other diverse applications.

MAPLE is a low-pressure, low-temperature, open-tank-in-pool type research reactor that uses low-enriched uranium (LEU) fuel. It can be designed for power levels between 10 and 40 MW_t. The core is compact and is both cooled and moderated by light water. Surrounding the light water core is a heavy water reflector tank, which maximizes the available neutron fluxes.

Access to the core is through an open chimney. Vertical in-core and out-of-core irradiation sites can be provided for radioisotope production, neutron activation analysis, and silicon doping. These are directly accessible from the pool top. Horizontal beam tubes, for neutron scattering and other applications, are provided; however, the number and locations vary depending on specific requirements. Loops for testing nuclear fuel and components can also be added.



MAPLE reactors are multi-purpose, with many applications.

Computer-aided drawing

The Need for a Research Reactor

The future competitiveness and standard of living of all nations in the emerging global economy will increasingly depend on scientific progress. In the 21st century, research reactors will be key facilities in this drive for technological innovation. With a research reactor, a country can:

- develop advanced materials for consumer and industrial products
- produce radioisotopes for medical, industrial and agricultural applications
- supply inspection, analysis and problem-solving services to industry and business
- provide support for a nuclear power industry
- establish a central training and teaching facility

Research reactors are used to improve rail steel, inspect aircraft turbine blades, provide radioisotopes for medical diagnosis and therapy, test power reactor components and provide an ongoing training facility.

Research reactors provide a wide range of applications at a low cost and with a high level of safety. Compared with alternate neutron sources, they are capable of producing a wider range of medical and industrial isotope products. As well, they provide a central research facility where the private sector and universities can combine their innovative strengths and contribute to a nation's long-term economic growth.

Advanced Materials, Advanced Products

A research reactor provides a source of neutrons that allows scientists and engineers to conduct basic or applied neutron beam research to:

- better understand the structure of materials
- develop advanced materials for new and improved consumer and industrial products

This valuable information about materials helps improve products that affect our daily lives—products such as jet aircraft, pharmaceuticals, computer disks and pocket calculators. As well, neutron beam research leads to improvements in industrial products and materials, such as polymers, metals and ceramics, gas pipelines, rail steel, welded structures, high-temperature superconductors, and biological materials.

Radioisotopes for Medicine, Industry and Agriculture

Research reactors provide a source for radioisotopes, which are used for medical diagnosis and therapy. More than 18 million medical procedures that use radioactive isotopes are performed each year worldwide. Industrial isotopes can be used for inspection purposes, such as examining welds in pipelines. Radioisotopes can also be used in agriculture, for example, to improve livestock productivity, to control insects and other pests, and to irradiate food.

Industrial and Commercial Services

Research reactors can provide neutrons for key inspection, analysis and problem-solving services for industry and business. These include neutron beam analysis, neutron radiography and neutron activation analysis. Neutron beam analysis provides unique information on the structure of materials. Additionally, industrial neutron radiography facilities can provide further non-destructive inspection of components and materials. For example, aircraft turbine blades and aerospace components can be inspected for flaws, and components can be viewed while operating. Neutron activation analysis facilities can provide an assaying capability for minerals as well as a forensic analysis tool.

Nuclear Power Industry Support

For those countries that have a nuclear power program, or that plan to have one in the future, a research reactor is a vital component of the supporting infrastructure. It can be used to test power reactor fuel, components, materials and coolants, as well as to provide key training.

Teaching and Training

A national research reactor is a scientific meeting place where researchers from many disciplines, and from many countries, can work together, exchange ideas and forge new collaborations. A research reactor provides an ongoing national training facility for new generations of researchers, continuing to foster important industrial research and to help retain this unique expertise.

The MAPLE Advantage

The MAPLE design offers a combination of both proven and state-of-the-art technology. AECL's commitment to research and product development continuously evolves its technology to advanced standards—constantly addressing customer needs for advanced features, reduced costs, improved performance, and enhanced safety.

MAPLE 1, designed, constructed and operated by AECL, started up in February 2000. The second reactor and the new isotope processing facility will begin operating later in 2000. The facilities are owned by MDS Nordion.

MAPLE is designed to meet today's most demanding requirements for safety and licensing.

It has passive safety features from its tank-in-pool design, as well as other safety features such as:

- a Plant Display System (PDS) that works in concert with the advanced Digital Control System (DCS) to enhance process monitoring and diagnostic capabilities, allowing staff to access and utilize data more effectively
- two independent and diverse safety shutdown systems
- two parallel and independent cooling loops
- a building design that incorporates containment and confinement features

MAPLE offers high performance with:

- a compact core design that provides very high neutron fluxes per unit of power
- high ratio of peak thermal flux in the reflector to total core power
- high fuel burnup
- standard LEU fuel, with the option to use advanced, high-density LEU fuels in the future

MAPLE offers flexibility, with options including:

- cold neutron source
- hot neutron source
- thermal and cold neutron guides
- irradiation rigs
- epithermal columns for boron neutron capture therapy
- fuellable sites in-core or in-reflector
- test loop for nuclear fuels and materials

MAPLE's design is both proven and current:

- incorporated into Korea's 30 MW_t HANARO multi-purpose research reactor, which has been in service since 1995
- two 10 MW_t MAPLE reactors, dedicated to isotope production—MAPLE 1 started up in February 2000; MAPLE 2 will begin operating later in 2000.
- pre-project activities completed for a new 40 MW_t state-of-the-art Canadian Neutron Facility (CNF) for Materials Research

The CNF, a MAPLE reactor, is designed as a state-of-the-art facility for advanced materials research and neutron beam applications.

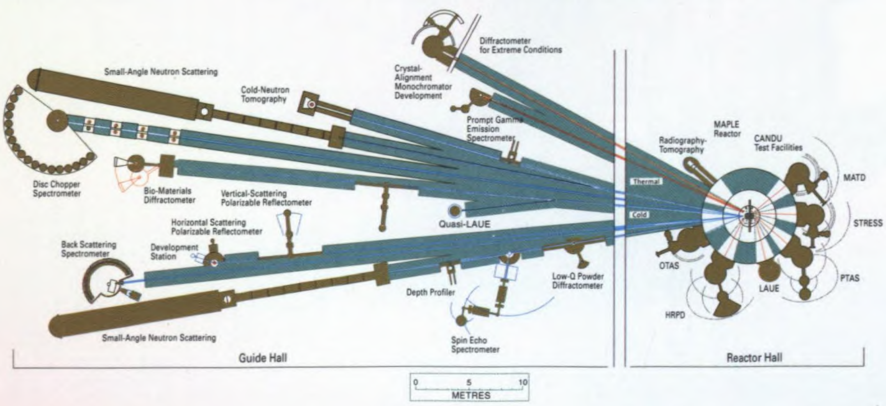
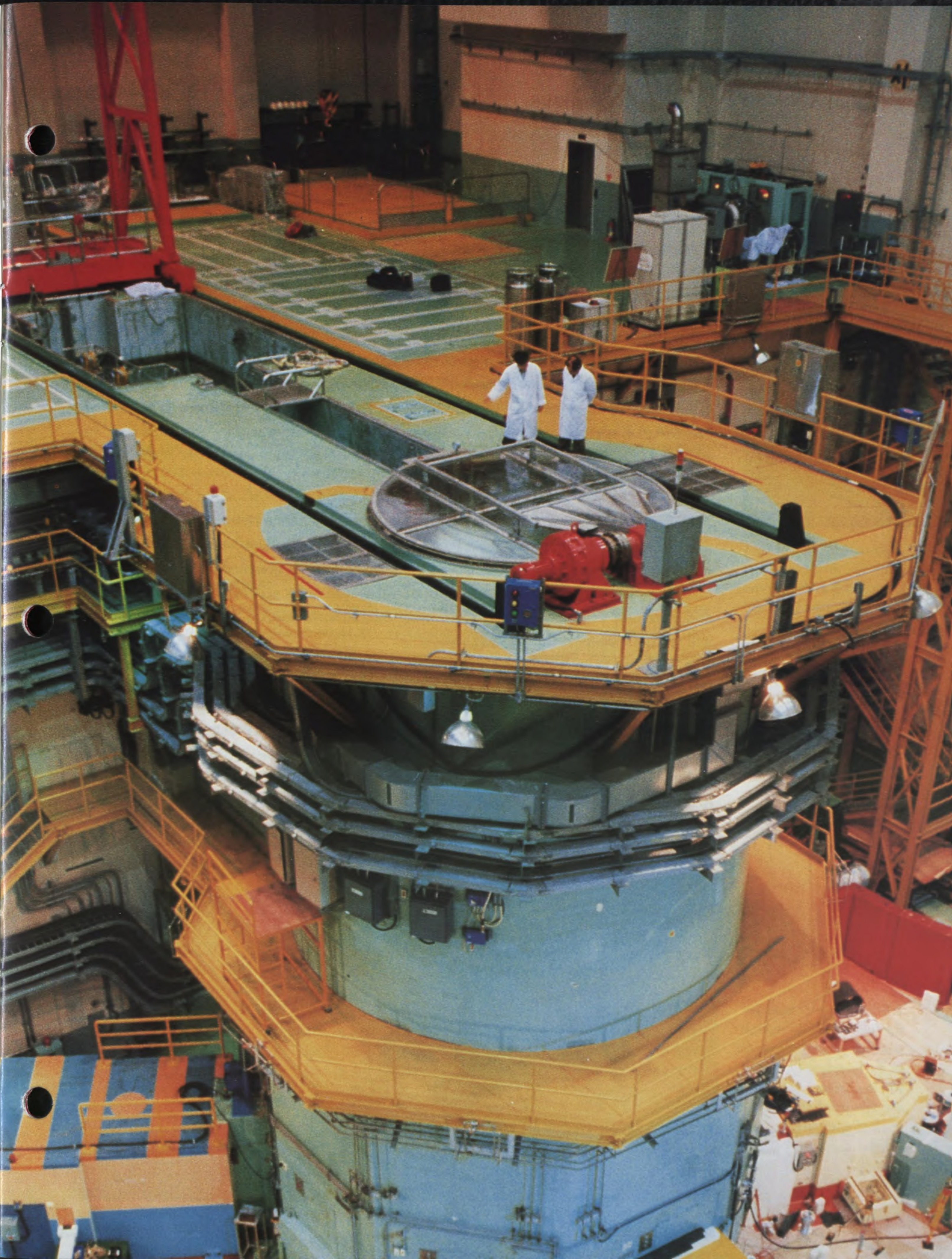


Photo on opposite page: MAPLE technology was incorporated into the Korea Atomic Energy Research Institute's (KAERI) HANARO multi-purpose research reactor.



The AECL Advantage: Experience and Commitment

AECL has a long history in research reactors. It has more than 50 years' experience operating research reactors, and has designed, developed and constructed 17 worldwide.

AECL has designed, developed and constructed 17 research reactors worldwide.

Recent Project Experience

In addition to its research reactor experience, AECL is one of the most successful exporters of commercial power reactors in the world today. The CANDU® nuclear power reactor was designed by AECL, and 34 have been built on four continents.

AECL's experience remains current. The company is overall project manager for three CANDU commercial power reactors that are currently under construction—two in China and one in Romania. As well, AECL designed, is constructing and will operate two MAPLE reactors and an associated processing facility that will be dedicated to isotope production. These reactors are for MDS Nordion, producer of most of the world's major diagnostic and treatment isotopes.

Adding even further to AECL's wide experience is its recent completion of pre-project activities for a new state-of-the-art research reactor, the Canadian Neutron Facility (CNF) for Materials Research. It is a MAPLE reactor and is designed for advanced materials research for industry and universities, as well as for testing power reactor fuels and materials. The CNF design incorporates the latest in neutron beam technology, and will feature a state-of-the-art cold source.

NRU—One of the World's Finest

AECL's National Research Universal (NRU) started up in 1957, and is still one of the world's finest research reactors. It is the centre for neutron beam research in Canada, and provides a research facility for testing reactor fuels and materials. NRU currently provides about 70% of the world's medical radioisotopes. The CNF is designed to replace NRU's neutron capabilities later in this decade.

AECL is project manager for two CANDU nuclear power reactors being built at the Qinshan Phase III site in China. The reactors are scheduled to begin producing electricity in 2003.

Partnership, Technology Transfer and Local Industry Participation

AECL has vast international experience in managing large sub-contractor groups and consortia, in turnkey projects and other contractual arrangements. The two CANDU units being built at the Qinshan site in China are a multinational endeavour, with major subcontractors from China, the Republic of Korea, Japan, the United States and Canada. AECL is also part of an international consortium to complete Cernavoda Unit 2 in Romania.

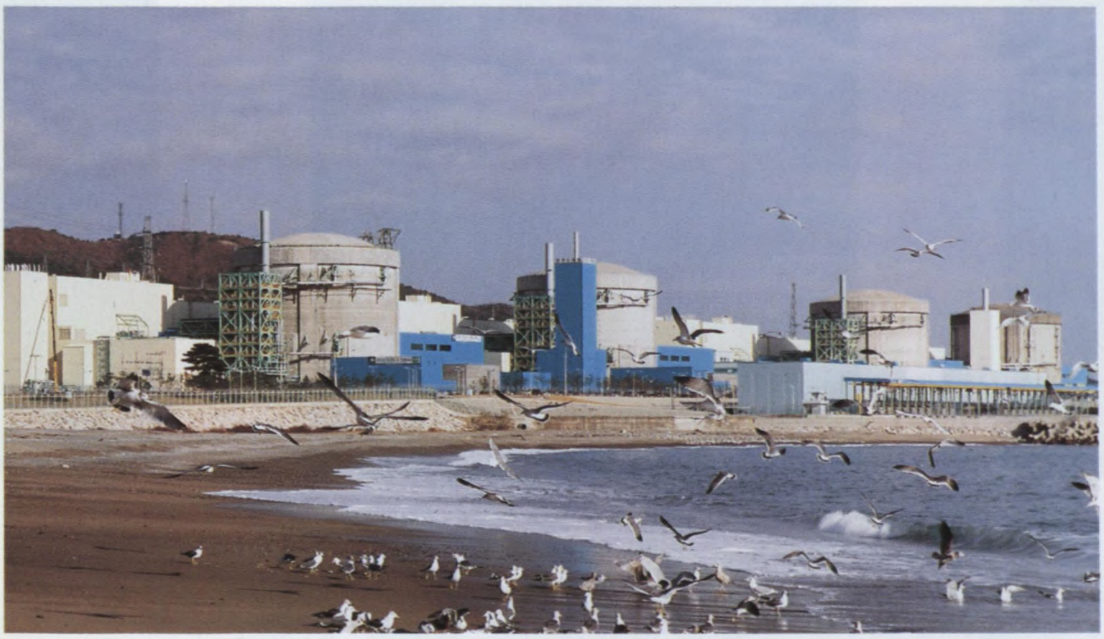
AECL is committed to transferring technology to its partners. Korea is an excellent example, with more than 20 years of close cooperation between AECL and various Korean organizations and companies. These include the Korea Atomic Energy Research Institute (KAERI) with whom AECL cooperated on the HANARO research reactor project.

Also, while the first CANDU commercial power reactor in Korea was a turnkey project, the client's responsibility for management and equipment has steadily increased for the subsequent three units. As well as Korea, other countries, such as Romania and Argentina, have also been transferred the technology to manufacture fuel for their CANDU reactors.

Romania manufactures fuel for its first CANDU reactor, which has been operating since 1996.

Long-term Commitment

AECL is a commercial corporation, wholly-owned by the Government of Canada. Clients can count on AECL for long-term support—from the evolutionary design of MAPLE, to the initial stages of the project, through to its completion and beyond. AECL provides support through the licensing process and the commissioning of the reactor, and has years of experience in operating research reactors. AECL works with customers over the life of the reactor to keep it operating at peak efficiency, extending the life of the facility and reducing maintenance costs.



AECL's 20-year partnership with Korea has resulted in the completion of the Wolsong four-unit CANDU reactor project in 1999.

MAPLE: Its Pedigree

AECL's evolutionary engineering design approach has resulted in several generations of multi-purpose reactors. Highlights from the past 50 years include:

AECL's evolutionary design approach has resulted in several generations of multi-purpose reactors.

1945 — ZEEP (Zero Energy Experimental Pile)

In 1945, this 10 watt research reactor achieved the first controlled nuclear chain reaction outside the United States. Built at AECL's laboratories at Chalk River, Ontario, it also provided valuable information on the characteristics of heavy-water-moderated fuel lattices for the reactors to come, including early CANDU commercial power reactors. ZEEP was retired from service in 1970.

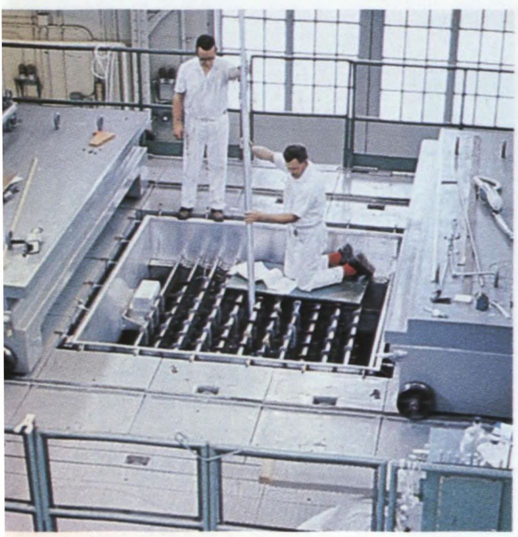
1947 — NRX (National Research Experimental)

This 42 MW_t research reactor achieved criticality in 1947 and generated the highest neutron flux available anywhere at the time. NRX, which was shut down in 1992, was operated by AECL to develop fuels, materials and nuclear components for power reactors, to produce radioisotopes for medicine and industry, and to generate neutron beams for basic and applied research. Reactors of the NRX design were supplied on a turnkey basis to India in 1960 and Taiwan in 1969.

1957 — PTR (Pool Test Reactor)

This 10 kW_t pool-type reactor was built at Chalk River in 1957. It used 93% enriched uranium-aluminum plate-type fuel. The reactor, which was retired from service in 1990, was used for burnup measurement of fissile samples from NRX.

1945 **1947** **19**



1957 — NRU (National Research Universal)

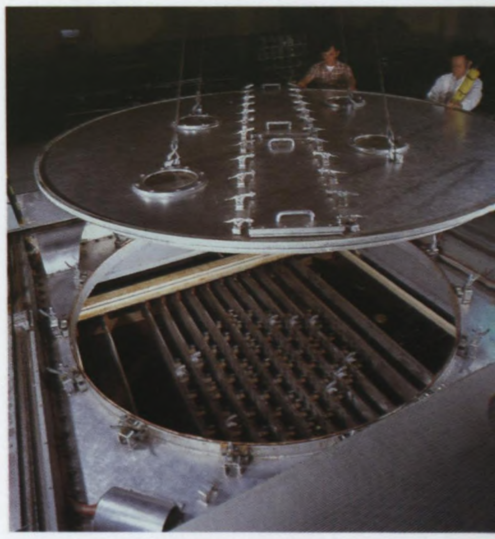
Designed as a 200 MW_t reactor, NRU began operating in 1957, and is still one of the world's best-performing research reactors. It produces a high percentage of the world's medical and industrial radioisotopes, including molybdenum-99, a critical isotope used for medical diagnoses. NRU's large irradiation space has been an important factor in the testing of fuel bundles and fuel-channel components for CANDU reactors. NRU is used for research into reactor fuels, materials and components, and is the centre for neutron beam research in Canada. Originally designed for operation with highly enriched uranium (HEU), AECL has been operating NRU with low-enriched uranium (LEU) fuel since 1991.

1960 — ZED-2 (Zero Energy Deuterium-2)

This larger version of ZEEP started up in 1960 to facilitate measurements on larger, more representative CANDU lattices. It has also been used for definitive studies of the effects of heavy water and alternative light-water and organic coolants. The reactor is still operating at Chalk River where it is used for reactor physics research.

NRU is still one of the world's best-performing research reactors.

57 — 1957 — 1960



1965 – WR-1 (Whiteshell Reactor-1)

The central experimental facility at AECL's Whiteshell Laboratories in Manitoba, Canada from 1965 to 1985, the WR-1 featured the first AECL-designed calandria fabricated from stainless steel. It also demonstrated the feasibility of an organic-cooled CANDU power reactor.

1968 – SLOWPOKE-2 (Safe Low Power Critical Experiment)

The prototype of this 20 kW_t reactor was tested in the PTR pool at Chalk River from 1968-1970. It was designed for neutron activation analysis, trace radioisotope production and as a tool for teaching nuclear science and engineering. It is the only reactor considered safe enough to be licensed for unattended operation. Eight SLOWPOKE reactors have been supplied to universities and research centres across Canada and in Jamaica. Six remain in operation.

1995 – HANARO

MAPLE's core design technology was incorporated into the Korea Atomic Energy Research Institute's (KAERI's) 30 MW_t HANARO multi-purpose research reactor, which started up in 1995. It has capabilities for fuel and materials testing, neutron beam experiments, isotope production, silicon irradiation and neutron radiography.

1965 — **1968** — **19**

MAPLE: A Current Technology

MMIRs (MDS Nordion Medical Isotope Reactors)

These two 10 MW_t MAPLE reactors are owned by MDS Nordion and will be dedicated to isotope production. AECL is the designer, constructor and operator of the two reactors that will have capability for bulk irradiation. MAPLE 1 went critical in February 2000, and MAPLE 2 and the new processing facility will begin operating later in the year.

CNF (Canadian Neutron Facility) for Materials Research

Proposed by AECL and the National Research Council of Canada (NRC) as a replacement reactor for the NRU research reactor at Chalk River Laboratories, the 40 MW_t CNF is designed to be a key component of a vital national materials research infrastructure for Canada in the 21st century. The CNF will provide Canada's scientific community with a state-of-the-art facility for advanced materials research and neutron beam applications. The CNF is a MAPLE research reactor that will have a cold source to open up new scientific applications, as well as experimental "loops" for CANDU power reactor fuels and materials research.

The CNF is designed as a state-of-the-art facility for advanced materials research and neutron beam applications.

95 — 1999 — 21st Century —

AECL Worldwide

AECL Head Office
Marketing & Sales
2251 Speakman Drive
Mississauga, Ontario
Canada L5K 1B2
Tel: (1-905) 823-9040
Fax: (1-905) 855-1383

AECL Argentina
Pedro Goyena 1510
1640 Martinez
Buenos Aires
Argentina
Tel: (54-114) 798-4633
Fax: (54-114) 798-6092

AECL China
Suite 2912 North Tower,
Beijing Kerry Centre
1 Guang Hua Road,
Chao Yang District
Beijing 100020
People's Republic of China
Tel: (86-10) 8529-9872
Fax: (86-10) 8529-9875

AECL Indonesia
Graha Aktiva,
Suite 401
JI. H.R.
Rasuna Said Blok X-1,
Kav. 03
Jakarta Selatan 12950
Indonesia
Tel: (62-21) 520-3531
Fax: (62-21) 522-0967

AECL Korea
8th Floor,
Duk Myung Building
170-9 Samsung-dong,
Kangnam-ku
Seoul 135-091
Republic of Korea
Tel: (82-2) 539-3030
Fax: (82-2) 567-0072

AECL Romania
1 Dimitrie Cantemir
Boulevard
SITRACO Center
(Building B2)
Entrance 2, Floor 6
Sector 4
Bucharest, Romania
Tel: (40-1) 330-3101
Fax: (40-1) 330-3103

AECL Thailand
Abdulrahim Place
990 Rama IV Road,
Suite 3302
Silom, Bangrak
Bangkok 10500, Thailand
Tel: (66-2) 636-2305
Fax: (66-2) 636-2307

AECL Turkey
177/19 Atatürk Bulvari
06680 Kavaklidere
Ankara, Turkey
Tel: (90-312) 417-3211
Fax: (90-312) 425-1000

Visit our website at:
http://www.aecl.ca

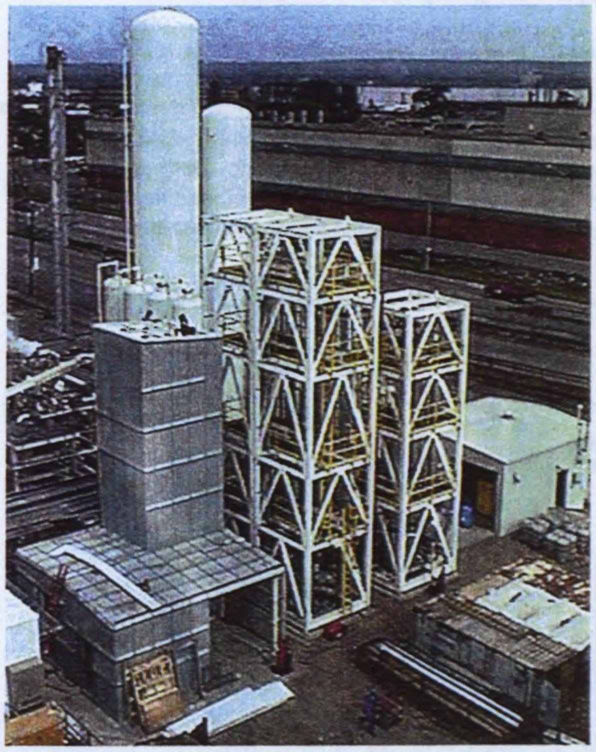
Publié aussi en français.

Printed in Canada. April 2000. Marcom Catalogue #3-1. D1364

CECEUD Heavy
Water Supply

Prototype CIRCE Plant Project

A Demonstration of AECL's New Heavy Water Production Technology



Prototype CIRCE plant in Hamilton, Ontario

AECL has undertaken a project to demonstrate a new heavy water production process called Combined Industrial Reforming & Catalytic Exchange (CIRCE). This process operates in conjunction with a hydrogen-producing Steam-Methane Reformer (SMR).

CIRCE technology has been developed over several decades. The key to the CIRCE process is AECL's new proprietary wet-proofed catalyst, developed in AECL's research laboratories. CIRCE is the most advanced—and potentially the lowest-cost—heavy water production process in the world. It is now ready to be demonstrated. The resulting heavy water production process will replace the older Girdler-Sulphide method.

The Prototype CIRCE Plant (PCP) demonstration project is located on the site of a new Steam-Methane Reformer owned and operated by Air Liquide Canada (ALC). The primary goals of the PCP are to demonstrate the CIRCE heavy-water production technology in an industrial setting, and to acquire valuable information on the lifetime of the specialized catalyst which underpins the technology. The PCP encompasses the full suite of new heavy water technology based on the new wet-proofed catalyst.

A Three-Stage Process

Stage 1: The advantage of AECL's proprietary wet-proofed catalyst is that it allows hydrogen isotopes to exchange readily between water and hydrogen. In Stage 1 of the PCP, deuterium is extracted from the hydrogen produced in the SMR, via the water feed to the SMR.

Hydrogen produced in the SMR is routed to a catalyst-packed column where it meets downflowing water on its way to the SMR. As the water trickles down over the catalyst, it collects deuterium from the upflowing hydrogen and enters the SMR substantially enriched in deuterium (see process diagram). Since the SMR contains deuterium-enriched water and hydrogen, its leak-tightness is important. As any traces of carbon monoxide (CO) in the hydrogen produced by the SMR would deactivate the catalyst, the hydrogen passes through a CO-removal step before entering the catalyst-packed column.

The CIRCE process is actually only Stage 1 of the PCP, performing the bulk of the deuterium enrichment. Two subsequent stages further increase deuterium concentrations to virtually pure heavy water.

Stage 2: Stage 2 uses a **B**ithermal **H**ydrogen-**W**ater (BHW) process, also based on wet-proofed catalyst technology. BHW exploits the effect of temperature on the equilibrium ratio of deuterium between water and hydrogen—the equilibrium ratio falls with rising temperature. With BHW, deuterium is concentrated between a cold tower (where water is enriched in deuterium) and a hot tower (where hydrogen is enriched in deuterium).

Stage 3: Stage 3 uses yet another variation of the wet-proofed catalyst technology, **C**ombined **E**lectrolysis and **C**atalytic **E**xchange (CECE). CECE is similar to CIRCE, with downflowing water becoming steadily richer in deuterium content as deuterium is stripped from upflowing hydrogen. However, with CECE, water is converted to hydrogen (and oxygen) using electrolysis rather than by an SMR.

AECL Atomic Energy of Canada Limited
EACL Énergie atomique du Canada limitée

CECE is a very effective process, well-suited to the small scale of Stage 3.

The prototype plant is designed to produce about 1 tonne/year of reactor grade (99.8%) heavy water. This compares with a projected production rate of 50 - 80 tonnes/year from a full scale plant. CECE technology can also be applied to upgrading heavy water contaminated with light water or for removing tritium from heavy water. Standing alone, the BHW process could be used to produce heavy water from large, pre-existing hydrogen streams.

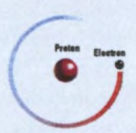
Project Schedule

The PCP Project was formally launched in July 1997 when Air Liquide was still planning their SMR project. Detailed engineering of the PCP was undertaken early in 1998, and the main construction effort began in January 1999. Commissioning is scheduled to begin in October 1999 with the plant being fully operational by April 2000.

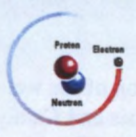
The PCP is a highly modular design, allowing streamlined construction schedule on the crowded site. The five process modules were built off-site by a structural fabricator, and were outfitted with process equipment, piping, and instrumentation and wiring prior to their delivery to site. Once on site, the modules were erected within three days, enabling the field construction to be completed within two months.

What is Heavy Water?

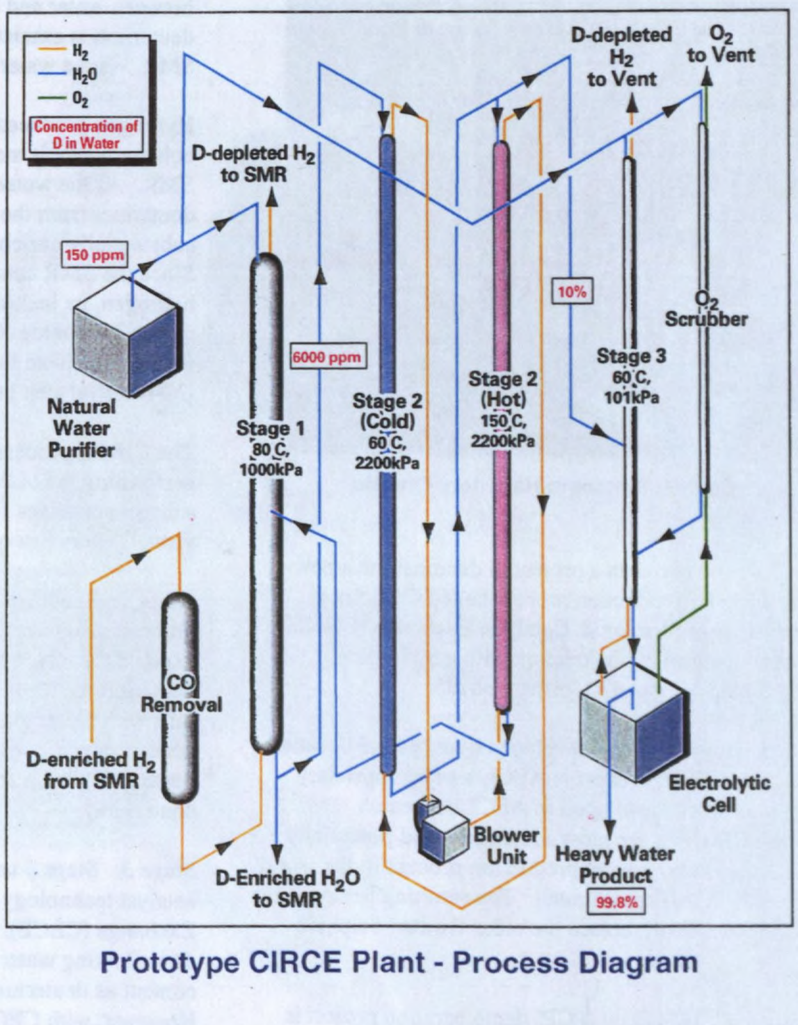
The difference between ordinary water and heavy water lies in the different makeup of hydrogen and deuterium (heavy hydrogen) atoms. Hydrogen, the major building block of "light" or "ordinary" water has a nucleus consisting of one proton. Deuterium, the major building block of "heavy water" (deuterium oxide [D_2O]) has one proton and one neutron. A heavy water molecule weights about 10% more than ordinary water.



Hydrogen Atom (H)



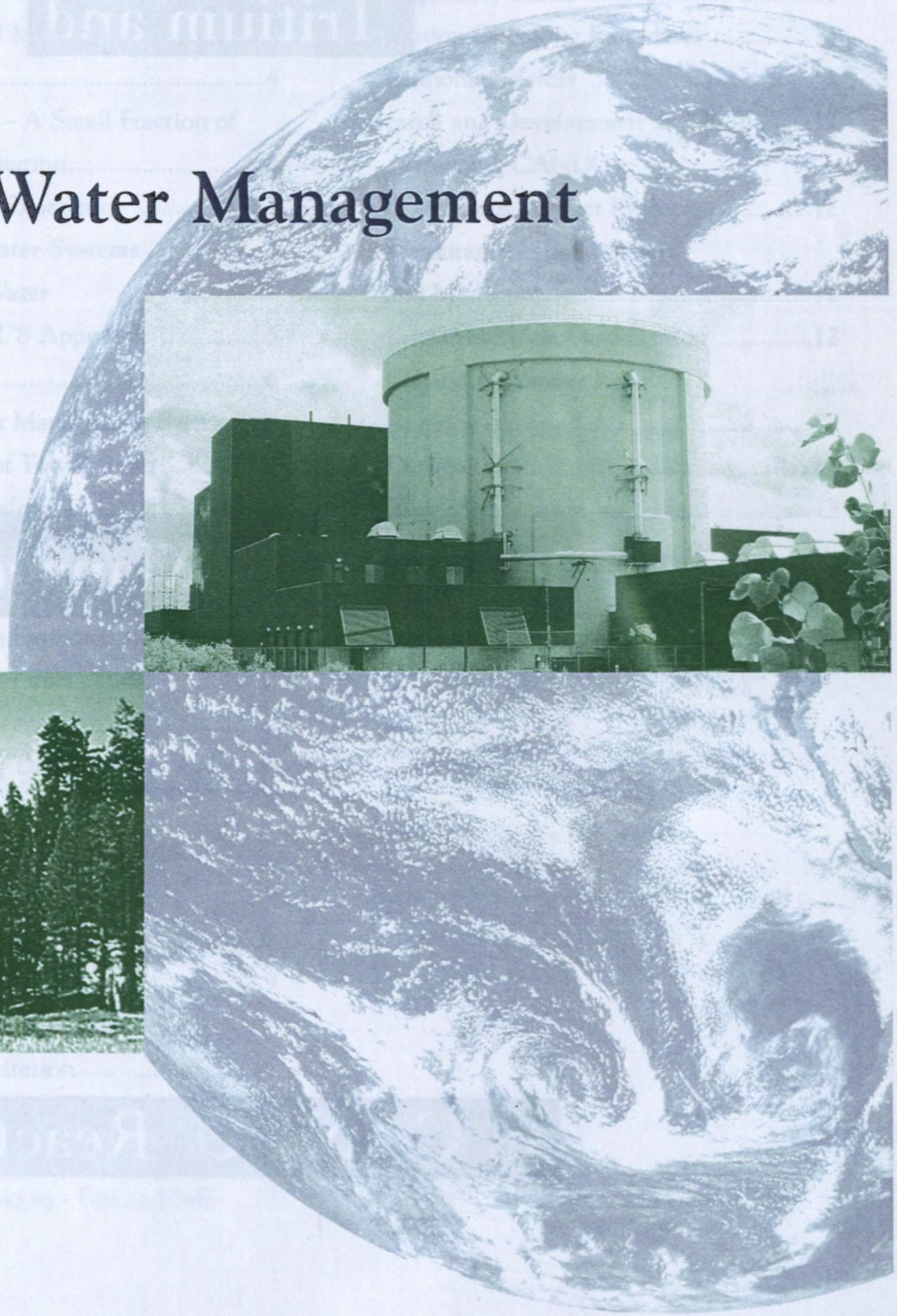
Deuterium Atom (D)



Prototype CIRCE Plant - Process Diagram

For more information please contact AECL: Christine Fahey 613-584-3311
Printed in Canada September 1999 Catalogue #8-7

Tritium and Heavy-Water Management in CANDU® Reactors



AECL
Atomic Energy of Canada Limited

Tritium and

Heavy-Water Management

in CANDU® Reactors

Table of **Contents**

Responsible **Nuclear Power**

For all Atomic Energy Canada Limited (AECL) customers, CANDU means much more than a nuclear station. It is the assurance that leading-edge CANDU® technology will stay leading-edge, maintained by some of the world's best nuclear specialists.

Protection of workers and the environment are among our highest priorities at AECL—something we carefully factor into the CANDU design and our underlying research and development. Our people are world-renowned for their knowledge and skill in the management of tritium, and for the conservation of a valuable resource—heavy water. All CANDU stations are designed to operate with emission levels considerably lower than recommended international standards.

Heavy Water— **The Best Moderator**

AECL's CANDU nuclear power reactors use natural uranium as fuel, and deuterium enriched water as a moderator and coolant. Heavy water is very effective(1) in slowing down neutrons in the chain reaction fission process. This, combined with other features of the CANDU design, produce the excellent neutron economy of the CANDU reactor.

Heavy water is the common name for deuterium oxide (D_2O). It is the same as ordinary "light" water (H_2O) except that the hydrogen atoms in each ordinary water molecule are replaced by "heavy" deuterium (D), a non-radioactive isotope of hydrogen. Deuterium atoms have a neutron in their nucleus, making a heavy water molecule about 10 per cent heavier than ordinary water. As a moderator, heavy water is eighty times more effective than light water at generating the thermal neutrons that initiate the fission process. This means natural uranium can be used in CANDU reactors, with no requirements for enrichment services and fuel reprocessing. The high neutron efficiency of the CANDU design also allows the flexibility of using other fuel cycles, such as uranium recovered from light water reactors (RU) and thorium.

(1) Although light water is more efficient than heavy water for slowing down neutrons, it is less effective in promoting fission because it absorbs more neutrons in the process.

AECL is the world leader in heavy water management. CANDU's heavy water systems have been extensively engineered, ensuring their high integrity and high reliability. Integrated monitoring, collection and recovery systems are also included to ensure station operators can manage their heavy water resource effectively. We regularly review the heavy water management operating procedures and strategies adopted at each station to improve the effectiveness of our CANDU heavy water management system designs.

Tritium—**A By-Product**

Tritium occurs naturally in the Earth's atmosphere due to the interaction of cosmic radiation with nitrogen and oxygen. Tritium is another, yet 'heavier', form of hydrogen that is created if a deuterium atom adds another neutron to its nucleus through the thermal neutron capture reaction $^2H(n,\gamma)^3H$ [or $D(n,\gamma)T$]. In the CANDU reactor, the principal method of tritium formation is through neutron capture by the deuterium in the molecules of heavy water. While this is the principal method of forming tritium, it can also be formed through ternary fission in the fuel, as it is in all reactor types. As well, tritium is formed by neutron reactions with the light elements, boron and lithium, used to control the water chemistry of the moderator and coolant systems.

Tritium Production

The rate of tritium production in heavy water depends on the number of neutrons produced by the reactor, and the amount of time the water spends in the reactor core. Since the heavy water used to cool the fuel circulates outside the reactor, it spends less time being bombarded by neutrons. As a result, the rate of tritium formation is about 60 times lower in the coolant than in the moderator. However, because the volume of water in the moderator is larger, the resulting concentration difference is about 40 times.

The level of tritium in each system depends on the quantity of heavy water, the rate of tritium production (which is affected by station operating efficiency), and the loss of tritium due to radioactive decay. Tritium levels in the moderator water build up with continued operation to the equivalent of a few tens-of-parts per million tritium over the lifetime of the reactor. Some stations choose to remove tritium from the heavy water, as part of their station operational activities and overall management strategy. However, CANDU stations are designed to accommodate the expected maximum levels of tritium, and operate with worker doses and radiological emissions as low as reasonably achievable in accordance with international recommendations.

Well-established Monitoring and Dosimetry

The uptake of small quantities of tritium is not a significant health hazard. Because tritium is a weak beta-emitter, it is one of the least radiotoxic radionuclides and only when tritium is ingested or inhaled does it pose a health risk to humans and other living things. Monitoring and dosimetry technologies are well-established and tritium's health effects well-understood.

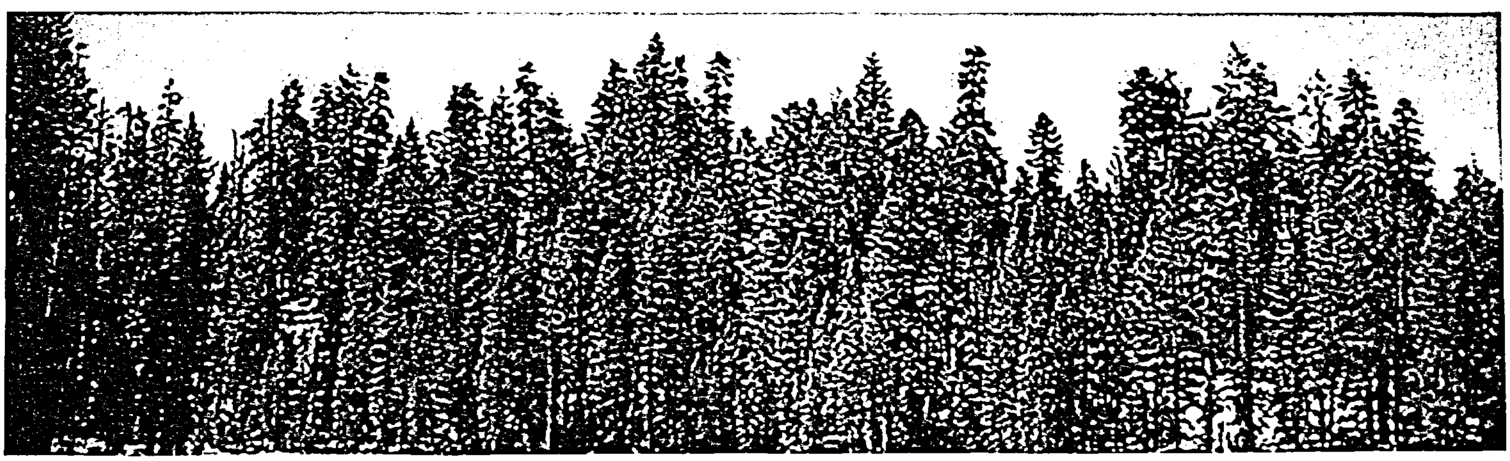
Tritium Release — A Small Fraction of Background Radiation

Although tritium is not particularly hazardous, it is of concern due to the fact that small amounts naturally escape as vapour or liquid from the reactor systems. The CANDU design ensures that worker radiation doses and environmental emission from all radioactive isotopes are well within regulatory limits. Doses to CANDU station workers are among the lowest in the world in operating reactors. Although tritium is a significant contributor to both worker dose and environmental emissions, its ease of detection at very low levels permits good control of the small amount that does escape.

Due to the value of heavy water, CANDU design and operations have placed considerable emphasis on minimizing the loss of heavy water from both the moderator and coolant systems, and the plant in general. While tritiated heavy water may escape in the form of liquid or vapour, specially-designed systems recover all but a trace of this heavy water, limiting the environmental emission of tritium to a small fraction of the environment's natural radiation levels.

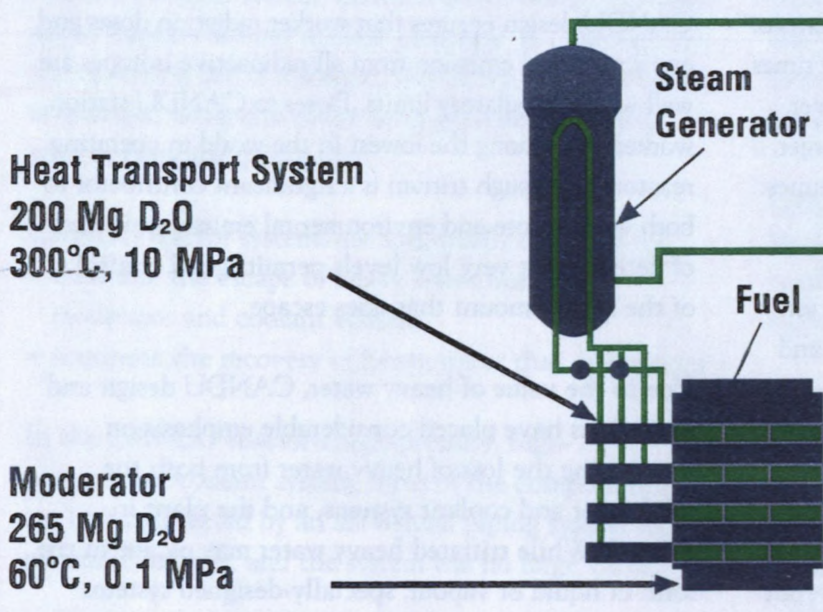
Four Decades of Experience

AECL has continued to improve tritium containment, tritium measurement (dosimetry), operating procedures, worker safety, and emissions control during more than four decades of research and development and CANDU plant operating experience.



CANDU **Heavy Water Systems**

The figure below is a schematic of the main heavy water systems in a CANDU reactor, with some parameters for a CANDU 6. (Note that the technical term for the coolant system is the Heat Transport System.)



In a CANDU Reactor, ~98% of the tritium inventory is contained in the moderator system and 2% is contained in the heat transport system.

Integrated Heavy Water Management—**AECL's Approach**

Excellent system design and effective operational tools combine with highly-trained management to ensure successful operation and maintenance of the heavy water systems in CANDU reactors.

Plant Design

CANDU plants are designed by AECL with a "defense-in-depth" approach—the use of multiple barriers. A multi-system, multi-structure design provides sealed barriers around nuclear components. Throughout the operating life of a station, the heavy water inventory is managed using this multi-level approach, coupled with operational protocols.

CANDU reactor systems are specifically designed to:

- minimize the escape of heavy water from the moderator and coolant systems
- maximize the recovery of heavy water that does escape

In the CANDU reactor's high-pressure, high-temperature coolant system, most of the components are interconnected by an all-welded piping system to minimize leakage, and the system has no large valves.

The moderator is a low-pressure, low-temperature system. Hence, the potential for heavy water escape is even less than that of the coolant system. As there are a number of valves in the moderator system, routine operations will cause a small amount of leakage. The moderator system, however, contributes less than 10 per cent to the total heavy water recovered in the reactor building's collection systems.

Heavy Water Management Systems

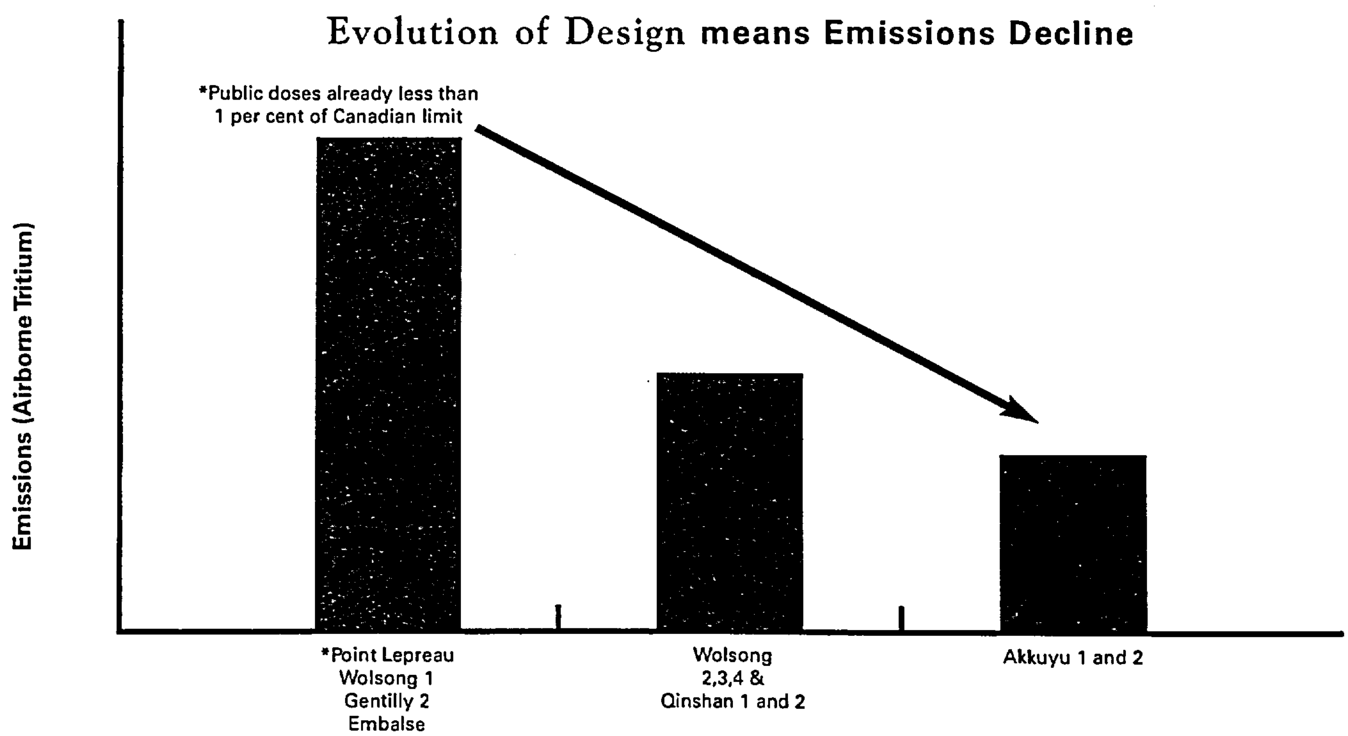
As heavy water can escape from the moderator and coolant systems as a vapour or liquid, *heavy water recovery systems* are designed to collect and recover this vapour or liquid as quickly as possible. Annual heavy water losses are a very small fraction of the heavy water inventory.

Separation of Two Systems

Because of the large difference in tritium content between the moderator and coolant systems, the recovered heavy water is *segregated* to avoid mixing.

Recovery, clean-up, upgrading and storage systems are all segregated to:

- separate the main process systems, coolant and moderator, through to the auxiliary systems
- provide atmospheric segregation of high and low tritium zones
- duplicate liquid collection systems
- duplicate vapour recovery systems
- duplicate sampling, and D_2O handling and storage systems

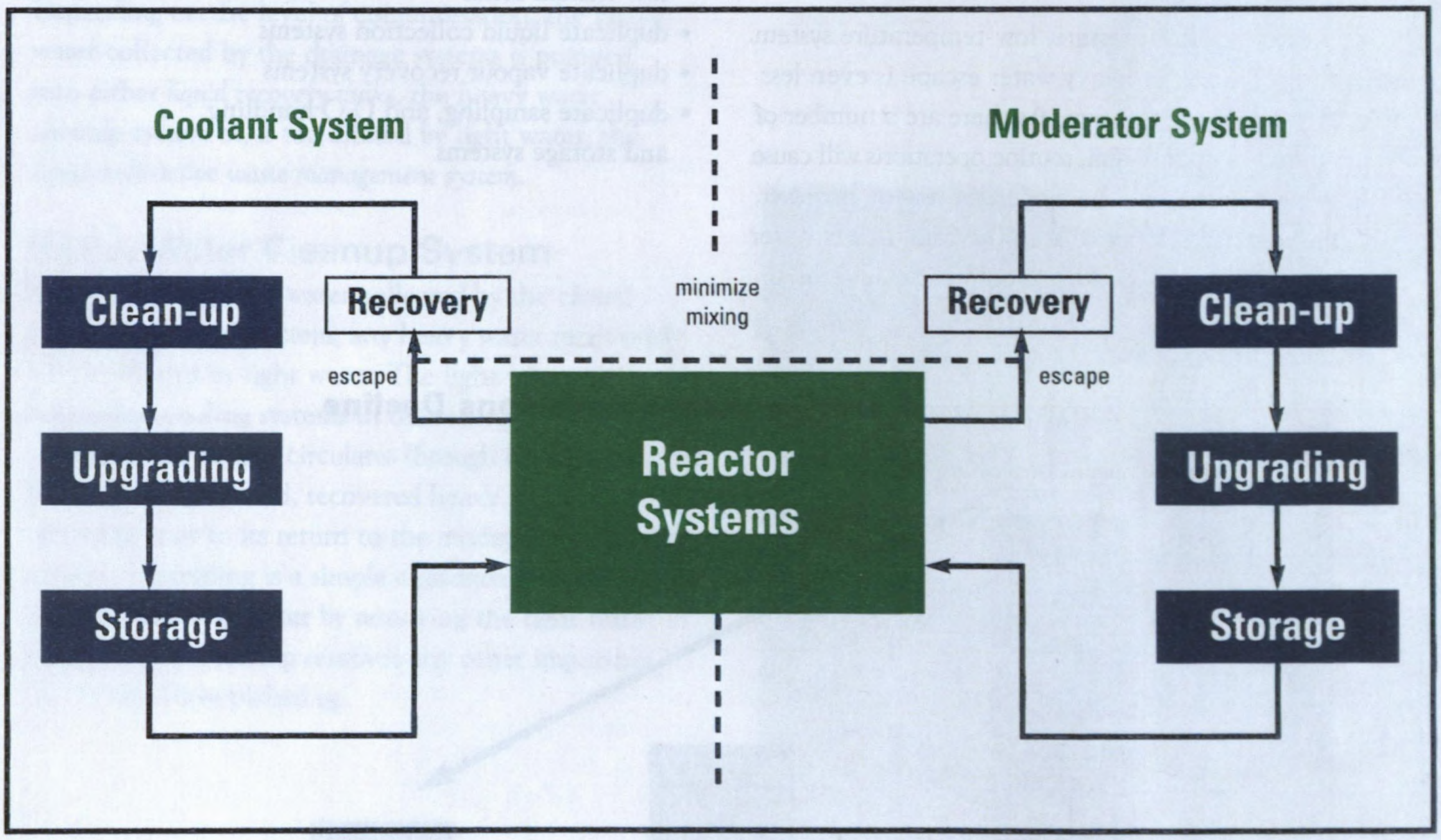


Station Layout: "Defense-in-Depth"

For Maximum Safety

A CANDU station is laid out to minimize the radiation dose incurred by operating personnel. Stations are classified into different "zones" depending on the level of hazard from all radionuclides. Areas of higher tritium levels are maintained at negative pressure relative to the surroundings. Because of the high tritium content in the moderator, all moderator equipment is enclosed to minimize any cross-contamination.

Heavy Water Handling Systems in CANDU



Liquid Recovery System

A *closed pipe network* serves certain moderator and coolant system components, such as seals and gaskets, and collects any liquid leakage. The closed network prevents heavy water from entering the containment building. With this system, recovered heavy water is kept pure, free of any light water vapour present in the containment building. After testing it for purity, the collected water is pumped directly back into the reactor.

Special Drainage System

A special drainage system is designed into CANDU units to collect any liquid heavy water that leaks from components unprotected by the closed piping network. Designed to accept the uncontrolled release of contaminated heavy water, any liquid leakage can be detected very quickly by leakage monitors built into the floor drains in all potential leak areas.

Liquid Recovery Tanks

Depending on the level of contamination, the heavy water collected by the drainage systems is pumped into either *liquid recovery tanks*, the heavy water cleanup system or, if too diluted by light water, the *liquid radioactive waste management system.*

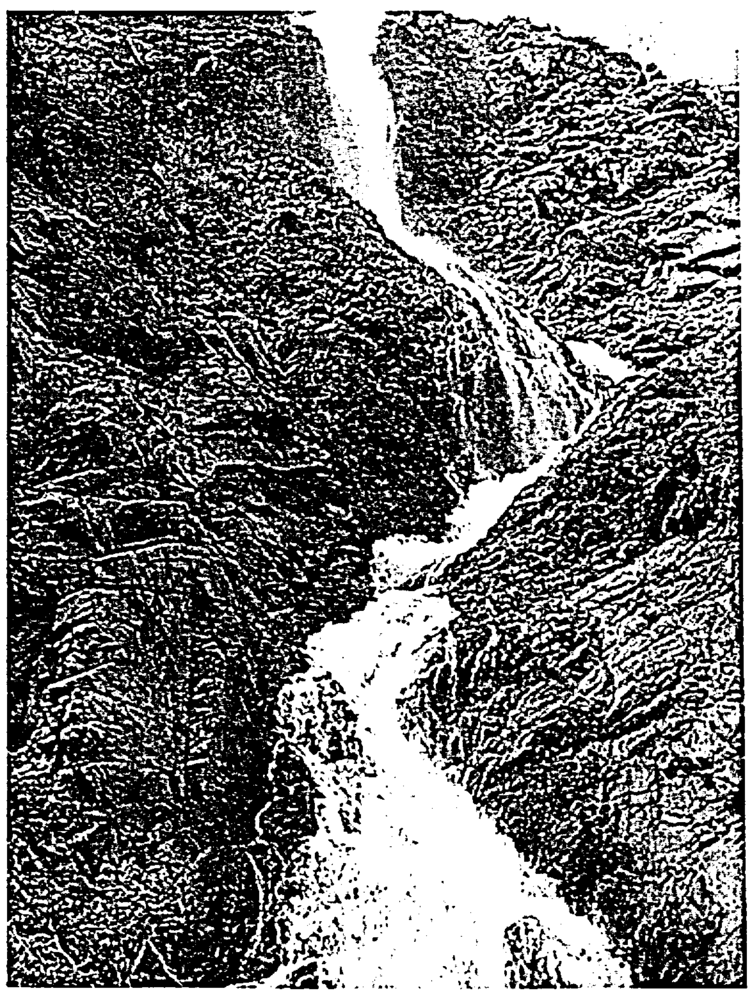
Heavy Water Cleanup System

Except for the heavy water collected by the closed pipework recovery system, any heavy water recovered will be diluted by light water. The light water can come from other cooling systems in the reactor, or water vapour in the air that circulates through the containment building. To be reused, recovered heavy water must be upgraded prior to its return to the moderator or coolant systems. Upgrading is a simple *distillation process* that purifies the heavy water by removing the light water molecules and cleanup removes any other impurities that it may have picked up.

Vapour Recovery Dryers

Heavy water escaping from the reactor systems as a *vapour* is recovered from the containment building's air by *dehumidifiers* or 'dryers'. Multiple dryers are installed in two segregated vapour recovery systems. By capturing the vapour, dryer systems optimize the recovery of heavy water. The heavy water can be removed from the dryers by a simple heating process and transferred to the cleanup system for recycling into the reactor systems. Vapour recovery systems are designed to

- maintain a dry atmosphere in the containment building, recovering heavy water from very small leaks as quickly as possible
- keep the airborne tritium level as low as possible
- maintain an air-flow pattern that prevents high-level tritium vapour from moving to adjacent areas
- minimize heavy water losses and tritium releases during routine maintenance on heavy water systems



Managing **Tritium**

A CANDU station is laid out to minimize the radiation dose incurred by operating personnel. Stations are classified into different "zones" depending on the level of hazard from all radionuclides. Areas of higher tritium levels are maintained at negative pressure relative to the surroundings. Because of the high tritium content in the moderator, all moderator equipment is enclosed to minimize any cross-contamination.

Monitoring and Measuring Tritium and Deuterium

Tritiated heavy water is particularly easy to detect since it is radioactive. Techniques have been developed that allow the determination of one tritium atom in 10^{18} hydrogen atoms.

For heavy water and tritium control, both water and air samples can be analyzed for either their *deuterium content* or their *tritium content.*

Due to the value of heavy water, the deuterium content of collected liquid and vapour is measured to determine the amount recovered. As well, the deuterium content of any water vapour that leaves the station, either through waste management or ventilation systems, is carefully measured to determine heavy water loss.

As part of AECL's defense-in-depth strategy to protect the worker, the environment and the public, three levels of tritium monitoring programs have been developed:

- measuring tritium-in-air in stations (Workplace)
- monitoring workers for tritium contamination (Worker)
- monitoring emissions and the environment (Public and Environment)

The results from each program are inter-related and together provide an integrated set of data for directing heavy water management activities.

Workplace Protection

To achieve safety goals, equipment and procedures are in place to monitor tritium levels throughout the station. AECL is the industry leader in the development of tritium measurement technologies. Operational radiation protection is designed into CANDU stations, and hand-held, portable and installed equipment is used to measure tritium throughout the workplace.

Worker Safety

The dynamics of tritium behaviour including, uptake, metabolism and retention in the body, are well-known. Since any radioactive dose can only come from tritium that has been ingested or inhaled, specialized tritium bioassay monitoring and dosimetry programs are in place to routinely monitor workers. These programs are based on recommendations from the International Commission on Radiological Protection (ICRP).

Public and the Environment — The ALARA Criterion

Stations strive to attain emission levels that are As Low As Reasonably Achievable (the ALARA criterion)— well below the limits set by local authorities for public safety and environmental protection. To satisfy this philosophy, the tritium content of all air and water streams leaving the station is monitored. The environment beyond the reactor boundary is also monitored to confirm emission measurements.

Easily Measured Emissions

Small amounts of tritiated water or water vapour escape even with the most proficient system design and operational efforts. Escape can occur through the radioactive waste management system's ventilation pathway, or through the liquid waste management system. Tritium emissions from the station are easily monitored and measured to ensure public safety.

Environmental Monitoring

The environmental dispersion of tritium is complex. To *predict* doses to the public, models of tritium behaviour upon release into air or water are available. To *confirm* the expected low tritium levels, procedures for environmental sampling are used.

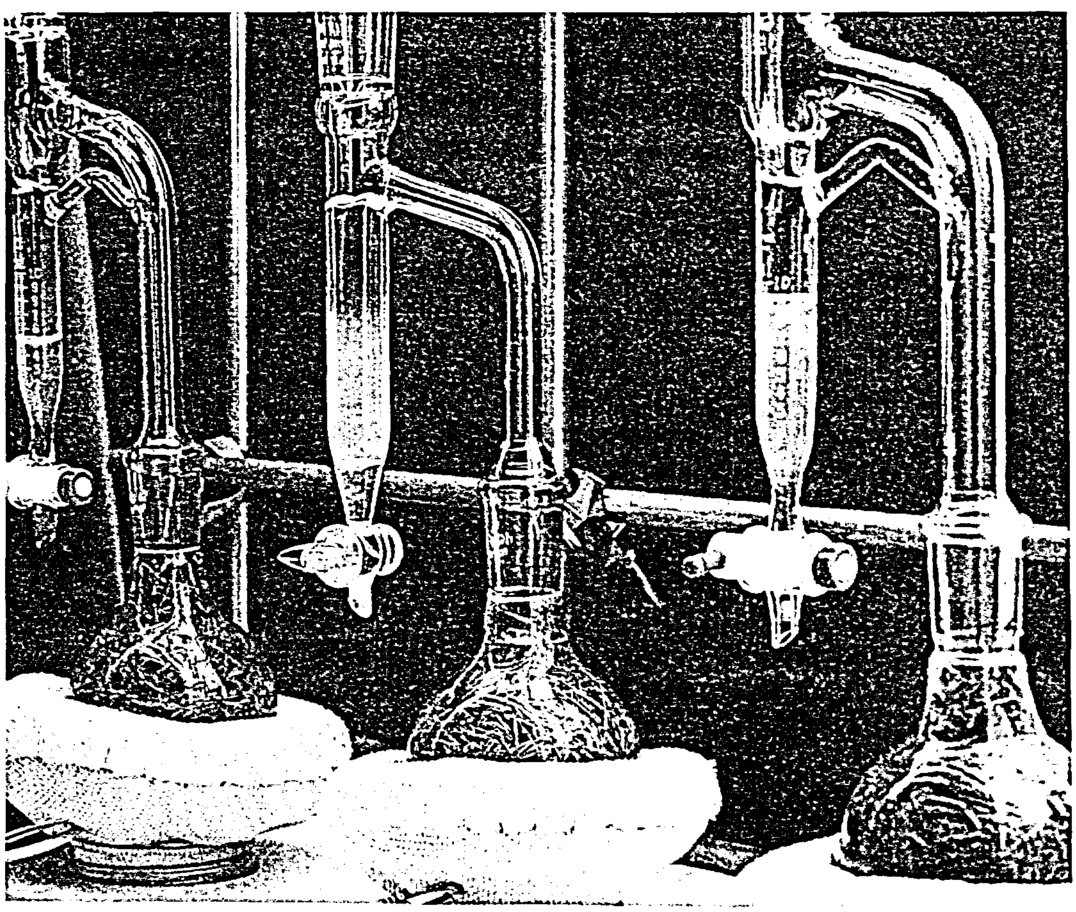
Measuring Techniques — Fast and Safe

A variety of instrumentation and sampling methods are used to evaluate tritium levels in the workplace and the environment. The tritium-monitoring programs, designed for worker and environmental protection, use a combination of tritium samplers and real-time monitors.

Response time is fast using real-time monitors that can measure tritium at much less than one part per trillion in air (1 part in 1,000,000,000,000). Tritium-in-air concentrations are measured down to a fraction of the level required to assure that worker dose limits are not exceeded. Real-time monitors provide worker protection against any sudden changes in the workplace hazard (e.g., a temporary leak caused by a maintenance activity).

A "sampler" method, in many cases, is the only practical solution for measurements where extremely high sensitivity is required. Over a period of time, a sample of sufficient volume is collected to determine the low tritium content, using very sensitive analysis techniques. Samplers can be located both within the station, in release pathways, and in the environment surrounding the station.

Where long-term performance and trends are of interest, environmental measurements are generally made using the "sampler" approach.



Tritium in vegetation is measured as part of AECL's environmental transport studies.

Flexibility for Station Management

The CANDU design allows each station to select heavy water and tritium management strategies that meet their operational requirements. A number of station-specific issues must be considered in the application of ALARA principles, and compliance with local requirements. Stations can readily incorporate the latest improvements in technology to evolve their management strategies.

Plant Aging

There is sufficient integrity and flexibility in the CANDU design to ensure that occupational dose and radiological emissions easily meet regulatory requirements, even with plant ageing. However, as the tritium concentrations in the heavy water systems increase with time, the need for attention to tritium emissions and worker dose is more critical than in the early years of operation. To meet the challenge posed by increased tritium inventories in the heavy water systems, station operators can choose from a number of strategies to maintain low worker doses and emissions.

Local Emission Limits Well Below Regulatory Limits

In their most recent publication, the International Commission on Radiological Protection recommends a set radiation emission limit of 1mSv – less than half the natural background rate in most places. A station's goal is to limit radiation doses to the environment and the public to well below regulatory limits, ensuring neither is put at risk. Dose exposures to the public depend on the types and quantities of radioactive materials that are emitted, and on the geographic and atmospheric conditions surrounding a station. Consequently, emission limits are site-specific.

Station Operating Procedures

Heavy water and tritium management equipment can be optimized to suit each plant's specific requirements. As such, the best operating procedures for installed equipment may vary. Exchange of information between stations, and assistance from AECL, ensures that the best practices are shared for routine operations.

Economic Factors

While heavy water is a valuable asset, its value is relative to other operating costs, and varies from station to station. Its value to each station can be influenced by labour rates, power costs, source of supply and strategic considerations such as corporate and national goals. Each station adopts the optimal management strategy for its conditions.

Research and Development at AECL

AECL has long-established research and development (R&D) programs in tritium health science; tritium in the environment; in-station management of heavy water and tritium; engineering improvements and heavy water production.

Activities range from improving processes, technologies, components and instrumentation for the containment, and recovery and monitoring of the tritiated heavy water inventory, to studies of fundamental behavior and interaction of tritium and tritiated heavy water with materials, the environment, and man.

Advancing CANDU — Continuous Product Evolution

AECL is committed to *continual product improvement.* An important component of the engineering and R&D programs is to review plant operating records and experience. This feedback is used to direct improvements in heavy water and tritium management technologies for CANDU designs.

AECL investigates various technologies for the continued successful management of heavy water and tritium in the CANDU product:

- monitoring instrumentation and techniques
- dosimetry
- tritium behaviour in the environment
- heavy water upgrading
- vapour recovery dryers
- water detritiation

Measurement Technologies and Methods

Gamma radiation, noble gases and low-air humidity in the station environment can all impact performance of tritium measuring instrumentation. On-line, real-time tritium monitoring methods have been a recent focus of the R&D effort. These include methods for monitoring tritium in the workplace, in water pathways, and in emissions from the station. Through design innovations, the use of special materials and alternate measurement principles, AECL continues to advance these systems to provide enhanced performance and accuracy.

As well, sampling methods and measuring techniques continue to be refined to increase accuracy, sensitivity and cost-effectiveness.

Instrumentation Qualification

AECL evaluates tritium sampling and monitoring instrumentation, as it becomes available, to determine its performance characteristics in the CANDU environment. We actively pursue new leading-edge technologies that are more sensitive and efficient to improve the quality of CANDU monitoring programs. AECL also develops new instruments for specialized CANDU needs.

Enhancing Vapour Recovery Dryer Systems

Over the years, AECL has acquired an excellent understanding of the operational parameters and physical-property data required to efficiently recover tritiated water vapour from air atmospheres. AECL has evolved the vapour recovery dryer system designs to improve reliability, and overall system performance in the CANDU environment. Using simulations and well-tested instrumentation, AECL optimizes and monitors dryer performance.

Dosimetry

The dosimetry for tritiated water intakes are well studied and understood for radiation protection purposes. Two recent AECL studies using human bioassay data have provided further confidence in the existing practice of tritium dosimetry. The ongoing research in dosimetry is focused on the modelling of tritium retention and excretion from tritium intakes other than tritiated water.

Water Detritiation

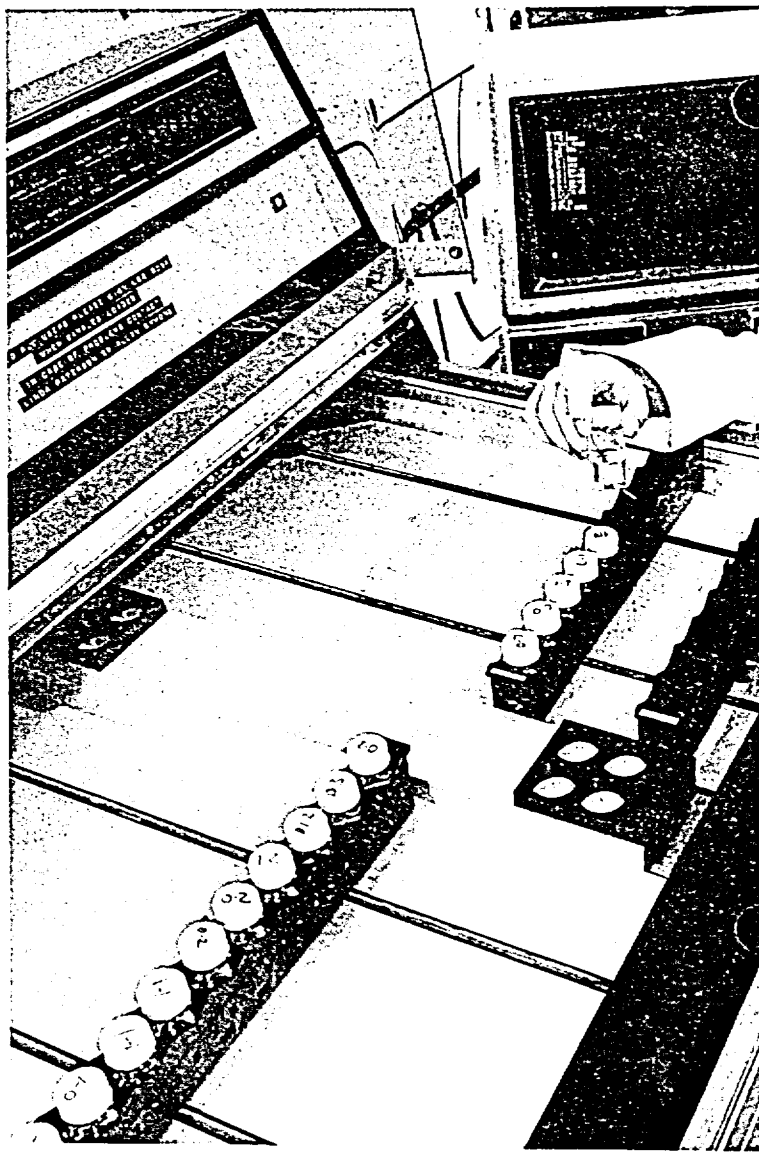
The process of removing tritium from heavy water is based on the hydrogen-water exchange reaction. AECL has recently developed an effective hydrogen-water exchange catalyst that allows this exchange to occur at low temperature. The catalyst makes the detritiation process simpler, and more cost-effective.

AECL's expert knowledge encompasses process design, materials selection and decontamination, waste management safe storage methods and measurement techniques for concentrated tritium. AECL has designed and constructed a detritiation process facility using this improved technology and the same containment and recovery principles as a CANDU station, and is demonstrating this technology for future commercial use.

Catalytic Exchange Process for Upgrading Heavy Water

Using AECL's hydrogen-water exchange catalyst, a project is underway to demonstrate the combined electrolysis and catalytic exchange (CECE) process for upgrading heavy water. This has the potential to be a more cost-efficient process than the water distillation process that is currently being used. The process is being demonstrated in a pilot-scale facility and should be available for commercial use by the year 2000.

Our R&D facilities allow for analysis, storage and manipulation of high-specific-activity tritium.



A Long-Term Commitment

AECL's scientific and engineering staff are committed to understanding and meeting current and future needs, while delivering practical, cost-effective solutions to our customers.

A global network of long-term partnerships brings Team CANDU together with the best minds in the world. AECL is proud to work closely with CANDU owners assisting them to effectively manage their heavy water inventory, and to protect their workers and their environment.

Acknowledgments

Joan Miller, B.Sc. (Hon.)
Manager, Chemical Engineering

Chas Boss, B.Sc.
Reactor Core Physics

For more information please contact your AECL Account Representative.

AECL Sheridan Park
(Head Office)
2251 Speakman Drive
Mississauga Ontario
Canada L5K 1B2
Tel: (1-905) 823-9040
Fax: (1-905) 823-1290

AECL Korea
8th Floor,
Duk Myung Building
170-9 Samsung-dong,
Kangnam-ku
Seoul 135-091
Republic of Korea
Tel: (82-2) 539-3030
Fax: (82-2) 567-0072

AECL China
Room 468,
Shangri-La Office Building
No. 29 Zizhuyuan Road
Beijing 100081
People's Republic of China
Tel: (86-10-6) 846-3858
(86-10-6) 846-3859
(86-10-6) 846-3864
Fax: (86-10-6) 846-3855

AECL Turkey
Ataturk Bulvari, No.177
Kat 5, Daire 19
06680, Kavaklidere
Ankara, Turkey
Tel: (90-312) 417-3211
Fax: (90-312) 425-1000

AECL Argentina
Pedro Goyena 1510
Martinez 1640
Buenos Aires, Argentina
Tel./Fax: (541) 798-4633
Tel./Fax: (541) 798-6092

AECL Indonesia
Graha Aktiva,
Suite 401
Jl. H.R.
Rasuna Said Blok X-1, Kav. 03
Jakarta Selatan 12950
Indonesia
Tel: (62-21) 520-3531
Fax: (62-21) 522-0967

AECL Romania
1 Dimitrie Cantemir Boulevard
SITRACA Center
(Building B2) Sector 4
Bucharest, Romania
Tel: (40) (1) 330-3101
Fax: (40) (1) 330-3103

AECL Russia
Marshal Vasilevskogo 1
Building 2, Entrance 3
Moscow - 123098
Russian Federation
Tel/Fax: 7-095-882-5800
or: 7-095-196-1513

Visit our website at:
www.aecl.ca

Printed in Canada—Document: RC-1993 (7-5) May 1998, D1004

Hot cells

Post-Irradiation Examination Services

AECL offers comprehensive remote handling services and facilities for the post-irradiation examination, analysis, testing, processing and repair of irradiated reactor fuel, reactor components, radioactive materials and equipment.

Our shielded facilities can serve the needs of LWR or CANDU® nuclear utilities, research laboratories, universities, hospitals and non-destructive testing laboratories.

More Than 30 Years Experience

AECL has more than 30 years experience in providing a comprehensive post-irradiation examination and testing service to organizations in Canada, the United States, Europe, South America, and Asia. Facilities and services are continuously upgraded to meet customer needs and regulatory requirements.

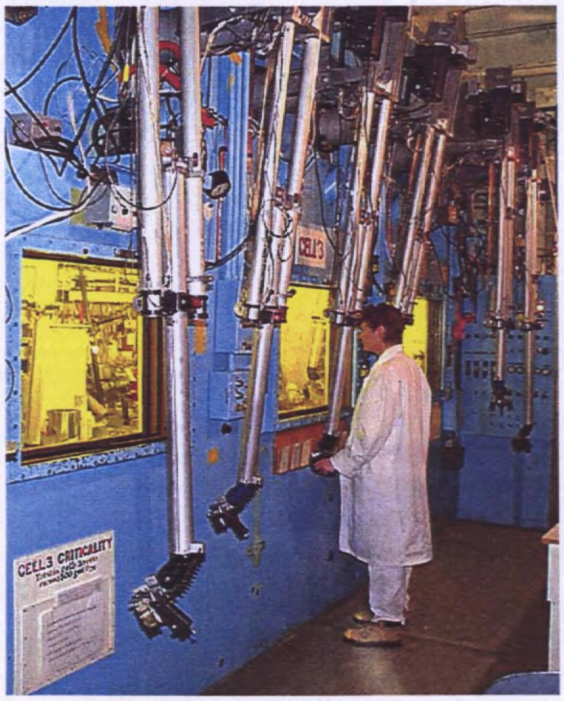
Specialists in inspection, testing and detailed examination of irradiated fuels and materials form the core of the shielded facility groups. They are supported by experts in fracture analysis, metallurgical and chemical engineering, analytical chemistry, materials science, and corrosion and wear.

Specialized Facilities - Operational Flexibility

The shielded facilities at Chalk River Laboratories provide a considerable degree of operational flexibility. Facilities include:

- a reactor bay for the receipt and initial processing of materials
- hot cells with remote handling equipment
- shielded casks for transfer of highly radioactive materials
- a shielded Scanning Electron Microscope, with direct sample transfer from hot cells

Individual hot cells are designed to handle up to 100 kCi of Co-60 or an equivalent (in terms of Bq-MeV) mixture of radioisotopes. Specialized hot cells are dedicated to mechanical testing and



AECL's shielded facilities provide a considerable degree of operational flexibility.

examination of irradiated non-fissile materials. Cells are equipped with computer controlled servo-hydraulic test frames for tensile, fatigue and other types of fracture testing at elevated temperatures and pressures. Others are equipped with cantilever beam fracture mechanics test rigs for delayed hydride crack initiation and velocity tests.

Our highly specialized and experienced staff offer a wide variety of services supported by in-house quality assurance procedures. They can:

- conduct non-destructive visual and dimensional examinations
- machine active samples into test specimens by remote means
- remotely dismantle, maintain and assemble radioactive equipment

AECL Atomic Energy of Canada Limited
EACL Énergie atomique du Canada limitée

- provide metallographic and ceramographic examination and interpretation
- examine corrosion products
- determine fuel burn-up and provide transuranic isotopic analysis
- determine hydrogen and deuterium content
- determine oxide thickness on fuel cladding and reactor materials using FTIR
- gamma scan fuel and reactor materials
- puncture irradiated fuel elements to collect and analyze fission gas samples and measure fuel element void volume and gas pressure
- conduct fracture toughness, tensile, compressive, impact and hardness tests
- conduct burst and fatigue tests
- assess crack initiation and sub-critical crack growth evaluation
- measure microdensity
- provide scanning electron microscope examination and interpretation
- conduct a full range of fuel and reactor component safety experiments
- remotely encapsulate and package waste
- perform surveillance testing for nuclear power stations to monitor changes in the properties of materials
- conduct specialized experiments based on client specifications

Handling

Irradiated fuel and fuel channel assemblies are dismantled and sectioned in our research reactor spent fuel bays and/or the large receiving cells. The bays can handle 75 ton shipping containers, with assemblies up to 4 meters long and 30 cm in diameter. AECL is currently modifying a dry hot cell receiving station to accommodate shipping containers up to 30 tons, with larger assemblies up to 4 meters long and 30 cm square. Smaller fuel assemblies and fuel channel components can be received directly into the cells.

Using remotely operated equipment, fuel assemblies and fuel channel components are dismantled, dimensioned and visually examined using a wide variety of optical instruments. For further examination, fuel and fuel channel sections are then transferred to a more specialized hot cell.

Support Services

AECL will also:

- facilitate shipment of radioactive materials to and from sites
- provide contract administration and project management
- provide requisite technical expertise and consultation
- undertake new experiments and accommodate a wide range of investigations
- archive experimental samples in storage blocks
- provide irradiation services in our high flux research reactor
- provide analyses by gamma spectroscopy, mass spectrometry and liquid chromatography, secondary ion mass spectrometry, inductively-coupled plasma spectroscopy, and other methods
- perform transmission electron microscopy and X-ray photoelectron spectroscopy

For more information, please contact your AECL Account Representative

AECL, Chalk River Laboratories
Chalk River, Ontario, Canada K0J 1J0
Tel.: (613)584-8811 Fax: (613)584-3250
Marc Robillard - Ext 3848
e-mail: robillardm@aecl.ca
or
Shaun Cotnam - Ext. 6080
e-mail: cotnams@aecl.ca

Related Products & Services

Hot Cell Workstations (Catalogue # 7-12)
Fracture & Failure Analysis (Catalogue # 7-13)
ZED-2 Research Reactor (Catalogue # 7-14)
Fuel Bundle & Fuel Channel Testing (Catalogue # 7-15)

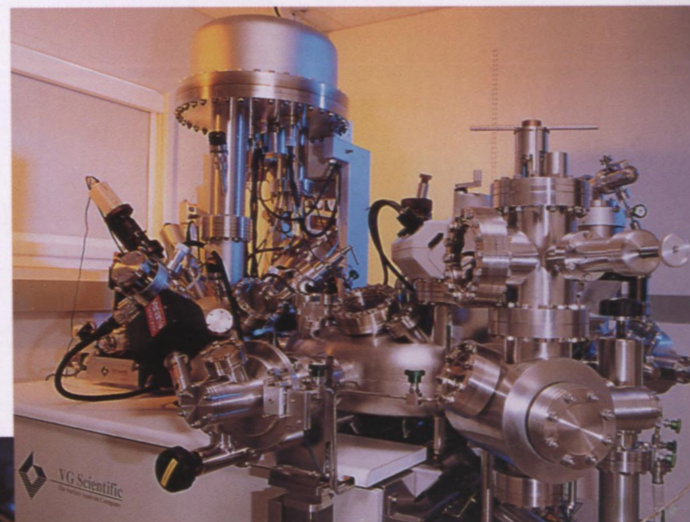
Printed in Canada October 1998 Catalogue # 7-11 D1088

Surface Science Labs

AECL's Integrated Nuclear Solutions

Surface Analysis

Surface Analysis



World-Class Expertise

State-of-the-Art Equipment

Effective Solutions

Post-Irradiation Facilities

AECL
Atomic Energy of Canada Limited

EACL
Énergie atomique du Canada limitée

Surface Analysis at AECL

AECL's world-class expertise in the surface science disciplines—metallurgy, chemistry, physics, microscopy and vacuum technology—combines the in-depth knowledge of our experienced staff with our extensive laboratory resources to help clients solve a wide range of industrial materials problems. Whether it's for materials analysis or to complement your R&D capabilities, AECL can provide cost-effective solutions. We are also a realistic alternative to equipping in-house facilities with expensive, under-utilized equipment.

The AECL Advantage

Active and Non-active Handling

Examination of the outer few atomic layers at surfaces and interfaces can provide considerable insight into the performance of metals and ceramics in the nuclear industry. AECL can handle radioactive as well as non-radioactive samples. We have a full range of analytical capabilities, and our hot cells, with shielded instruments, include a metallographic lab and a shielded machine shop. Radioactive samples can be accommodated through all phases of preparation and analysis in these shielded facilities, and can be dissected, tested and analyzed with our specialized equipment.

Surface analysis techniques can be used either to pinpoint problems or to confirm the success of a manufacturing process.

Surface Analysis Methods

Experts at our Sheridan Park and Chalk River locations combine the use of state-of-the-art technology with a thoughtful, integrated approach to problem solving. Their experience ranges from fundamental research on metals to commercial contracts for failure analysis. Materials experience includes metal and alloy reactor components, metal-oxide corrosion deposits, ceramic oxide fuel materials, and polymers and coatings used elsewhere in nuclear power plants. AECL's key areas of expertise include:

- material identification, characterization, and qualification
- mechanical failure analysis
- corrosion analysis
- non-destructive testing and analysis
- sample preparation for metallographic and surface analysis
- metallographic examination
- characterization of radioactive specimens
- process qualifications, for example, decontamination and cleaning

Technique	Key Uses	Key Benefits	Equipment Highlights
Scanning Auger Microscopy (SAM)	• Microanalysis in the upper few atomic layers • Elemental analysis from Be to U at ≤0.1 at. % • May provide chemical-state information in favourable cases	• High spatial resolution from a well-focused electron beam, point analyses and 'line scans' • Depth resolution on the order of a few atomic layers • Secondary electron imaging and elemental mapping • Relatively fast semi-quantitative analyses • Compositional depth profiles in instruments equipped with ion guns	• Perkin Elmer PHI 670 Auger Nanoprobe in Class C Radioisotope Laboratory • Schottky field-emission electron gun for high brightness and spatial resolution • Ion gun for sputter removal of surface layers and Zalar Rotation for high performance depth profiling • In-situ fracture stage for fracturing samples under ultra-high vacuum (minimal surface contamination) • Noran EDX system for X-ray analysis (B to U)
Scanning Electron Microscopy (SEM) and Energy/Wavelength Dispersive X-Ray (EDX/WDX) Microanalysis	• High spatial resolution image of surface morphology • Elemental analysis from C to U at ≤0.1 at. %	• Exceptional spatial resolution and depth of field • An effective physical image of the sample when detecting secondary electrons • Atomic number contrast in sample when detecting backscattered electrons • Quick semi-quantitative elemental analysis	• JEOL 5400 SEM with EDX, capable of light element detection, for analysis of inactive materials • JEOL 840A SEM with Noran EDX system housed in Class C Radioisotope Laboratory • A shielded JEOL 840A SEM, in a licensed facility, with a Noran EDX system and two WDX spectrometers for characterization of highly radioactive materials
Secondary Ion Mass Spectrometry (SIMS)	• Depth profiling • Ion imaging • Quantitative microanalysis, with *ppm* sensitivity, using appropriate standards	• *ppm* sensitivity • Isotopic analysis • Detection of all elements, including hydrogen • Compositional depth profiles with excellent depth resolution • Ion imaging with sub-micron spatial resolution	• CAMECA IMS 6F ion microanalyzer modified to accommodate radioactive materials • Instrument housed in Class B Radioisotope Laboratory • Both Cs^+ and duoplasmatron (oxygen) ion sources • Can be operated as either an ion microprobe or ion microscope

Technique	Key Uses	Key Benefits	Equipment Highlights
X-Ray Photoelectron Spectroscopy (XPS) XPS is also known as Electron Spectroscopy for Chemical Analysis (ESCA)	• Surface analysis of solids for all elements except H • Readily obtainable chemical state information • Thin film analysis • Detection limits on the order of ~0.01 at. %	• Suitable for all types of solids in virtually any form • Low risk of damage on even radiation-sensitive materials • Straightforward quantitative analysis • Imaging capabilities with spatial resolution ≤10 μm • Compositional depth profiles in instruments equipped with ion guns	• *VG Scientific ESCALAB 220i-XL Imaging-XPS* with an X-ray monochromator and twin-anode sources • High-performance Schottky field-emission electron gun for auxiliary SAM, SEM and EELS analyses • UHV pocket chamber for heating and cooling, controlled gas exposure, and ion etching of radioactive materials • Unique fracture stage for retention and analysis of both fracture surfaces • Instrument housed in Class B Radioisotope Laboratory and fitted with appropriate shielding for studies of highly radioactive materials
X-Ray Diffraction	• Texture, line-broadening, residual stress and powder analyses for both non-active and radioactive materials	• Precise measurement and analysis • Extensive specimen preparation capabilities for non-active and radioactive materials	• Rigaku 12kW rotating anode diffractometer, with a Cu rotating anode target • Philips texture goniometer with Ni-filtered CuKα radiation for generating full pole texture plots • A θ/2θ goniometer with a graphite monochromator, used on a second port for line-broadening or powder analysis
Surface Metrology	• Precise measurement of surface texture—roughness, waviness and BAC parameters, for non-active materials	• Precise measurement and analysis of manufactured components • Fretting analysis of tested fuel bundles and fuel channels • Characterization of fuel bundles	• Taylor Hobson Form Talysurf Mark I, equipped with METREX "profileView SLR" software for on-screen analysis
Remote Optical Microscopy for Post Irradiation Examination	• Surface microscopy of metals and ceramics	• Microscopic examination of highly radioactive materials at magnifications from 16X to 1250X • Image analysis of layers/coatings and volume fraction measurements • Digital imaging and archiving (images can also be captured on 4x5 inch Polaroid film, 35 mm film, videotape, or digitally)	• A Leica Telatom 4 and a Reichert Telatom with radiation-resistant optical components • Bright field, polarized light, differential interference contrast, and oblique lighting capabilities • Microhardness tester • Computer-controlled scanning stage

AECL's strength in related disciplines is an advantage to our customers. Here a zirconium fragment is examined in AECL's metallurgy laboratory.

AECL staff have established a track record for thoroughness and commitment to technical excellence, for valid diagnosis of failure or malfunction, and for meeting tight deadlines. Experts in related disciplines, including failure analysis, materials evaluation and materials R&D, are readily available, when required. AECL's Chalk River infrastructure is especially supportive of work involving radioactive materials. Health physicists and surveyors, regulatory documentation and approvals specialists, internal and external dosimetry, and protective services/security personnel are available on site.

AECL's Secondary Ion Mass Spectrometer (SIMS).

An Unbiased Opinion

AECL provides customers with an unbiased third-party opinion, and all results are fully documented and confidential.

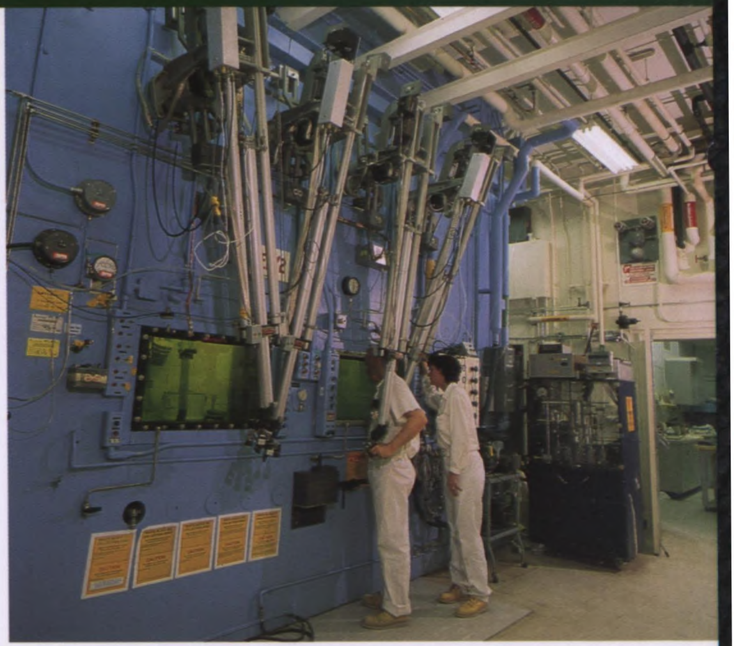
Multidisciplinary Techniques

AECL offers clients the benefit of a multidisciplinary service, including:

- Fourier transform infrared (FTIR) and laser Raman spectroscopy
- gamma and Mössbauer transmission spectroscopy
- electrochemical testing for corrosion susceptibility
- quantitative hydrogen and deuterium analysis, by either hot vacuum extraction mass spectrometry (HVMS) or differential scanning calorimetry (DSC)
- X-ray and neutron diffraction
- fuel burnup and transuranic isotopic analysis
- anaerobic chambers for sample preparation in inert environments

Specimen undergoing X-Ray Photoelectron Spectroscopy (XPS).

Staff at AECL's hot cell facilities provide comprehensive remote-handling services for post-irradiation examination, analysis, testing, and processing of irradiated materials.



Post-Irradiation Examination (PIE) Facilities

To complement our surface analysis capabilities, AECL offers comprehensive remote-handling services and facilities for post-irradiation examination, analysis, testing, processing and repair of irradiated reactor fuel, reactor components, radioactive materials and equipment.

Specialists in inspection, testing, and the detailed examination of irradiated fuels and materials form the core of the shielded facility groups. They are supported by experts in fracture analysis, metallurgical and chemical engineering, analytical chemistry, materials science, and corrosion and wear.

The shielded facilities at Chalk River Laboratories provide a considerable degree of operational flexibility. They include:

- a reactor bay for the receipt and initial processing of materials
- hot cells with remote-handling equipment
- shielded casks for transfer of highly radioactive materials
- a shielded Scanning Electron Microscope, with direct sample transfer from hot cells

Individual hot cells are designed to handle up to 100 kCi of cobalt-60 (Co-60) or an equivalent (in terms of Bq-MeV) mixture of radioisotopes. Specialized hot cells are dedicated to mechanical testing and the examination of irradiated non-fissile materials. Cells are equipped with computer-controlled servo-hydraulic test frames for tensile, fatigue and other types of fracture testing at elevated temperatures and pressures. Others are equipped with cantilever beam fracture mechanics test rigs for delayed hydride crack initiation and velocity tests.

The major PIE services provided by AECL are:

- non-destructive visual and dimensional examinations
- machining of radioactive materials
- metallographic and ceramographic examinations
- fuel burnup and transuranic isotopic analysis
- SEM/EDX/WDX, DSC and FTIR analysis
- gamma spectroscopy
- mechanical testing
- determination of hydrogen/deuterium
- measurements of fission gas release

A Successful Track Record—Satisfied Clients

AECL has provided expertise and services to a variety of industrial clients from the nuclear power utilities, chemical and process industries, oil and gas producers and refiners, steel manufacturers, universities and government agencies, semiconductor, pump, ceramic, and catalyst manufacturers.

For more information please contact your
AECL Account Representative or

AECL CANDU & Technical Services
AECL Head Office
2251 Speakman Drive
Mississauga, Ontario, Canada L5K 1B2
Tel: (905) 823-9040 Fax: (905) 823-9866

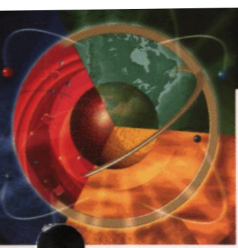
Chalk River, Ontario:
Tel: (613) 584-3311 Fax: (613) 584-1812

Related Products and Services

CANDU & Technical Services (Marcom Catalogue #5-1)
EQ Assessment and Testing Services (12-1)
Fuel Channel Inspection Services (7-1)
Post-Irradiation Examination Services (7-11)
Zirconium Services (5-20)

Printed in Canada. March 2000. Marcom Catalogue #5-18. D1395

Fuel Development
Labs



CANFLEX™

A New Generation of CANDU® Fuel

Enhanced Reactor Performance

Increased Safety Margins

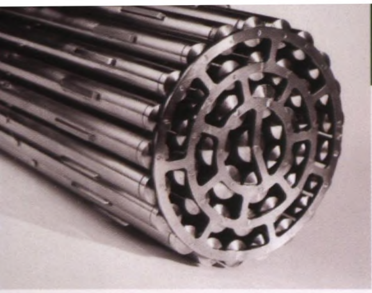
Improved Economics

Future Fuel Cycle Options

AECL
Atomic Energy of Canada Limited

EACL
Énergie atomique du Canada limitée

CANFLEX™



CANFLEX—A New Generation of CANDU Fuel

Atomic Energy of Canada Limited (AECL) and the Korea Atomic Energy Research Institute (KAERI) have redefined CANDU fuel bundle design with CANFLEX—**CAN**DU **FLEX**ible Fuelling. It is designed to further enhance fuel performance, reduce both capital and operating costs, and as a vehicle for the introduction of fuel cycle options into current and future CANDU reactors. Initially, utilities will be able to use CANFLEX with natural uranium (CANFLEX NU), and later with other CANDU fuel cycle options.

Increased Operating Margins

Designed for the CANDU pressure tube, the 43-element CANFLEX fuel bundle, has two element sizes and two principal benefits—enhanced thermalhydraulic performance and a more balanced radial power distribution, providing CANDU plant operators with greater operating flexibility through improved operating margins.

Enhanced Reactor Performance

Lower Ratings:

In existing reactors, at current power levels, the maximum linear element rating in a CANFLEX bundle is 20% lower than the 37-element bundle, improving the ability to achieve higher fuel burnup, and reducing the consequences of most design-basis accidents.

Higher CHF:

Studies and testing have also resulted in a unique, patented arrangement of non-contacting appendages on the bundle, which increase turbulence around the elements. These appendages enable a higher bundle power before critical heat flux (CHF) occurs, leading to a net gain in critical channel power (CCP) of up to 8% over the 37-element fuel.

Analyses to date also show that the CANFLEX NU bundle increases the safety margins with respect to channel integrity and radiological doses.

CANFLEX has undergone extensive testing and analysis throughout all stages of design and manufacture.

Reactor operators can introduce CANFLEX bundles alongside the existing 37-element fuel bundles during normal on-power refuelling.

Rigorous Qualification Testing

CANFLEX development began in 1986 and, since 1991, AECL has partnered with the Korea Atomic Energy Research Institute (KAERI) to complete CANFLEX development, qualification testing and analysis.

Testing and analysis have included:

- irradiation in AECL's NRU research reactor
- thermalhydraulic qualification in both water and Freon
- fuel handling and fuel channel qualifications
- endurance testing
- measurements of the reactor physics parameters in AECL's ZED-2 research reactor

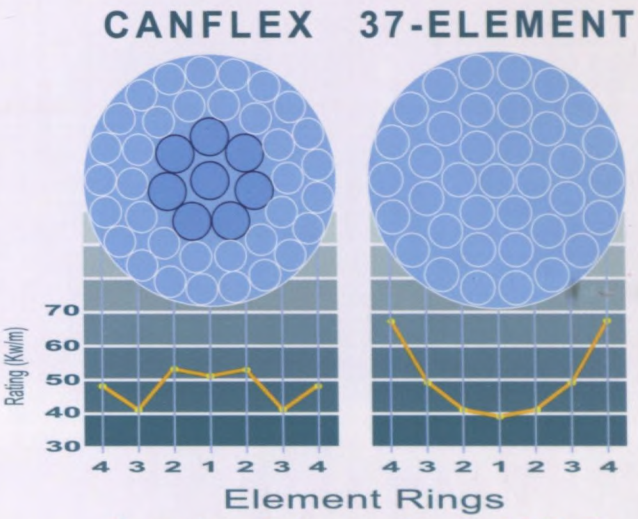
Approved by the Atomic Energy Control Board (AECB), a two-channel, 24-bundle, demonstration irradiation using CANFLEX NU began in September 1998 at Point Lepreau NGS, New Brunswick, Canada. The first four bundles were discharged in March 1999, and a further refuelling took place in August 1999. Fuel handling experience, irradiation data and in-bay photographs show that the in-reactor performance of the CANFLEX NU fuel met all design criteria and that it is fully compatible with existing CANDU reactors. Full-core implementation has been supported by a water CHF test in preparation for full-core safety analysis.

Through all phases of design, testing and validation, a comprehensive CANFLEX information database has been compiled, and extensive computer modelling has been done. The database and computer modelling capabilities will ably support future large-scale fabrication and licensing.

The Transition to CANFLEX

Following full-core analysis, CANFLEX NU will be available for commercial use by the end of 2000.

CANFLEX NU has been designed to have handling characteristics that are similar to those of the existing 37-element fuel—which continues to operate exceptionally well within its design parameters. These characteristics provide the operators with the ability to introduce CANFLEX NU bundles during normal on-power refuelling.



Comparison of element ratings for CANFLEX and 37-element bundles with NU fuel

CANFLEX NU bundles can be used in conventional CANDU fuel handling systems with no equipment modifications, and can be phased in over a period of time during normal on-power refuelling, with no waste of existing fuel. In fact, as demonstrated at Point Lepreau, fuel channels continue to operate normally when containing a mix of both CANFLEX NU and 37-element fuel.

A CANFLEX fuel design manual and performance specification will be supplied to customers under a licensing agreement.

CANFLEX Economics

To facilitate discussion and to provide an economic basis for a decision to implement the use of CANFLEX NU fuel, a detailed economic model has been prepared to include all investments, effects on annual utility revenues, and annual operating costs. The assessment fully demonstrates that the returns from CANFLEX are significant.

AECL and KAERI have developed a new generation of fuel bundle—CANFLEX—to increase fuel performance and cost efficiency, and to allow for fuel cycle options. Here officials from AECL, KAERI, New Brunswick Power, and Zircatec Precision Industries—manufacturers of the first CANFLEX fuel bundles—celebrate the start of the demonstration irradiation at Point Lepreau NGS.

Flexibility = Future Fuel Cycle Options

One of CANFLEX's distinct advantages is that it is designed to serve as the fuel carrier for a variety of fuel cycle options for CANDU reactors. While significant benefits can be achieved using CANFLEX NU, it is expected that further benefits will be achieved with alternate fuel cycles such as slightly enriched uranium (SEU), or recycled uranium (RU) from the conventional reprocessing of Light Water Reactor (LWR) spent fuel. In the long term, thorium and DUPIC (**D**irect **U**se of Spent **P**WR Fuel **In** **C**ANDU) are also options. CANFLEX SEU and CANFLEX RU will be available as options in the near future.

A key element in AECL's plant life management strategies, CANFLEX NU assists stations in recovering the loss of thermalhydraulic margins that can occur because of various ageing phenomena. Current projections show substantial benefits can be realized by changing to CANFLEX NU fuel.

Enhanced Reactor Performance

FEATURES	BENEFITS
Higher (up to 8%) Critical Channel Power (CCP)	• Potential uprating of reactor power
Lower (up to 20%) peak linear element power ratings for the same bundle power	• Greater operating and safety margins
CANFLEX is compatible with existing 700 MWe class CANDU 6 reactors and 600 MWe class Pickering reactors, and is compatible with other CANDU designs	• Accessibility • Uses existing equipment • Minimal changeover costs
Evolutionary design built on foundation of more than 30 years' operating CANDU reactors	• Proven technology • Long-term economic benefits • Ongoing support by AECL experts

For more information, contact your
AECL Account Representative
or AECL CANDU & Technical Services

AECL Head Office
2251 Speakman Drive
Mississauga, Ontario, Canada L5K 1B2
Tel: (1-905) 823-9040
Fax: (1-905) 823-9866

Chalk River, Ontario:
Tel: (1-613) 584-3311
Fax: (1-613) 584-1812

Visit our website at:
http://www.aecl.ca

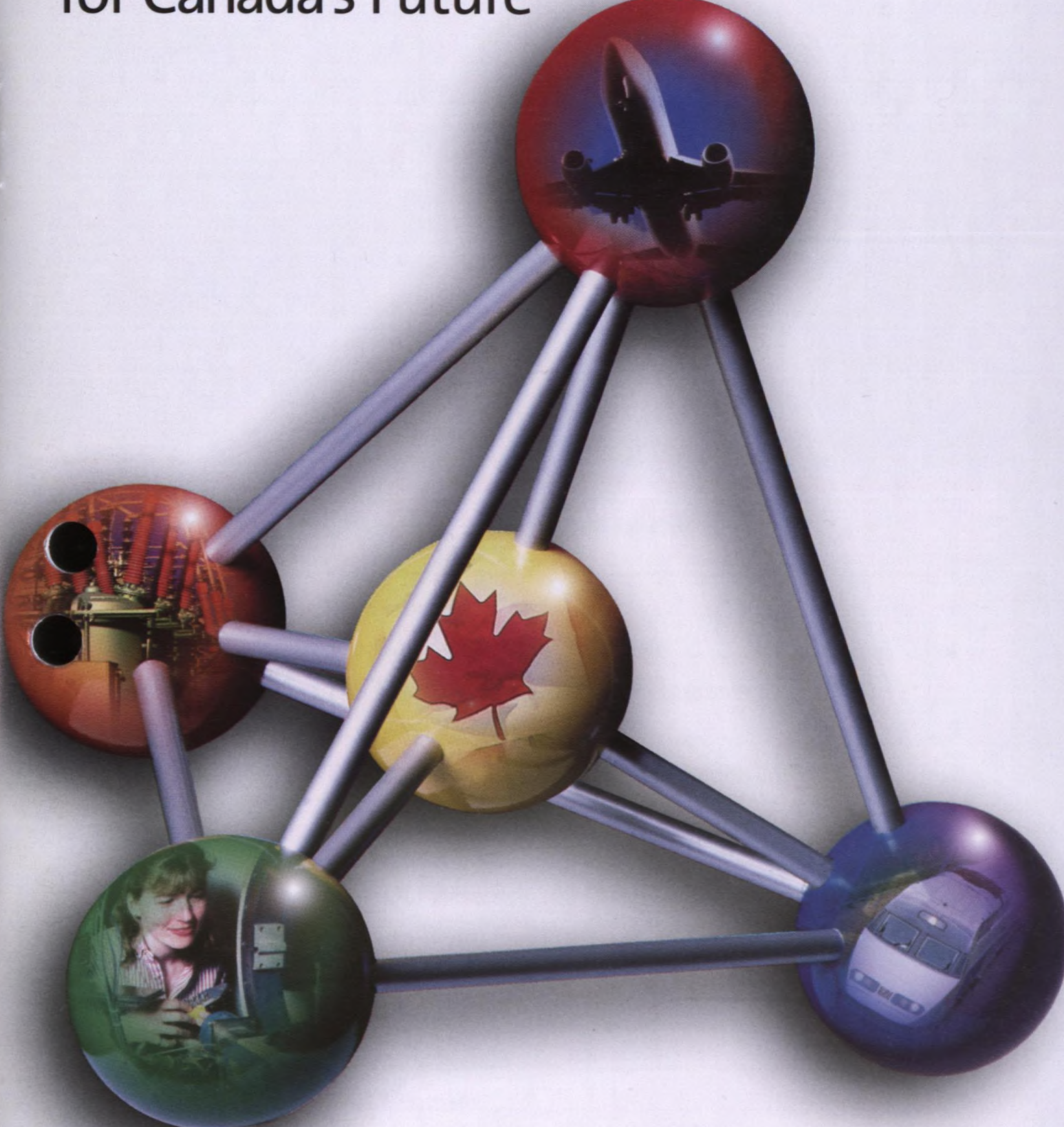
Publié aussi en français.

Printed in Canada. October 1999. Catalogue #6-3. D1239

CNF

CNF Proposal

Leading-Edge Technology for Canada's Future



CNF Executive Summary

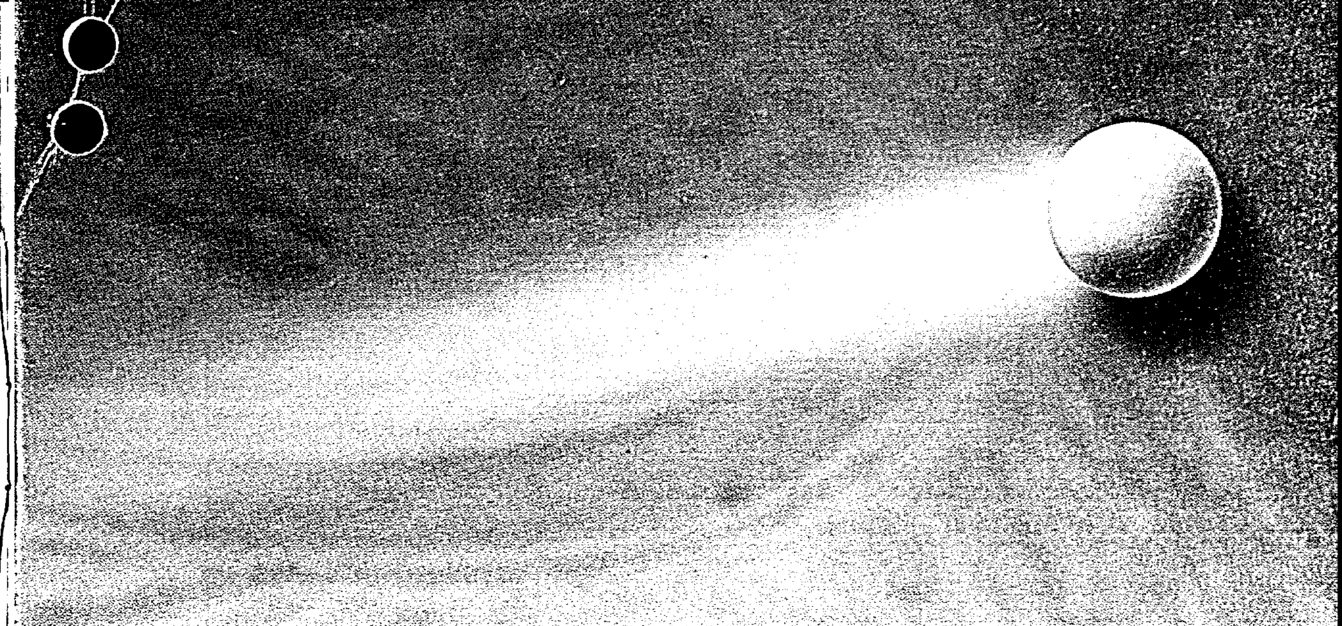
Canadian Neutron Facility for Materials Research

NRC · CNRC
National Research Council Canada
Conseil national de recherches Canada

AECL
Atomic Energy of Canada Limited

EACL
Énergie atomique du Canada limitée

CANDU® (CANada Deuterium Uranium) is a registered trademark of
Atomic Energy of Canada Limited (AECL)



Executive Summary
1999 April

Table of contents:

CNF Project

Artist's Concept of CNF Building

The National Research Council of Canada (NRC) and Atomic Energy of Canada Limited (AECL) jointly propose a new Canadian Neutron Facility for Materials Research (CNF) to support next-generation neutron-based materials research and innovation in Canada.

The purpose of the proposed CNF is two-fold:

- to provide the advanced materials research capability to meet the needs of Canadian universities and industry
- to provide an essential testing facility to advance the CANDU® power reactor design and ensure the future competitiveness of the Canadian nuclear industry.

The proposal will be brought forward with full regard for academic, research and industrial stakeholders.

A CNF Project, planned to begin in 1999, would have a projected reactor start-up in 2005. The total estimated cost for the reactor and program facilities at the Chalk River site is $388 million: $208 million for the CNF reactor and $90 million each for the CANDU development facilities and the neutron beam facilities.

"The Canadian Neutron Facility offers unprecedented potential for the advancement of materials research in Canada and is indispensable for the continued success of Canada's nuclear power program."

Bertram Brockhouse,
Canadian Nobel Laureate (Physics)

Background

In the past five decades, Canada has been well positioned internationally in the field of advanced materials research—for the Canadian nuclear industry, for other industrial applications and for university research. This was, in a large part, due to the ingenuity and foresight of the nuclear research community and the Canadian government in designing and building the world-renowned NRX and NRU research reactors at AECL's laboratories at Chalk River.

However, the NRX research reactor is now permanently shut down and the NRU reactor—Canada's pre-eminent research reactor since 1957—will be shut down before the end of the year 2005. The closure of NRU will coincide with an increasing demand for knowledge of the structure and dynamics of materials. It will also coincide with a projected shortage of neutron beam sources worldwide.

All industrialized, and some newly industrialized countries, have access to neutron beams from research reactors. However, because of the growing international awareness of the critical importance of neutrons for advanced materials development, the global demand is now exceeding supply.

Australia, China, Germany, Holland, Japan, Egypt and Thailand have identified the requirement for advanced materials research facilities in the 21st century and are already constructing, or planning to construct, new research reactors. In addition, all nuclear vendor countries have access to government-supported research reactors to augment their commercial programs.

NRU, the primary neutron irradiation facility in Canada, will come to the end of its life by 2005.

The National Value of the CNF

The Canadian Neutron Facility is a key component of a revitalized national materials research infrastructure for the 21st century. The future competitiveness and standard of living of all nations in the emerging global economy will increasingly depend on scientific progress and technological innovation. In particular, national competitiveness will be closely linked to the innovative capabilities of nations in information technologies, biotechnologies and advanced materials. The OECD nations have identified the development of new materials, and supporting process technologies, as a strategic priority for the 21st century.

An intense neutron source is essential to Canada's CANDU nuclear industry, both nationally and in the international marketplace. And it is a key part of the essential suite of materials probes and test facilities on which an advanced industrial economy must rely for enhanced productivity. Only with a complete set of these facilities can Canada meet the challenges that confront a wide range of industries.

The role of NRC, as the Government of Canada's lead science and technology agency, is to ensure that the materials research infrastructure is in place, and operated to meet stakeholder needs.

The role of AECL, as a federal Crown corporation and leader of Canada's nuclear industry, is to ensure that key research and product development facilities are available to support existing customers, and to continue to evolve its CANDU and research reactor products. AECL's goals are to remain competitive in the global marketplace, and to ensure that CANDU technology is available to Canada in the future, when the need for new and environmentally-sound electricity generation arises.

The Importance of Materials Research to the CANDU Industry

For more than 40 years, NRU has provided the primary neutron irradiation facilities that were key to the development of the CANDU reactor as a major source of electrical power.

The independent R&D Advisory Panel to AECL's Board of Directors strongly supports the collaboration between the National Research Council of Canada and Atomic Energy of Canada Limited in proposing the Canadian Neutron Facility for Materials Research.

The Panel is convinced that the CNF and its research and development (R&D) facilities will:

- provide an essential, effective and economic testing facility to support and advance the CANDU power reactor design
- ensure the future competitiveness of the Canadian nuclear industry
- provide an advanced materials research capability to meet the needs of the Canadian Universities and industry.

The case for the CNF is based on the need for an engineering-scale, high thermal-neutron flux, high fast-neutron flux reactor to provide the essential support required for AECL to ensure long-term competitiveness of the CANDU product. This goal can only be met by providing an experimental capability for testing the behaviour of materials and components when subjected to an intense flux of neutrons.

The nuclear industry is based on the mastery of sophisticated technology, often on the leading edge of scientific development. Indeed, CANDU technology is partly responsible for Canada's international reputation for large-scale technical excellence. It is the existence of this technical and scientific maturity that is essential in attracting future national and international customers for CANDU reactors.

Four AECL-designed CANDU 6 units at the Wolsong site in Korea. Wolsong 1, in-service since 1983, was the top-performing reactor in the world in 1997.

Canadian and foreign buyers of the CANDU system place critical importance on the degree of AECL's commitment to research and development. To be economically attractive, a nuclear plant must have a continuous high capacity factor for 30-40 years. A purchasing utility must, therefore, be convinced that the vendor will have the capability to back up the technology over its full operating lifetime.

With AECL's continued (and enhanced) capabilities in these areas, CANDU technology and the Canadian nuclear industry will have the tools to prosper in the 21st century. Federal government support for the CNF should be viewed in the context of the substantial levels of direct and indirect government support that are provided to competing light-water reactor technologies in the U.S., France, Japan and Germany. Building the CNF is a key component of a successful ongoing industry, and ensures a future CANDU option for Canada—clean electricity supporting the Kyoto Protocol on Climate Change.

The Importance of Materials Research for Universities and Industry

Neutron beams can provide unique information that is key to the understanding and control of advanced materials. Neutron beam research provides scientists and engineers with valuable information about materials that affect our daily lives. The results of neutron beam research include improvements in everyday products, such as jet aircraft, high-speed trains, plastics, pharmaceuticals and magnetic devices such as computer disks, pocket calculators and lightweight magnets in automobiles. As well, neutron research improves industrial products and materials, such as polymers, metals and ceramics, gas pipelines, railsteel, welded structures, CANDU pressure tubes, high-temperature superconductors, biological materials, and synthetic nanostructures.

For the future, much more needs to be known about biological materials and polymers. The CNF will provide an entirely new capability for Canada in these rapidly growing areas. It will provide copious beams of neutrons whose wavelengths match the larger-scale structures of importance in the life sciences and in new soft materials. Larger wavelengths are produced by cooling neutrons to low energies. These cold neutrons from the CNF will open the door to many new fields of science and technology and will create applications for neutron beams that were not previously possible in Canada. Moreover, the unique sensitivity of the neutron to hydrogen and deuterium allows a scientist to highlight a chosen part of a complex biological structure. The CNF neutron beams will provide an effective research tool in such areas as biological membranes, blood cells, block co-polymers, colloids, gels, networks of microcracks and precipitates in alloys.

Recognizing that economic competitiveness is linked to innovative capabilities in materials-based technologies, a special committee of the Natural Sciences and Engineering Research Council recommended in its 1994 report, *Canada's Future In Materials Research,* that Canada make an immediate commitment to develop a fully-equipped reactor-based national source for neutron beam research. In 1998, the National Research Council produced a report, *Future Prospects for Neutron Beam Research and Technology Development in Canada,* which concluded that: "Neutron beam sources are part of an essential suite of materials probes to which advanced industrial economies must have access in order to respond to the challenges of materials research…Future access to high flux neutrons is a critical issue for the future growth of the Canadian neutron scattering and materials research community at large".

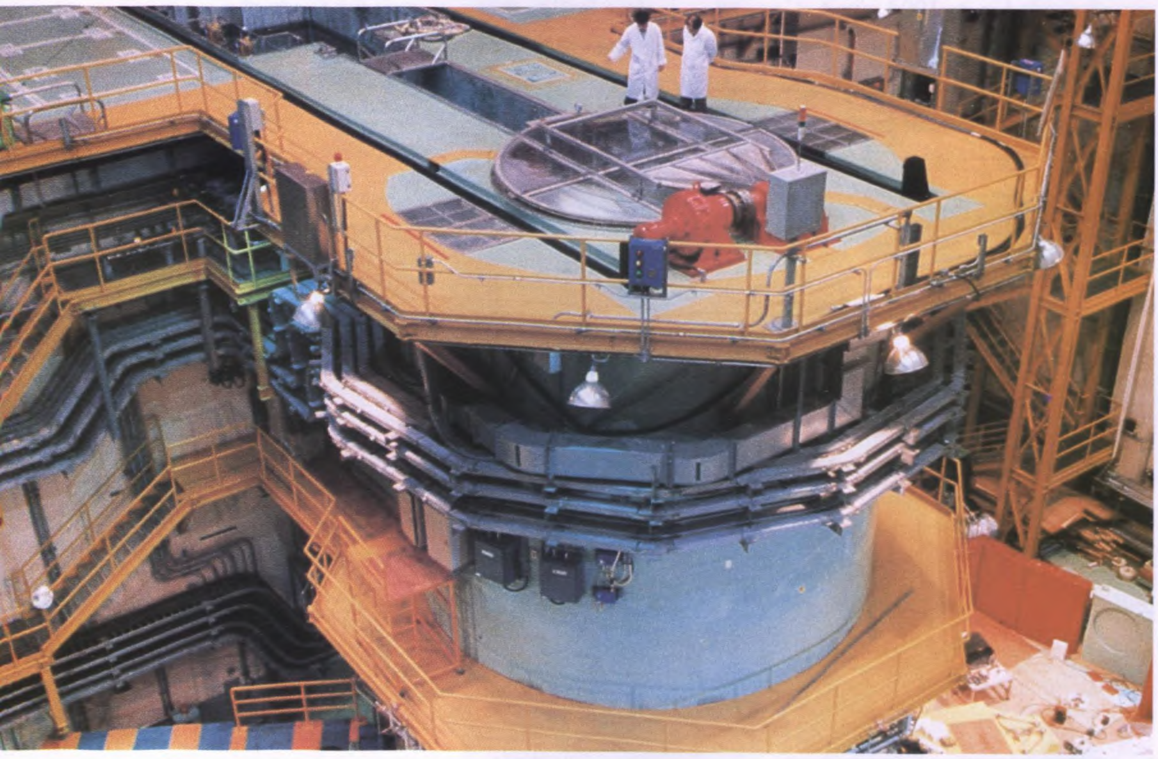
The 1998 International Proposal Review Committee found the CNF to be "a world-class facility that will meet the needs of a broad spectrum of university and industrial materials research."

Neutron beam research provides scientists and engineers with valuable information about materials that affect our daily lives.

CNF Design

The source of neutrons for the CNF is a 40 MW_t pool-type reactor based on AECL's well-established MAPLE (Multipurpose Applied Physics Lattice Experiment) technology. MAPLE reactors are among the most advanced multipurpose research reactors available today. The first demonstration of MAPLE technology is Korea's HANARO research reactor, which started up in 1995.

Two MAPLE reactors, dedicated to the production of medical isotopes, are now under construction at AECL's Chalk River site, for MDS Nordion. This project is on schedule and on budget. As well, MAPLE research reactor technology is offered in a proposal currently being developed for the Australian Nuclear Science and Technology Organization (ANSTO). The MAPLE reactors benefit from AECL's extensive experience in the design, construction and safe operation of both research reactors and CANDU power reactors worldwide.



MAPLE's breakthrough design technology was incorporated into the Korea Atomic Energy Research Institute's HANARO multipurpose research reactor, which began operation in February 1995.

AECL is constructing two MAPLE reactors for MDS Nordion at its Chalk River site. They will be dedicated to the production of medical isotopes.

The CNF reactor assembly is located at the bottom of a 15.6-metre-deep, light-water-filled pool. The reactor systems include the fuel, the process and service systems, the control system, and two independent shut-down systems. The compact light-water-cooled and -moderated core uses low-enriched uranium fuel, consistent with international nuclear non-proliferation guidelines. This rod-type fuel—U_3Si_2-Al (19.7 wt% U-235)—generates a flux of fast neutrons in the core and a high thermal neutron flux that extends into the surrounding heavy water reflector tank. The maximum unperturbed thermal-neutron flux is 4×10^{18} neutrons·m^{-2}·s^{-1}.

The CNF MAPLE Advantage

- state-of-the-art Canadian technology
- high neutron fluxes per unit power
- low fuel costs
- two independent shut-down systems
- passive pool, ensuring reactor cooling
- containment building designed to accommodate extreme events
- designed for ease of operation and maintenance
- modest staffing requirements

CANDU Research and Product Development

The neutrons in the reactor core are used to irradiate advanced fuels, materials and components in special test sections or "loops" that reproduce a nuclear power reactor's operating environment. The materials and components are then examined and tested in shielded "hot cells" to obtain information on their performance under power reactor conditions. Irradiation research and proof-testing has been an essential element in ensuring a successful CANDU nuclear industry.

Neutron Beam Facilities

Beams of neutrons are guided to experimental stations outside the reactor core, where they are used as powerful probes of materials. This technique—pioneered in Canada by Canadian Nobel Laureate Bertram Brockhouse in the 1950s and now used all over the world—is called neutron scattering.

A suite of neutron instruments in the CNF will provide Canada with state-of-the-art capabilities for research in wide-ranging fields of science and engineering. The cold source, which is a key element of many European facilities, will open new fields of research for Canadian scientists.

CNF Facilities for Advanced Materials Research

6 thermal beams in the reactor hall

1 cold source feeding seven neutron guides

1 thermal source feeding two neutron guides

1 new spectometer directly viewing the cold source

5 instruments relocated from NRU

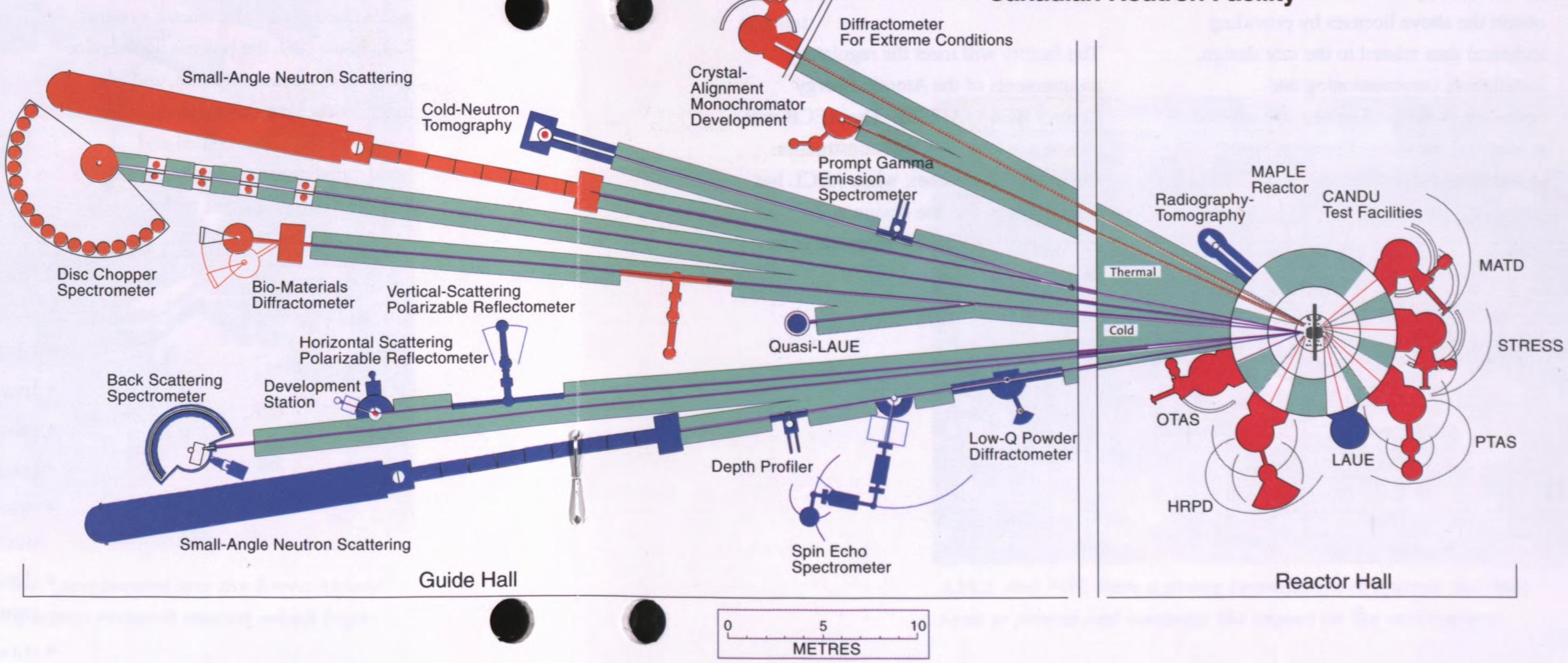
5 new instruments in the Guide Hall

Provisions for 23 instrument stations

CNF Facilities for CANDU Research and Product Development

Horizontal Fuel-Test Facilities	3 test sections, each with up to 3 CANDU bundles, connected to 2 loops
	Bottom test section can be replaced with a high integrity test section for future severe fuel damage Blowdown Test Facility (BTF) tests
	CANTHERM advanced fuel channel capability
Vertical Fuel-Test Facilities	1 test loop with 2 test sections for multi-element partial fuel bundles
	Space to connect one test section to a second loop
	Space for a BTF loop system
Materials Irradiation Facilities	4 split-core sites
	4 fast neutron sites
Hot Cells	1 general purpose cell
Service Irradiation Facilities	6 vertical tubes including:
	1 hydraulic rabbit system
	Provision for a pneumatic rabbit system

Canadian Neutron Facility



Safety and Licensing

The Canadian nuclear reactor safety philosophy and practice has evolved over four decades. A long-standing basic principle is that the licensee (owner/operator) has the main responsibility for achieving a high standard of safety. The operator of the CNF is responsible for ensuring the health and safety of its employees and the public, as well as the protection of the environment.

The overall safety objective for the CNF is to protect individuals, society and the environment by establishing and maintaining an effective defence against radiological hazards.

NRC will support AECL in its efforts to obtain the above licenses by providing technical data related to the safe design, installation, commissioning and operation of the cold source, the neutron guides and the suite of neutron beam instruments proposed.

Good design practice and construction, including the use of appropriate codes and standards and a quality assurance program, will ensure reactor safety for normal operation and anticipated abnormal events. Operating procedures for the reactor will ensure that radioactive releases and the resultant radiation doses are as low as reasonably achievable. The defence-in-depth strategy will be followed in the design of the CNF to compensate for potential human and mechanical failure and unexpected occurrences. Abnormal events will be prevented, then mitigated, then accommodated, in that order; and a series of barriers will prevent, reduce or slow down releases of radioactivity into the environment.

The facility will meet the regulatory requirements of the Atomic Energy Control Board (AECB). The AECB will issue a site approval, and construction and operating licenses, when AECL has demonstrated that the design and operation of the facility meets all safety requirements.

Environmental Considerations

AECL and NRC are committed to operate facilities so as to protect and to minimize the impact on the environment. Protection of the environment means protection against adverse changes to public health and safety and the socio-economic environment. The environmental assessment of proposed projects provides a systematic approach for identifying potential adverse environmental effects before they occur. The activities in the various stages in the life of the facility, including site investigation and preparation, construction, operation, maintenance and decommissioning, will be examined for their potential for significant adverse environmental effects. Appropriate mitigation measures will be taken into account.

Public participation is an important element of an open and balanced environmental assessment process. A public communication plan will be implemented to ensure that public feedback is obtained and concerns addressed where needed. The environmental assessment will meet the requirements of the Canadian Environmental Assessment Act (CEAA). A Comprehensive Study will be carried out and an Environmental Impact Statement prepared for submission. On acceptance, the Canadian Environmental Assessment Agency will recommend that the Minister of the Environment approve project start.

AECL and NRC have a strong commitment to operate facilities so as to protect and minimize the impact on the environment.

Project Schedule

The CNF project schedule for the reactor and CANDU facilities has an estimated duration of 72 months, and encompasses major activities in engineering, safety and licensing, procurement, construction, installation, and commissioning. The NRC Beam facilities will be completed by month 96.

A risk analysis was carried out for the concept first developed in 1994, and it defined the major areas of uncertainty associated with both cost and schedule. Since 1995, AECL has carried out a pre-project program that focused on these areas of uncertainty. This will reduce the level of funding that the full project would need to set aside for risk and contingency. The present schedule reflects the advances made and the risk management activities planned during the pre-project phase.

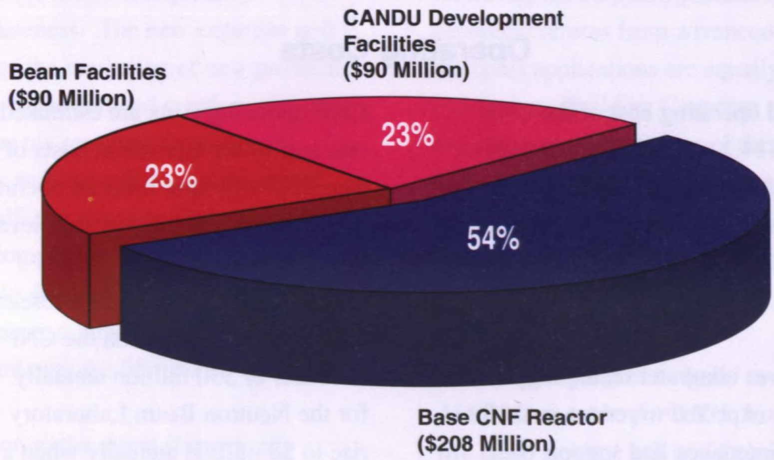
The schedule for obtaining a construction license was identified as a major schedule uncertainty. Consequently, a key pre-project activity has been an up-front licensing process with the AECB. This is focused on reaching agreement before project start that there are no fundamental barriers to licensing the CNF. A companion activity was to define the scope and consequent schedule of the environmental assessment that must be completed to confirm the acceptability of the CNF siting. Together these two initiatives have reduced the schedule risk associated with licensing.

CNF Project Milestones

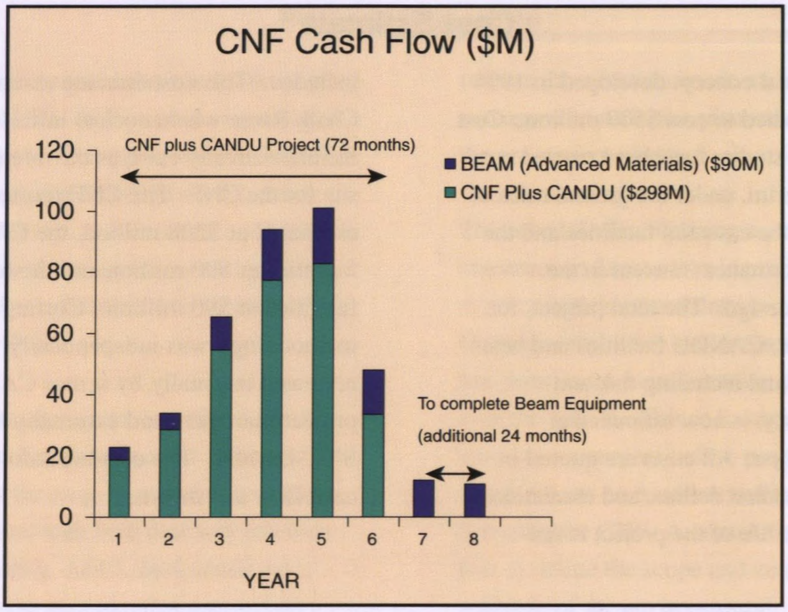
Engineering Funding Approval	Month 0
Construction License Approval	Month 30
Construction and Installation Complete	Month 60
Nuclear Commissioning Complete (CNF and CANDU facilities)	Month 72
Beam Instrument Commissioning Complete (NRC Beam facilities)	Month 96

Cost Estimate

The original concept developed in 1994 was estimated to cost $500 million. Cost reduction studies have been carried out in the interim, under the ground rules of retaining the essential facilities and the high performance inherent in the MAPLE design. The total project, for the reactor, CANDU facilities and beam facilities, and including risk and contingency, is now estimated at $388 million. All costs are quoted in 1998 Canadian dollars, and escalation during the life of the project is not included. This cost estimate assumes Chalk River, where nuclear infrastructure facilities already exist, as the reference site for the CNF. The CNF reactor is estimated at $208 million, the CANDU facilities at $90 million and the beam facilities at $90 million. Costing methodology was independently reviewed internally by senior CANDU project managers and externally by SNC-Lavalin. The cost breakdown and cash flow are shown.



Cost Estimate Breakdown — Reactor, CANDU Facilities and Beam Facilities ($388 Million)



Operating Costs

The annual operating cost of the CNF reactor is $14.2 million. This includes labour, fuel, electricity, materials and heating costs. Computing, waste storage and design, safety and licensing costs are also added.

Use of newer computer technology for the CNF is expected to reduce costs for further maintenance and support over current NRU expenditures. Also, being a new facility, the CNF will incur less design, safety and licensing support costs than NRU currently requires.

CNF operating costs are estimated to be one-half of the equivalent costs of NRU. The CNF will have reduced operations, maintenance and support staff levels.

Costs for AECL's in-reactor research programs that depend on the CNF are in the order of $30 million annually. Costs for the Neutron Beam Laboratory will rise to $8 million annually when a mature program is operating in 2006/2007. Securing operational funds will be the responsibility of the CNF owner/operator, the CANDU Program, and the Beam Laboratory operator, respectively.

Economic Impact

The CNF project will yield significant benefits for companies that are vendors and subcontractors for components and services. The CNF will include advanced electronics, computing hardware and software, custom design and engineering and heavy equipment. Canadian companies will be contracted to supply, assemble and commission 90 per cent of the components for the reactor, CANDU development facilities, and the neutron beam laboratory. The stringent demands of the project will require firms to develop new skills and technologies that will improve their subsequent competitiveness. The new expertise will encourage the marketing of new products, business expansion and creation of new jobs. The tax revenues from direct contracts and expanded capabilities will be a significant return to Canada. After project completion, suppliers can look forward to 40 years of revenue from maintenance, upgrades and new equipment over the lifetime of the facility.

In addition to the direct stimulus of economic activity, the research and development conducted at the CNF will help ensure Canada's global competitiveness. In the CANDU business, for example, the Wolsong Project in the Republic of Korea—CANDU Units 2, 3, 4—benefitted from nuclear technology largely developed through research reactor proof-testing. The project returned about $1 billion to the Canadian economy. The Qinshan Project in China—two CANDU 6 reactors—is providing 27 000 person-years of high-tech and industrial jobs for Canada. This economic stimulus is ongoing, with 10-12 additional off-shore CANDU sales projected over the next 10 years.

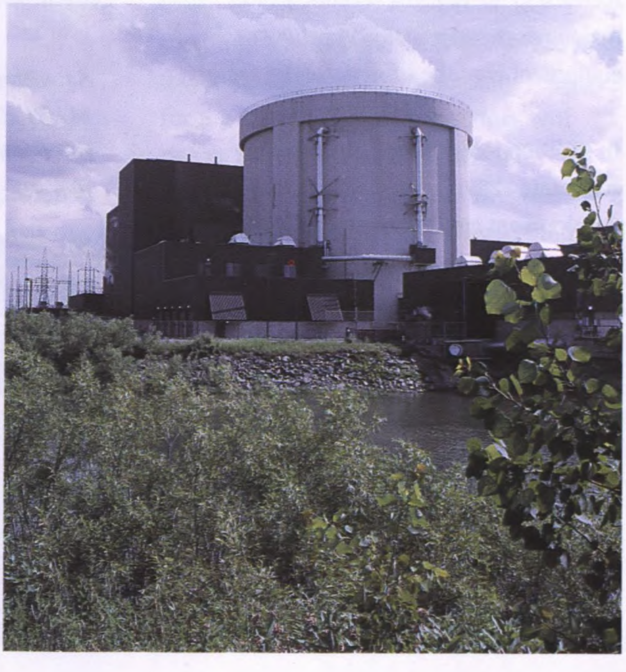
The neutron beam laboratory will provide powerful insights to help Canadian companies solve materials problems and efficiently develop new products. The economic returns from advanced materials applications are equally impressive. Building Canadian materials expertise over the lifetime of the CNF will return to Canada 10-35 per cent annually on the investment, based on experience in other industrialized countries.

As with the project to build two MAPLE reactors for MDS Nordion, the CNF project will yield significant benefits for Canadian suppliers.

Project Implementation

The construction of the CNF would represent a major undertaking for AECL and Canadian private sector companies. It is estimated that more than 90 per cent of the scope of the CNF project could be supplied by Canadian firms. Expertise is available within AECL and the Canadian nuclear industry to undertake projects of this complexity and magnitude. NRC will coordinate its implementation activities to be consistent with AECL, and has access to experienced personnel, including Project Management resources.

AECL, in particular, has managed, or is managing, nuclear power projects in Argentina, China, Korea and Romania, and has extensive project management and engineering expertise from similar projects in Canada and in other foreign countries. AECL has designed and constructed seventeen research reactors; for example, NRX, NRU, WR-1 and the SLOWPOKE series. These all were built largely with Canadian resources. AECL has also supplied the reactor assembly, associated equipment and services for HANARO (the Korean research reactor) on a fully commercial basis, and is presently constructing two MAPLE reactors under the MMIR project at Chalk River Laboratories, on behalf of MDS Nordion.



As with earlier CANDU power reactor projects, Canadian companies will supply a major percentage of the CNF project scope.

Management Model

The CNF will require a management structure that emphasizes the facility's national character and is representative of all stakeholders. For example, one could envisage a Management Authority with Directorates responsible for Reactor Operations, CANDU Facilities and the Neutron Beam Laboratory.

Decommissioning

AECL and NRC will produce a detailed CNF Decommissioning Plan for the AECB. This will be based on a 40-year operating life for the CNF, followed by a 70-year decommissioning period.

Experience gained in the decommissioning planning for the MAPLE 1 and MAPLE 2 isotope reactors at Chalk River will provide an invaluable template for the CNF Decommissioning Plan.

For the CNF reactor building, including the reactor, beam hall and enclosed equipment, a two-phase decommissioning process is envisaged. The first phase would be immediately following facility shutdown, and the second phase 30-40 years hence. From MAPLE 1 and MAPLE 2 planning experience, a CNF decommissioning provision with a present value estimated in the range of $60 - 80 million (1998 $) would cover future facility decommissioning including fuel disposal. This will be detailed in the formal licensing submission.

AECL has experience in decommissioning of earlier research reactors and prototype power reactors.

Summary

- The National Research Council of Canada (NRC) and Atomic Energy of Canada Limited (AECL) jointly propose a new Canadian Neutron Facility for Materials Research (CNF) to support next-generation neutron-based materials research and innovation in Canada for the 21st century. The proposal is brought forward with full regard for academic, research and industrial stakeholders.
- The purpose of the CNF is to provide:
  - i) the advanced materials research capability to meet the needs of Canadian universities and industry, thus ensuring Canadian competitiveness on many fronts in the global arena
  - ii) an essential testing facility to advance the CANDU power reactor design. This will ensure the Canadian nuclear industry ($6 billion annual contribution to the Canadian economy) remains competitive and that CANDU is available to Canada in the future, when the need for new, environmentally-sound electricity generation arises, as dictated by the Kyoto Protocol on Climate Change.
- During the construction and operational phases of the CNF, local and national economic stimulation is substantial. Ninety per cent (90%), about $350 million, of the CNF can be provided by Canadian firms.
- All industrialized, and some newly industrialized countries, have access to neutron beams from research reactors. However, because of the growing international awareness of the critical importance of neutrons for advanced materials development, the global demand is now exceeding supply.
- Australia, China, Egypt, Germany, Holland, Japan and Thailand have identified the requirement for advanced materials research facilities in the 21st century and are already constructing, or planning to construct, new research reactors.
- All nuclear vendor countries have access to government-supported research reactors to augment their commercial programs.
- Several generations of Canadian materials researchers will be trained at this facility, providing a continuous, strong knowledge-base in Canada.

- A CNF Project, planned to begin in 1999, would have a projected reactor start-up in 2005. The total estimated cost for the reactor and program facilities is $388 million. The CNF reactor is estimated at $208 million; CANDU development facilities are estimated at $90 million, while the neutron beam facilities are $90 million.
- Operating costs for the CNF are estimated at $14.2 million annually, about half those of the current NRU research reactor. Operating costs for the CANDU programs will be about $30 million annually. The operating costs for the CNF Neutron Beam Laboratory are projected to be $8 million annually when the operation is mature in 2006/07. Operating funds will be contributed by the CNF owner/operator, the CANDU Program, and by the Beam Laboratory operator, respectively.
- AECL and NRC will produce a detailed CNF Decommissioning Plan for the AECB. From MAPLE 1 and MAPLE 2 planning experience, a CNF decommissioning provision with a present value estimated in the range of $60 - 80 million (1998 $) would cover future facility decommissioning including fuel disposal, and will be detailed in the formal licensing submission.
- With a strategic investment in the CNF, the federal government can lay the foundation for a revitalized materials research infrastructure to support innovation, knowledge and productivity for Canada.

NRC · CNRC
National Research Council Canada
Conseil national de recherches Canada

AECL EACL
Atomic Energy of Canada Limited
Énergie atomique du Canada limitée

Publié aussi en français Printed in Canada
1999 April

The CNF - Leading Edge Technology for Canada's Future

Dr Ian J. Hastings, **AECL**

Executive Summary

The National Research Council of Canada and Atomic Energy of Canada Limited are proposing to government a new Canadian Neutron Facility for Materials Research (CNF). The CNF (Figures 1 and 2) will ensure the continuation and augmentation of two critical functions now performed at Chalk River Laboratories by the NRU research reactor (Figure 3), which will not operate beyond 2005: to be an essential testing facility to advance the CANDU® power reactor design ensuring that CANDU is available now and in the future to provide environmentally-sound electricity; and to be a world-class neutron beam laboratory that supports advanced materials research in Canadian universities and industry.

The CNF will provide economic benefits to Canada by generating unique information on the structure and performance of materials in a wide range of industrial applications, using neutron techniques. As well as being a cornerstone of CANDU reactor development, the CNF will support the development of the totally new fields of science and technology that will drive Canadian industries of the next century.

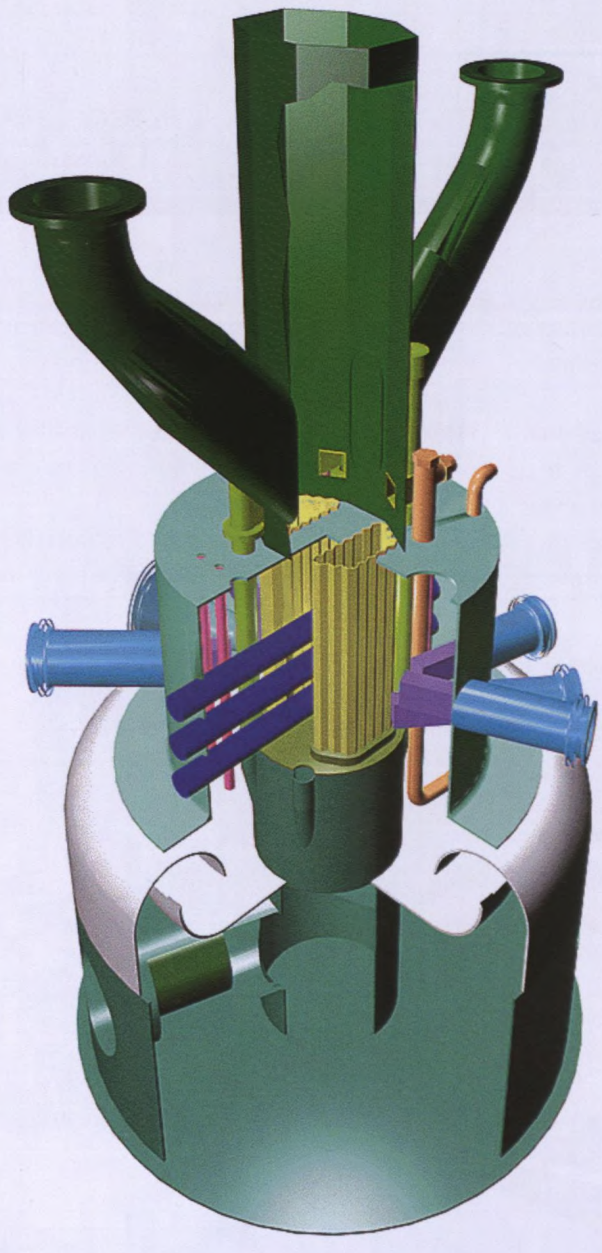


Figure 1. Sectional view of the CNF reactor.

Background

In the past five decades, Canada has been well-positioned internationally in the field of advanced materials research—for the Canadian nuclear industry, for other industrial applications and for university research. This was, in a large part, due to the ingenuity and foresight of the nuclear research community and the Canadian government in designing and building the world-renowned NRX and NRU (Figure 3) research reactors at AECL's laboratories at Chalk River. However, the NRX research reactor is now permanently shut down and the NRU reactor—Canada's pre-eminent research reactor since 1957—will be shut down before the end of the year 2005.

Figure 2. Artist's impression of the CNF Building, including the neutron beam guide hall on the right.

The closure of NRU will coincide with an increasing demand for knowledge of the structure and dynamics of materials. It will also coincide with a projected shortage of neutron beam sources worldwide.

All industrialized, and some newly-industrialized countries, have access to neutron beams from research reactors. However, because of the growing international awareness of the critical importance of neutrons for advanced materials development, the global demand is now exceeding supply. Australia, China, Egypt, Germany, Holland, Japan and Thailand have identified the requirement for advanced materials research facilities in the twenty-first century and are already constructing, or planning to construct, new research reactors. In addition, all nuclear vendor countries have research reactors to support their commercial programs.

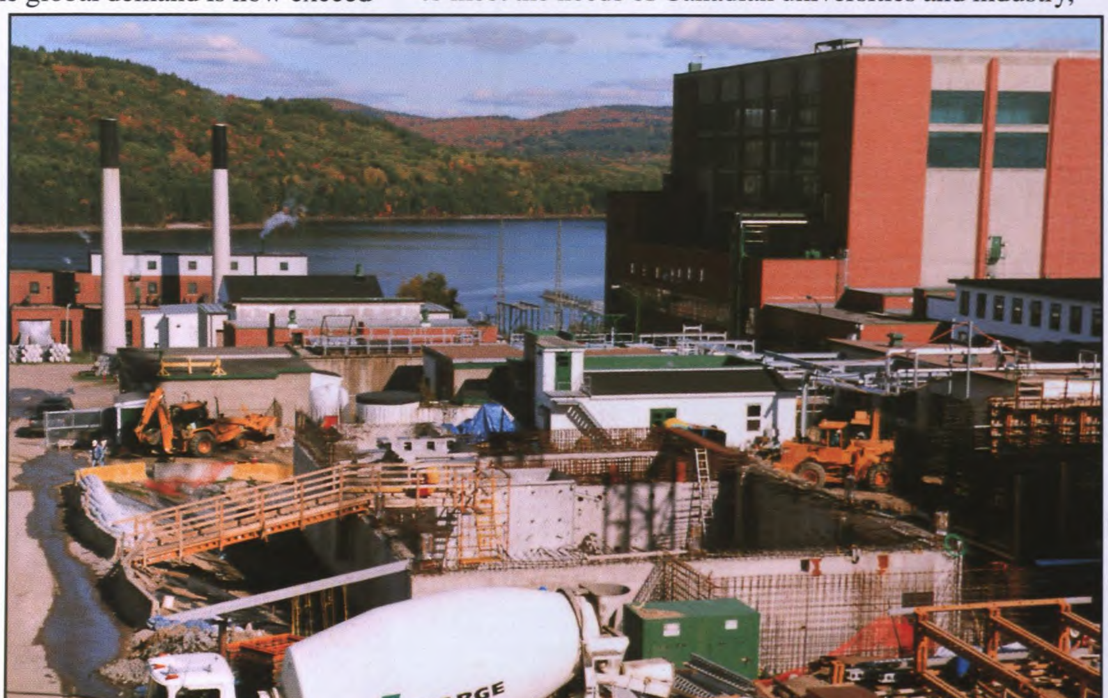


Figure 3. NRU, the primary irradiation neutron facility in Canada, will come to the end of its life by 2005.

The CNF Proposal

The National Research Council of Canada (NRC) and Atomic Energy of Canada Limited (AECL) are jointly proposing a new Canadian Neutron Facility for Materials Research (CNF) to support next-generation neutron-based materials research and innovation in Canada. The proposal is brought forward with full regard for academic, research and industrial stakeholders. The purpose of the proposed CNF is two-fold:

- ❑ to provide the advanced materials research capability to meet the needs of Canadian universities and industry,

- to provide an essential testing facility to advance the CANDU® power reactor design, to ensure the future competitiveness of the Canadian nuclear industry, and to have CANDU available to Canada now and in the future to provide environmentally-sound electricity.

A CNF project, beginning in 1999/2000, would have a projected reactor start-up in 2005/06. The total estimated cost for the reactor and program facilities at the Chalk River site is $388 million (1998$): $208 million for the CNF reactor and $90 million each for the CANDU development facilities and the neutron beam facilities.

Figure 4: Facilities for CANDU Development

Horizontal Fuel-Test Facilities	**3 test sections, each with up to 3 CANDU bundles, connected to 2 loops** **Bottom test section can be replaced with a high-integrity test section for future severe fuel damage Blowdown Test Facility (BTF) tests** **CANTHERM advanced fuel channel capability**
Vertical Fuel-Test Facilities	**1 test loop with 2 test sections for multi-element partial fuel bundles** **Space to connect one test section to a second loop** **Space for a BTF loop system**
Materials Irradiation Facilities	**4 split-core sites** **4 fast neutron sites**
Hot Cells	**1 general purpose cell**
Service Irradiation Facilities	**6 vertical tubes including:** **1 hydraulic rabbit system** **Provision for a pneumatic rabbit system**

The CNF Reactor

The CNF reactor (Figure 1) is based on AECL's well-established MAPLE technology. An artist's impression of the CNF Building, including the neutron beam guide hall, is shown in Figure 2. The reactor assembly is located at the bottom of a 15.6-metre-deep light-water-filled pool. The core is separated into two halves, with the space between containing three horizontal test sections, each capable of being fitted with a full-diameter CANDU fuel channel, holding three CANDU fuel bundles per channel. Cooling systems can simulate current and advanced CANDU conditions. Key systems include the fuel, the process and service systems, the control system, and two independent shutdown systems. The reactor uses low-enriched uranium fuel (U_3Si_2-Al, 19.7 wt% U-235), satisfying international nuclear non-proliferation guidelines. The fuel generates a flux of fast neutrons in the core and a high thermal flux in the surrounding heavy water reflector tank; a maximum unperturbed thermal neutron flux of 4×10^{18} neutrons.$m^{-2}.s^{-1}$ is achieved.

Figure 5. Facilities for advanced materials research using neutron beams

6 thermal beam tubes in the reactor hall
- **1 cold source feeding seven neutron guides**
- **1 thermal source feeding two neutron guides**
- **1 new spectrometer directly viewing the cold source**
- **5 instruments relocated from NRU**
- **5 new instruments in the Guide Hall**
- **Provision for 23 instrument stations**

Experimental Facilities

Experimental facilities are shown for CANDU development (Figure 4) and advanced materials research (Figure 5). The neutrons in the reactor core are used to irradiate advanced fuels, materials and components in test sections that reproduce a nuclear power reactor's operating environment. Additionally, the effects of different cooling conditions and chemistry can be simulated. After irradiation, these materials are examined and tested in shielded "hot cells" to obtain information on their performance under power reactor conditions. Irradiation research and proof-testing has, and continues to be, an essential element in ensuring a successful CANDU nuclear industry.

For advanced materials research, beams of neutrons are guided to experimental stations outside the reactor core, where they are used as powerful probes of materials. This technique, pioneered at Chalk River by Canadian Nobel Laureate Bertram Brockhouse in the 1950s and now used world-wide, is called neutron scattering. The neutron-beam instruments in the CNF will provide Canada with state-of-the-art capabilities in wide-ranging fields of science and engineering. Most importantly, the cold neutron source, a new capability for Canada, will open new research opportunities for Canadian scientists, particularly in the emerging fields of bio-materials and polymers.

Status

Pre-project technical activities specific to the CNF have been underway for four years supporting MAPLE technology, including a cost- and schedule-reduction program with the principle of maintaining CNF performance with the highest-priority facilities, "up-front" licensing with the Atomic Energy Control Board (AECB), and preliminary discussions on environmental assessment. The CNF will meet the regulatory requirements of the AECB; the AECB will issue a site approval. and construction and operating licenses, when

AECL and NRC have demonstrated that the design and operation of the facility meets all safety requirements. The environmental assessment will meet the requirements of the Canadian Environmental Assessment Act (CEAA). A Comprehensive Study will be carried out and an Environmental Impact Statement prepared for submission to the Canadian Environmental Assessment Agency.

Current costing and project scheduling for most efficient use of funding assume the close availability of nuclear infrastructure, including hot cells and appropriate human resources. Chalk River Laboratories has been the reference site and is the preferred site for the CNF. It is the most cost-effective in terms of existing supporting nuclear infrastructure, human resources and co-located R&D and advanced materials programs. Additionally, the waste and future liabilities associated with the CNF are confined to, and manageable at, a single site. AECL and NRC will produce a detailed CNF Decommissioning Plan for the AECB. This will be based on a 40-year operating life for the CNF, followed by a 70-year decommissioning period. Experience gained in the decommissioning planning for the MAPLE 1 and MAPLE 2 isotope reactors at Chalk River will provide an invaluable template for the CNF Decommissioning Plan.

"The Canadian Neutron Facility offers unprecedented potential for the advancement of materials research in Canada and is indispensable for the continued success of Canada's nuclear power program." - Bertram Brockhouse, Canadian Nobel Laureate (Physics)

CNF Economic Impact

The CNF project will yield significant benefits for companies that are vendors and subcontractors for components and services. The CNF will include advanced electronics, computing hardware and software, custom design and engineering and heavy equipment. Canadian companies will be employed to supply, assemble and commission 90 per cent of the components for the reactor, CANDU development facilities, and the neutron beam laboratory. The stringent demands of the project will require firms to develop new skills and technologies that will improve their subsequent competitiveness. The new expertise will encourage the marketing of new products, business expansion and creation of new jobs. The tax revenues from direct contracts and expanded capabilities will be a significant return to Canada. After project completion, suppliers can look forward to 40 years of revenue from maintenance, upgrades and new equipment over the lifetime of the facility.

In addition to the direct stimulus of economic activity, the research and development conducted at the CNF will help ensure Canada's global competitiveness. In the CANDU business, for example, the Wolsong Units 2, 3, 4 CANDU project in the Republic of Korea benefited from nuclear technology largely developed through research-reactor proof-testing. The project returned about $1 billion to the Canadian economy. The Qinshan Project in China, two CANDU 6 reactors, is providing 27 000 person-years of high-tech and industrial jobs for Canada. This economic stimulus is ongoing, with the additional off-shore CANDU sales projected over the next 10 years. The neutron beam laboratory will provide powerful insights to help Canadian companies solve materials problems and efficiently develop new products. The economic returns from advanced materials applications are equally impressive. Building Canadian materials expertise over the lifetime of the CNF will return to Canada an estimated 10-20% annually on the investment made today.

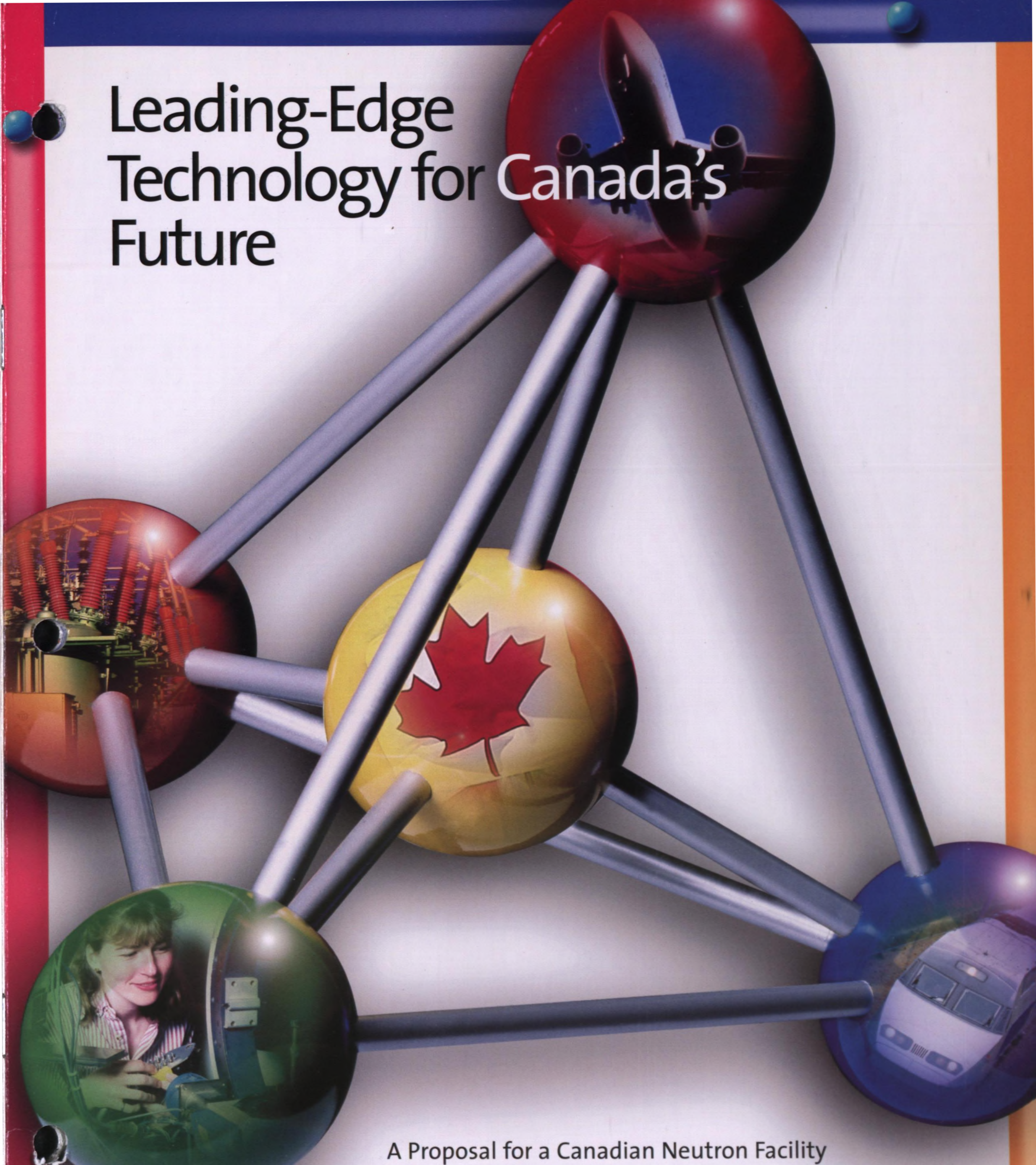
Summary

The CNF will provide an essential testing facility to advance the CANDU power reactor design, to ensure the future competitiveness of the Canadian nuclear industry, and to have CANDU available to Canada now and in the future to provide environmentally-sound electricity. Additionally, the CNF will provide insights to resolve technological issues facing other Canadian industry sectors beside nuclear: aerospace, oil and gas, automotive, materials production and manufacturing. The CNF will include unique new measurement capabilities that enable industrial developments in the newly-emerging fields of bio-materials, polymers, complex fluids and electronic devices. Young materials researchers who are trained at the CNF will provide talent that is urgently needed by Canadian industry and Canadian universities to foster Canada's transition to a knowledge-based economy.

With a strategic investment in the CNF, the federal government can lay the foundation for a revitalized materials research infrastructure to support innovation, knowledge and productivity for Canada in the next century.

Figure 6. As with the project to build two MAPLE reactors for MDS Nordion at Chalk River, the CNF Project will yield significant benefits to Canadian suppliers.

Leading-Edge Technology for Canada's Future



A Proposal for a Canadian Neutron Facility for Materials Research

NRC · CNRC
National Research Council Canada
Conseil national de recherches Canada

AECL EACL
Atomic Energy of Canada Limited
Énergie atomique du Canada limitée

The Canadian Neutron Facility: Leading-Edge Technology for Canada's Future

The National Research Council of Canada (NRC) and Atomic Energy of Canada Limited (AECL), in partnership with universities and industry, are jointly proposing a new Canadian Neutron Facility for Materials Research (CNF) to support next-generation neutron-based materials research and innovation in Canada.

The purpose of the proposed CNF is two-fold:

- to provide an advanced materials research capability to meet the needs of Canadian universities and industry

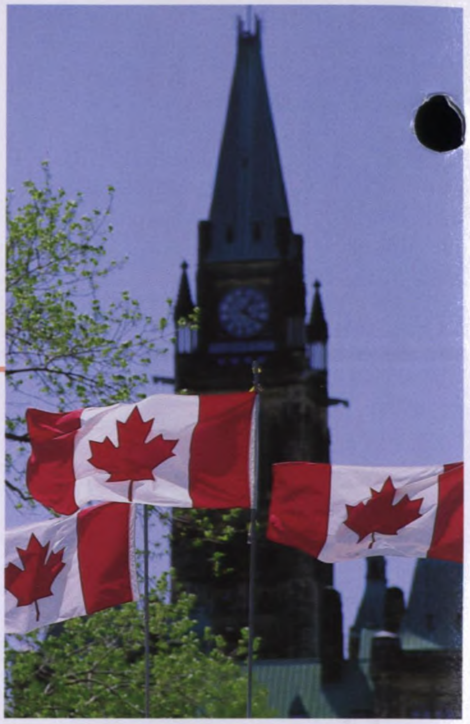
- to provide an essential testing facility to advance the CANDU power reactor design and ensure the future competitiveness of the Canadian nuclear industry

Construction of the CNF is planned to begin in 1999, with projected start-up of the reactor in 2005. The total estimated cost for the reactor and program facilities at the Chalk River site is $388 million.

The Canadian Neutron Facility is a key component of a revitalized national materials research infrastructure for the twenty-first century.

Revitalizing Canada's Materials Research Infrastructure

The Canadian Neutron Facility is a key component of a revitalized national materials research infrastructure for the twenty-first century. The future competitiveness and standard of living of all nations in the emerging global economy will increasingly depend on scientific progress and technological innovation. In particular, national competitiveness will be closely linked to the innovative capabilities of nations in information technologies, biotechnologies and advanced materials. The OECD nations have identified the development of new materials, and supporting process technologies, as a strategic priority for the twenty-first century.



The 1997 Speech from the Throne and the February 1998 Canadian Federal Budget have highlighted the importance of knowledge and innovation for long-term economic growth. To help achieve the country's strategic goals, the Canadian government—in partnership with universities and industry—can lay the foundation for a revitalized materials

research infrastructure for Canada. This can be accomplished by strategic investments in key national facilities. The Canadian Neutron Facility for Materials Research will fit that strategy and will forge a strong link between industrial and university research.

The development of all new and improved materials requires an ever deeper understanding of their behaviour and performance. A wide range of advanced and complementary materials probes has been developed over the years for this purpose.

An intense neutron source is essential to Canada's CANDU nuclear industry, both nationally and in the international marketplace. And it is a key part of the essential suite of materials probes and test facilities on which an advanced industrial economy must rely. Only with a complete set of these facilities can Canada meet the challenges that confront a wide range of industries.

The role of NRC, as the Government of Canada's lead science and technology agency, is to ensure—in partnership with universities and industry—that the materials research infrastructure is in place, and operated to meet their needs.

"I strongly endorse the approach and activities being undertaken by AECL and NRC to obtain a new Canadian Neutron Facility for Canada".
Dr. Albert Driedger, FRCPC
Clinical Professor
Diagnostic Radiology and Nuclear Medicine
London Health Sciences Centre

The role of AECL, as a federal Crown corporation and leader of Canada's nuclear industry, is to ensure that key research and product development facilities are available to support existing customers, and to continue to evolve its CANDU and research reactor products. AECL's goals are to remain competitive in the global marketplace, and to ensure the CANDU technology is available to Canada in the future when the need for new and environmentally-sound electricity arises.

With the completion of the Canadian Neutron Facility—along with the Canadian Light Source Synchrotron Facility in Saskatchewan and the upgrading of TRIUMF in British Columbia—Canada will have a materials research infrastructure that includes major facilities for cutting-edge research and innovation well into the next century.

"The Canadian Neutron Facility offers unprecedented potential for the advancement of materials research in Canada and is indispensable for the continued success of Canada's nuclear power program."
Bertram Brockhouse
Canadian Nobel Laureate
(Physics) 1994

The development of all new and improved materials requires an ever deeper understanding of their behaviour and performance.

A History of Leadership

In the past five decades, Canada has been well-positioned internationally in the field of advanced materials research—for the Canadian nuclear industry, for other industrial applications and for university research. This was, in a large part, due to the ingenuity and foresight of the nuclear research community and the Canadian government in designing and building the world-renowned NRX and NRU research reactors at AECL's laboratories at Chalk River.

However, the NRX research reactor is now permanently shut down and the NRU reactor—Canada's pre-eminent research reactor since 1957—will be shut down before the end of the year 2005. The closure of NRU will coincide with an increasing demand for knowledge of the structure and dynamics of materials. It will also coincide with a projected shortage of neutron beam sources worldwide.

"The Canadian neutron beam laboratory has provided Marubeni Canada Ltd. with access to a unique measurement probe, which has provided a basis for business with clients in Japanese heavy industries. The Canadian expertise in neutron beam research is world-class and should be retained by ensuring there is a neutron source into the twenty-first century."

Mr. Jun Fukuhara
President & CEO
Marubeni Canada Ltd.

The Competitive Environment

All industrialized, and some newly-industrialized countries, have access to neutron beams from research reactors. However, because of the growing international awareness of the critical importance of neutrons for advanced materials development, the global demand is now exceeding supply.

Germany, Australia, Japan, Egypt, Holland, Thailand and China have identified the requirement for advanced materials research facilities in the twenty-first century and are already constructing, or planning to construct, new research reactors. In addition, all nuclear vendor countries have research reactors to support their commercial programs.

"In today's high-tech economy, directed research and development lead to increased competitiveness. The collaboration between IVACO, McGill University and the NRC neutron laboratory illustrates how Canadian industries can benefit from the existence of a federally-supported infrastructure for science and technology."

Gordon Silverman
Vice President and General Manager
IVACO ROLLING MILLS

The recent OECD projections for neutron beam sources show that many existing research reactors around the world are reaching the end of their life. The survey predicts a serious reduction in research capacity, unless new sources are brought on line. This situation is particularly critical on the North American continent where beam time has been seriously oversubscribed for several years. The CNF will fill a critical gap in the North American infrastructure, both for advanced materials research and for the nuclear industry.

The CNF Reactor—World-class Canadian Technology

The source of neutrons for the CNF is a 40 MW pool-type reactor based on AECL's well-established MAPLE technology. MAPLE reactors are among the most advanced multipurpose research reactors available today.

The first demonstration of MAPLE technology is Korea's HANARO research reactor, which started up in 1995. Two MAPLE reactors, dedicated to the production of medical isotopes, are now under construction at AECL's Chalk River site, for MDS Nordion. This project on schedule and on budget.

As well, MAPLE research reactor technology is being offered in a proposal currently being developed for the Australian Nuclear Science and Technology Organization. The MAPLE reactors benefit from AECL's

Four AECL-designed CANDU 6s at the Wolsong site, Korea. Wolsong 1 was the top-performing reactor in the world in 1997.

extensive experience in the design, construction and safe operation of both research reactors and CANDU power reactors worldwide.

The CNF reactor assembly is located at the bottom of a 15.6-metre-deep, light-water-filled pool. The compact light-water-cooled and -moderated core uses low-enriched uranium fuel, consistent with international nuclear non-proliferation guidelines. This rod-type fuel generates a flux of fast neutrons in the core and a high thermal neutron flux that extends into the surrounding heavy water reflector tank. The maximum unperturbed thermal-neutron flux is 4×10^{18} neutrons$\cdot$m$^{-2}\cdot$s^{-1}.

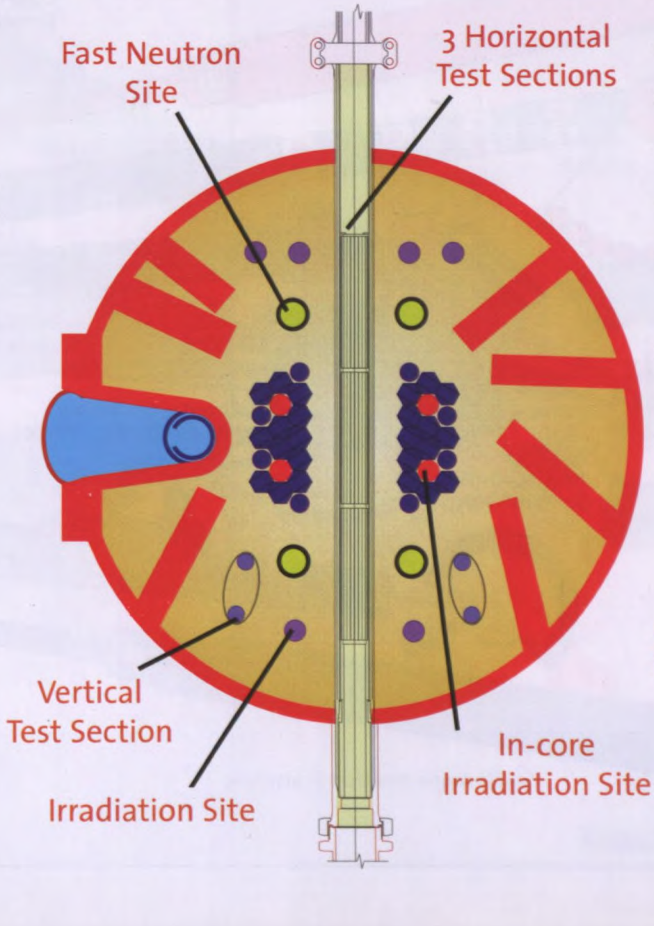
The CNF reactor will house a national user facility, including a cold source and guide hall for neutron beam research, and test facilities for CANDU fuels, fuel channels, materials and components.

Operating the CNF as a National Facility

All stakeholders will be invited to provide input to secure a consensus on a management structure for the CNF. This will ensure equitable access to all users.

The CNF MAPLE Advantage

- state-of-the-art Canadian technology
- high neutron fluxes per unit power
- low fuel costs
- two independent shut-down systems
- passive pool, ensuring reactor cooling
- containment building designed to accommodate extreme events
- designed for ease of operation and maintenance
- modest staffing requirements



Plan view of CNF MAPLE core showing CANDU test facilities.

Neutrons: A Powerful Tool

Research reactors provide a source of neutrons through the fission process. Within the core of the CNF, the neutrons will be used to test materials to ensure they will perform reliably in CANDU power reactors. In addition, small beams of neutrons extracted from the reactor will tell researchers where the atoms are in a material and how they move.

Neutron Beam Research

Beams of neutrons are guided to experimental stations outside the reactor core, where they are used as powerful probes. This technique—pioneered in Canada by Canadian Nobel Laureate Bertram Brockhouse in the 1950s and now used all over the world—is called neutron scattering. Neutrons can be used to probe materials on length scales ranging from a tenth of the size of an atom up to the large biological molecules or polymers. Neutrons can also observe atomic movements on a very short time scale.

A device in the reactor, called a cold-neutron source, is used to cool the neutrons to low energy to provide the specialized beams needed for advanced applications. This will be the first time cold neutrons are available in Canada.

CNF Facilities for Advanced Materials Research

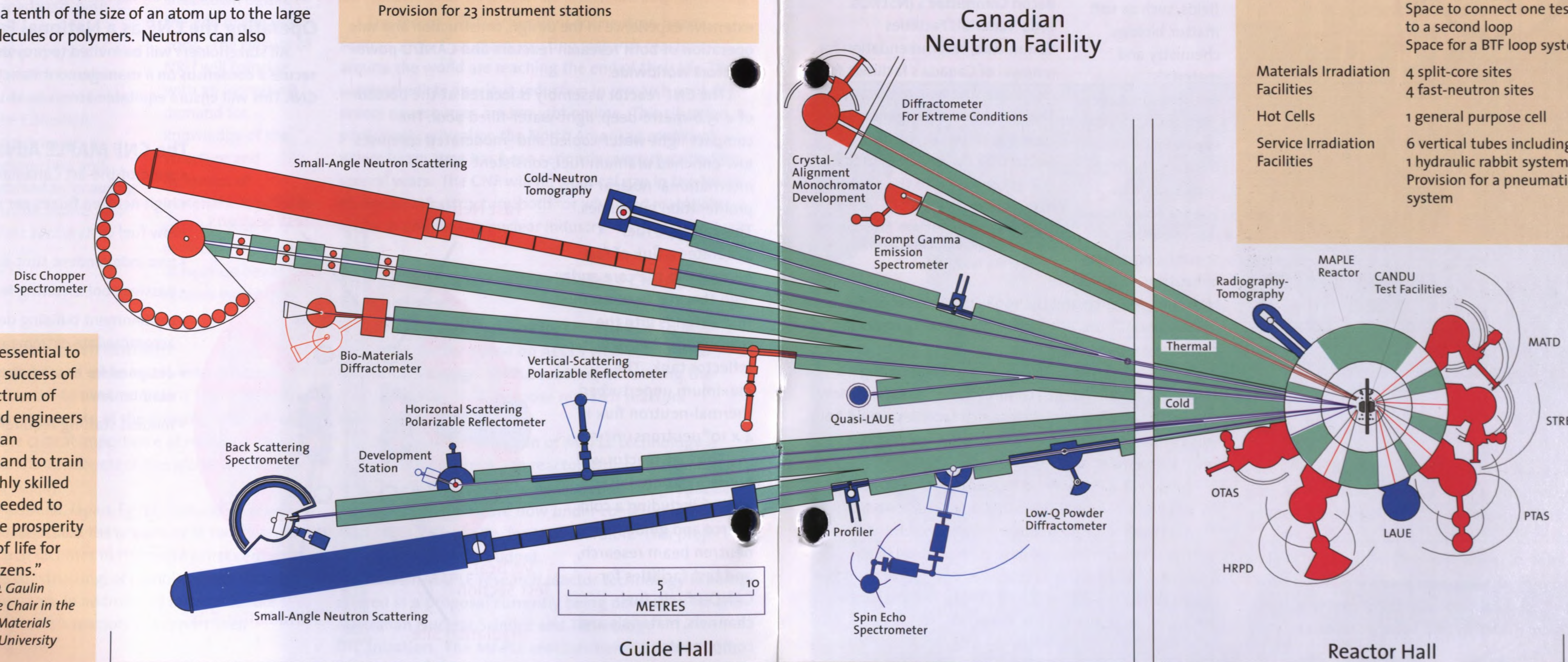
- 6 thermal beam tubes in the reactor hall
- 1 cold source feeding seven neutron guides
- 1 thermal source feeding two neutron guides
- 1 new spectrometer directly viewing the cold source
- 5 instruments relocated from NRU
- 5 new instruments in the Guide Hall
- Provision for 23 instrument stations

In-core Research

The neutrons in the reactor core are used to irradiate materials and components in special test sections or "loops" that reproduce a nuclear power reactor's operating environment. The materials and components are then examined and tested in shielded "hot cells" to obtain information on their performance under power reactor conditions. Irradiation research has been an essential element in ensuring a successful CANDU nuclear industry.

CNF Facilities for CANDU Research and Product Development

Horizontal Fuel-Test Facilities	3 test sections, each with up to 3 CANDU bundles, connected to 2 loops Bottom test section replaceable with a high-integrity section for future severe fuel damage (BTF) tests CANTHERM advanced fuel channel capability
Vertical Fuel-Test Facilities	1 test loop with 2 test sections for multi-element partial fuel bundles Space to connect one test section to a second loop Space for a BTF loop system
Materials Irradiation Facilities	4 split-core sites 4 fast-neutron sites
Hot Cells	1 general purpose cell
Service Irradiation Facilities	6 vertical tubes including: 1 hydraulic rabbit system Provision for a pneumatic rabbit system



> "The CNF is essential to the research success of a broad spectrum of scientists and engineers from Canadian universities, and to train the new, highly skilled innovators needed to ensure future prosperity and quality of life for Canada's citizens."
>
> *Dr. Bruce D. Gaulin*
> *Brockhouse Chair in the Physics of Materials*
> *McMaster University*

Neutron Beam Research

Improving Our Lives

Neutron beam research provides scientists and engineers with valuable information about materials that affect our daily lives. The results of neutron beam research include improvements in everyday products, such as jet aircraft, high-speed trains, pharmaceuticals and magnetic devices such as computer disks, pocket calculators and lightweight magnets in automobiles. As well, neutron research improves industrial products and materials, such as polymers, metals and ceramics, gas pipelines, rails, steel, welded structures, CANDU pressure tubes, high-temperature superconductors, biological materials, and synthetic nanostructures.

Neutron beam research provides scientists and engineers with valuable information about materials that affect our daily lives.

Neutrons can precisely locate hydrogen atoms in the presence of heavy atoms. This is important in developing new therapeutic drugs whose structures must be known in order to control their function. Hydrogen and deuterium scatter neutrons very differently, a fact that allows scientists to zoom in on a chosen region within a molecule. This is of great importance, for example, in the study of biological materials and polymer research.

Neutrons are a uniquely valuable, deeply-penetrating, non-destructive materials probe. They have been used in a wide range of materials research, both in forward-looking university programs and in projects of direct value to industry. They provide fundamental information that cannot be obtained with any other probe.

The use of neutron beams for materials-related research has broadened extensively since the pioneering days. Today, new fields, such as soft matter, biology, chemistry and materials engineering, have emerged as rapidly-expanding frontiers. Both the 1996 European Science Foundation report on the scientific prospects of neutron scattering research and the 1998 OECD report on future sources of neutrons emphasize the growing importance of these emerging disciplines.

> "Given the outstanding tradition of neutron scattering in Canada and the limited life left to the existing facilities, we support the Bacon Committee's (NSERC's 1994 Materials Facilities Committee) recommendation for renewal of Canada's facilities for research using neutron beams. This is made more urgent by the currently uncertain future of neutron beam resources in the U.S. as compared to the situation in Europe and Japan."
>
> *International Assessors' Report in the Review of Canadian Academic Physics, 1997*

In 1994, the Natural Sciences and Engineering Research Council (NSERC) commissioned a major review to identify which materials research facilities would be most valuable to Canada in the future. The NSERC Review concluded that:

Canada should make an immediate commitment to develop a fully-equipped, dedicated reactor-based national source for neutron beam research.

The CNF will accommodate both neutron beam research and CANDU power reactor development. It is a shared rather than a dedicated facility. This maximizes the return on investment to Canada.

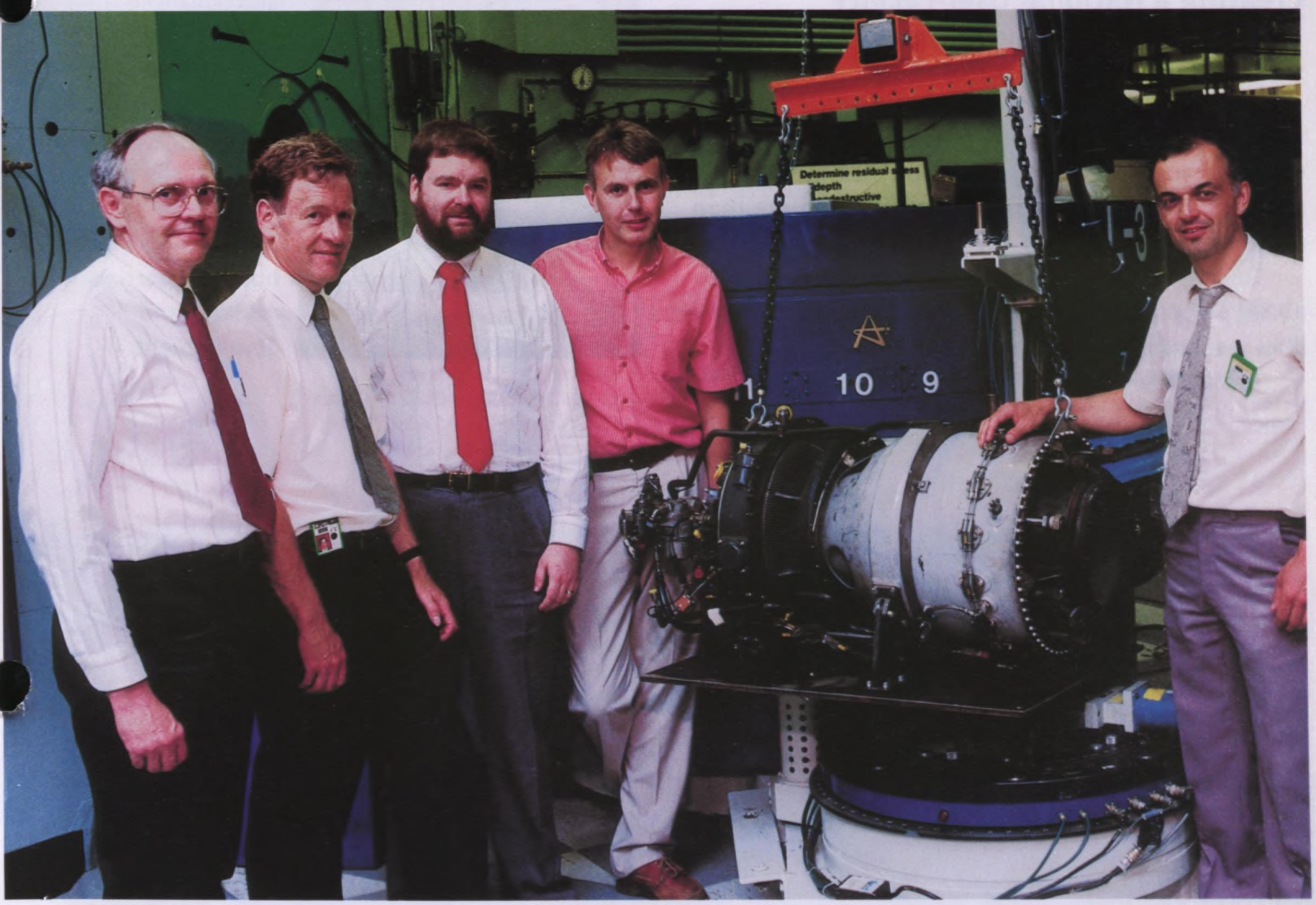
Long-standing Canadian Excellence

Canada's reputation for world-class research in neutron scattering can be traced back to the pioneering work performed at Chalk River by Bertram Brockhouse who shared the 1994 Nobel Prize in Physics with Clifford Shull of the U.S.A.

Delivering Tangible Benefits to Industry

NRC's Applied Neutron Diffraction for Industry (ANDI) program leads the world in scanning for residual stress at depth in engineering components. Residual stress is a major cause of failure in industrial structures. The ANDI program gives industry fast access to proprietary neutron beam analysis, to help avoid the risks of costly in-service failure, improve industrial processes, and certify new product designs.

Only neutrons can directly detect residual stress deep inside alloys and ceramics, and so contribute to the reliability and safety of new industrial products.



Canadian, U.S. and U.K. aerospace corporations have made good use of neutron beam technology at Chalk River to test jet engine components and landing gear at the design stage.

Opening New Fields for Canadian Science

The CNF will contain a source of cold neutrons. This first Canadian cold neutron laboratory will open up new fields of science that have not been possible with the thermal neutron beams from NRU. The cold source will produce the intense beams of low-energy neutrons that are required for advanced materials and industrial applications. Warm neutrons from the reactor moderator are cooled by entering a container of cold liquid hydrogen. The cold neutron "brightness" from the CNF will be ten times greater than that available from NRU. This will enable Canada to compete with European research centres where cold neutrons have long been exploited.

Cold neutron science opens new fields of study such as polymer and colloid chemistry; membranes and other biological structures; materials science and engineering; interfaces in nanostructural science; assay of trace impurities and contaminants, and high-contrast radiography.

Creating a National User-Facility

One hundred Canadian and international scientists and engineers currently conduct their research at the Chalk River neutron facilities each year and, at any given time, twenty graduate students are using the facilities for their thesis research. The total number is expected to more than triple with the advent of the CNF.

The Canadian Institute for Neutron Scattering (CINS) plays a valuable role in providing a network that links researchers from coast to coast.

Strengthening Global Research Connections

The steady-state CNF will be complementary to facilities in foreign countries where most new capacity has been in pulsed neutron sources based on accelerators, rather than reactors. An example is the large US$1.3 billion Spallation Neutron Source announced in 1998. For atomic and magnetic research, steady-state sources are well-suited for selecting a particular regime of energy and momentum, while pulsed spallation sources are effective for large-scale mapping of energy and momentum space.

Investment in a new reactor in Canada will give Canadians reciprocal access to a much wider and costlier range of specialized facilities in other countries, and will promote international collaboration.

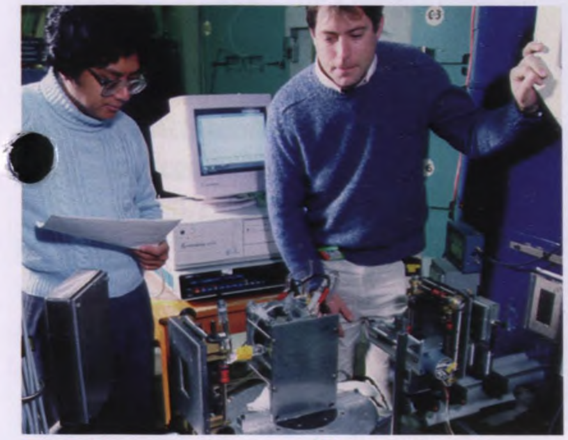
Testing rail steel for industry: Corporations come to Chalk River from Canada, Europe, the U.S.A. and Japan to solve their industrial problems.

With its cold source and advanced instrumentation, the Canadian Neutron Facility will rank with the best steady-state neutron laboratories in North America, constituting a strong hub for materials research and development.

Canadian Applied Neutron Research Highlights

- Leads the world in neutron stress scanning at depth in actual industrial components
- Pioneered the use of neutrons to directly study hydride formation, a critical failure process in nuclear and energy industry components
- Confirmed fitness-for-service of space shuttle booster rocket casing after Challenger disaster
- Linked key stress patterns to rail steel failures to improve the Canadian rail product
- Played a key role in validating new fuel channel specifications in support of international CANDU sales
- Developed technology to see sub-microscopic corrosion process at work in practical liquid chemical environment

Neutrons are uniquely valuable as materials probes because they generally detect light elements as easily as heavier elements. This is in contrast with X-rays and gamma rays. Moreover, neutron contrast between isotopes of the same chemical element—for example, the isotopes hydrogen and deuterium—makes neutrons of enormous importance for the study of biological materials and polymers, as well as for alloys. As foreseen in the recommendation of the 1994 NSERC Committee, the Canadian Neutron Facility will, therefore, complement the Canadian Light Source through its different capabilities.



Chalk River and University of Western Ontario scientists see how corrosion develops through the thin film at the metal surface.

Training and Retaining Canadian Expertise

The CNF will help train top research talent in Canada. It will provide opportunities for small- and medium-sized Canadian firms to develop and commercialize new technologies spun off from the facility. And it will create a unique environment where Canadian researchers from varied disciplines will interact, exchange ideas and forge new collaborations. As well, the Canadian Institute of Neutron Scattering offers courses, summer schools and workshops to train young researchers from Canada and abroad.

The CNF will give Canadian industry easy and direct access to world-class facilities for proprietary research, thus helping to foster industrial research and retain this essential expertise in Canada.

"I am totally convinced, as are many of my colleagues, that neutrons can provide valuable information of benefit to an industry such as ours. It would be a great shame if the ability to do neutron scattering for industrial research in Canada were to disappear."
Dr. Stuart MacEwen
Principal Scientist
Alcan International Limited

Workshop on Neutron Scattering at Chalk River.
The CNF will help train and retain top research talent in Canada.

The Canadian Nuclear Industry

> "Nuclear Power accounted for the greater part of the lowering of carbon intensity of the energy economies of the OECD countries over the last 25 years."
>
> *Executive Director International Energy Agency of the OECD, 1997*

Economic Benefits through Industrial Innovation

According to an Ernst and Young study in 1993, the Canadian nuclear industry has produced substantial economic benefits for Canada. The industry directly employs 26,000 people, contributes a $6 billion annual stimulus to Canada's gross domestic product and, in 1996, produced Canada's single-largest ($2 billion) export order.

> "Canada needs irradiation facilities of its own to provide support for the needs of the power reactor industry, supplying energy to industrial and domestic customers."
>
> *"The Needs and Options Study of Irradiation Requirements in Canada" by R.D. Page and J.E.S Stevens (COG-91-148) 1991*

At the same time, CANDUs have provided a safe and reliable source of electricity to industry and to the populations of three Canadian provinces, while also contributing through exports to the strength of the Canadian economy. Domestic CANDUs produce more than 50 per cent of Ontario's electricity, and 17 per cent nation-wide.

Nuclear Energy—Key to Climate Change Initiatives

Nuclear energy contributes to air quality by displacing fossil fuel burning. CANDU power reactors provide safe, clean, environmentally-sound electricity on four continents.

In Canada, by partially replacing fossil fuel with CANDU nuclear power, the Canadian nuclear industry has avoided the release of more than one billion tonnes of carbon dioxide into the environment. With the Kyoto Accord in 1997, continuing availability of an electricity generator such as CANDU—which does not produce greenhouse gases—is of critical strategic importance.

C A N D U C h r o n o l o g i c a l

1945

The ZEEP research reactor at Chalk River sustains the first controlled nuclear chain reaction outside the U.S.A.

1947

The NRX research reactor begins operation— the most powerful reactor of its time.

1957

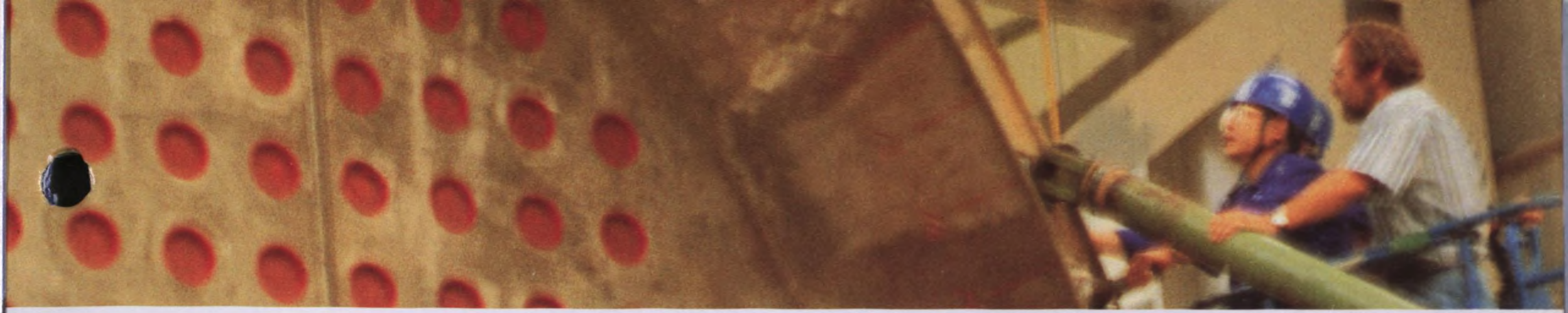
The NRU research reactor starts up.

1962

The Province of Ontario receives nuclear-generated electricity for the first time from the NPD station at Rolphton.

1973

The Pickering station is completed, producing more electricity than any nuclear power station in the world at that time.



AECL: Leading Canada's Nuclear Industry

AECL leads Canada's nuclear industry. Through its "CANDU Business", AECL develops, designs and markets CANDU power reactors, MAPLE research reactors and MACSTOR waste storage facilities, and manages the construction of nuclear reactor projects worldwide. The corporation also supplies support services for power and research reactors. The Wolsong Project in Korea—four CANDU 6 reactors—has returned more than $1 billion to the Canadian economy.

As well, five other CANDU units have been constructed overseas, and three more units are currently under construction in China and Romania. These, along with recent large MAPLE and MACSTOR projects, are also having a positive economic effect in Canada. Significant new commercial opportunities are currently being pursued, in a highly competitive global marketplace.

Advanced nuclear technology, developed in programs based at the CNF, will be of critical strategic importance to Canada in the twenty-first century. They will contribute to Canada's global competitiveness, having a positive effect on the Canadian economy through export revenues, job creation and enhancement of the GDP.

AECL's CANDU projects have a positive effect on Canada's economy. Two CANDU 6 reactors are currently under constuction at the Qinshan Phase III site in China.

Business Highlights

1974

AECL makes its first international CANDU 6 sale.

1983

CANDU wins seven of the top 10 places for lifetime performance among the world's reactors.

1987

CANDU wins one of 10 awards for the top Canadian engineering achievements of the past century.

1995

The HANARO research reactor, incorporating AECL's MAPLE core design, starts up in the Republic of Korea.

1998

Eleven 700 MWe class CANDU 6 reactors, designed by AECL, are operating or under construction on four continents.

Total CANDU Reactors: 34

Improving and Evolving CANDU

AECL provides the research that underpins the CANDU Business. This includes improvements to current reactors, to the effectiveness and safety of the CANDU product at home and abroad, and to the evolution of advanced reactors that will keep Canada at the forefront well into the future. This is done in competition with other suppliers as they too hone their product for the international marketplace. The reactors of the next century will perform even more efficiently and reliably while maintaining their high standards of safe operation. Key components of CANDU reactors are the fuel elements, the pressure tubes that contain them and the coolant environment in which they operate.

The success of the CANDU Business, both domestically and in the international sales arena, is founded on the use of research reactors to test and demonstrate materials and components and ensure their reliability before they are deployed in new CANDU designs. This is the basis for AECL's evolutionary design strategy for CANDU. Innovations are introduced only when proven through exhaustive testing.

Meeting Long-Term Commitments

Ongoing development of CANDU technology is needed to meet increasingly rigorous customer and public demands for further enhanced performance and safety. Current CANDU owners and potential customers expect a long-term commitment by AECL to maintain the R&D necessary to ensure the continuing viability of operating CANDU reactors, and the development of advanced CANDU designs. These will feature more passive safety systems, lower capital and operating costs, greater reliability, easier maintenance, longer plant life, and the ability to exploit CANDU's fuel cycle flexibility.

Exploiting Fuel Cycle Flexibility

The advanced CANFLEX fuel bundle—the optimal carrier for new fuel cycles in CANDU—is a telling current example: It is the result of a 15-year analytical and experimental program.

CANDU Reactors completed or under construction world-wide

* 600 MWe class units and above

CANDU's unique neutron-efficient design allows a variety of nuclear fuels to be used. To date the simplest—a once-through uranium dioxide fuel cycle—has been effectively employed. But the development of new fuels and fuel cycles, which is dependent on individual customer requirements, will be a key to CANDU's ability to compete in the future.

All new fuel designs need to be rigorously tested, from individual elements through to full-scale bundle tests in a research reactor that provides the correct irradiation environment. This critical application has been demonstrated over five decades in NRU and other research reactors. The CNF will provide an essential test bed for improved fuel designs. In particular, it will provide the ability to test fuel in horizontal full-diameter CANDU channels, and to duplicate the same effects as are encountered in the horizontal channels of a CANDU reactor.

The CNF will supply the conditions to test full-diameter CANDU pressure tubes in conditions of controlled chemistry, temperature and pressure.

Pressure Tube Materials—Key to Improved Economics

The reactor lifetime, and consequently the contribution of capital to the cost of electricity, depends on the performance of the zirconium-alloy pressure tubes that are the heart of CANDU. These pressure tubes are required to maintain their integrity over 30 to 40 years in an environment of radiation, pressure, temperature and corrosion. Their ability to attain, or exceed, their design life has a direct impact on the overall economics of the reactor, and therefore the cost of the electricity generated.

An ongoing, advanced R&D program is necessary to understand and solve the interdisciplinary issues involved in developing enhanced pressure tube materials. And a key requirement is a source of fast neutrons, intense enough to provide an accelerated lifetime test, and capable of reproducing the environmental conditions found in a power reactor. The CNF will supply the conditions to test full-diameter CANDU pressure tubes in conditions of controlled chemistry, temperature and pressure.

The CNF and the CANDU Business Strategy

The CNF was designed specifically to meet CANDU irradiation requirements identified by AECL for at least the next 30 years. These requirements are clearly aligned with AECL's overall CANDU development strategy:

- to further enhance reactor safety
- to enhance reactor economics
- to fully exploit fuel cycle flexibility

The CNF incorporates in-core experimental facilities to test the basic fuels and materials, components, and coolant chemistry of the CANDU reactor. It provides the ability to change and substitute new experimental facilities when required, including postulated advanced reactor conditions. No other foreign reactor will be available in the next century that can meet the conditions required to test CANDU fuels and pressure tubes, and to deliver a safe, reliable and cost-effective product.

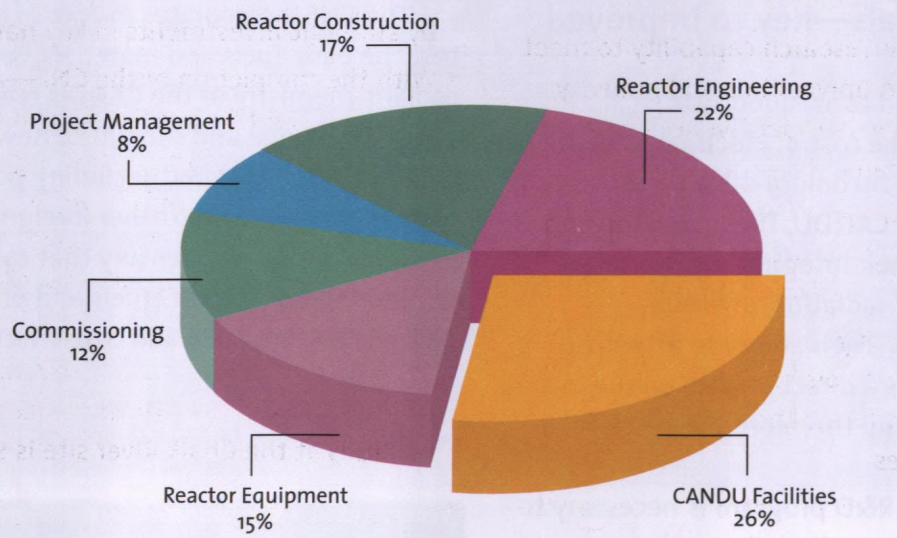
In-core testing in a research reactor was an essential component of AECL's 15-year program to develop the new advanced CANFLEX fuel bundle.

Cost Estimate for the Canadian Neutron Facility

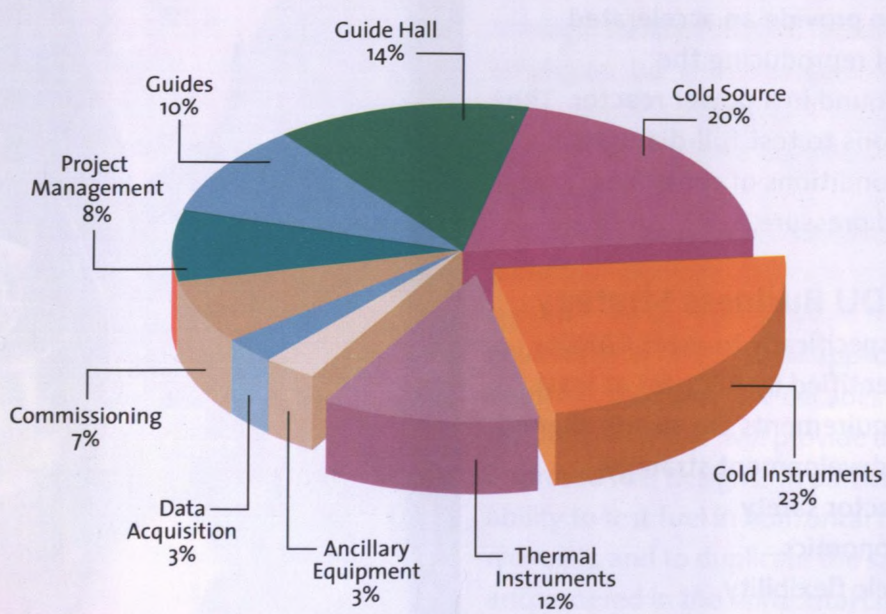
Reactor source of neutrons plus CANDU Facilities	**$ 298M**
Neutron beam facilities	**$ 90M**
Total estimated cost for CNF	**$ 388M**

Base Cost, including contingency plus risk (1998 dollars)

Reactor Neutron Source including CANDU Facilities



Neutron Beam Facilities



Summary

- The National Research Council of Canada (NRC) and Atomic Energy of Canada Limited (AECL)—in partnership with universities and industry—are jointly proposing a new Canadian Neutron Facility (CNF) to support next-generation neutron-based materials research and innovation in Canada for the twenty-first century.
- The CNF is a key component of a revitalized national materials research infrastructure.
- The purpose of the CNF is to provide:
  - an advanced materials research capability to meet the needs of Canadian universities and industry, thus ensuring Canadian competitiveness on many fronts in the global arena
  - an essential testing facility to advance the CANDU power reactor design, thus ensuring the Canadian nuclear industry—with its $6B annual contribution to the Canadian economy—remains competitive and that CANDU is available to Canada in the future when the need for new, environmentally-sound electricity arises
- Several generations of Canadian materials researchers will be trained on this facility, providing a continuous knowledge-base in Canada, and a centre that will retain Canadian talent.
- All industrialized, and some newly-industrialized countries, have access to neutron beams from research reactors. However, because of the growing international awareness of the critical importance of neutrons for advanced materials development, the global demand is now exceeding supply.
- Germany, Australia, Japan, Egypt, Holland, Thailand and China have identified the requirement for advanced materials research facilities in the twenty-first century and are already constructing, or planning to construct, new research reactors. In addition, all nuclear vendor countries have research reactors to support their commercial programs.
- The Canadian government—in partnership with universities and industry—can lay the foundation for a revitalized materials research infrastructure for Canada by strategic investments in key national facilities.
- With the completion of the CNF—along with the Canadian Light Source Synchrotron Facility in Saskatchewan and the upgrading of TRIUMF in British Columbia—Canada will have a materials research infrastructure that includes major facilities for cutting-edge research and innovation well into the next century.
- Construction of the CNF is planned to begin in 1999, with projected start-up of the reactor in 2005. The total estimated cost for the reactor and program facilities at the Chalk River site is $388 million.

Canadian Neutron Facility Steering Committee

Arthur J. Carty (Chair)
President, National Research Council of Canada (NRC)

Allen Kilpatrick
President and CEO, Atomic Energy of Canada Limited (AECL)

Thomas A. Brzustowski
President, Natural Sciences and Engineering Research Council (NSERC)

Peter George
President, McMaster University

J. Fraser Mustard
President, The Founders' Network

Reid Morden
Partner, Sussex Circle

David F. Torgerson
Vice-President, Research and Product Development, AECL

Kevin Fitzgibbons (Secretary)
National Research Council

For more information, contact

Walter Davidson
Coordinator (National Facilities)
National Research Council of Canada
100 Sussex Drive
Ottawa, Ontario
K1A 0R6
Tel.: (613) 990-0914
Fax: (613) 993-4291
E-mail: walter.davidson@nrc.ca

NRC Website: http//www.nrc.ca

Ian J. Hastings
Director, Strategic Initiatives
AECL
2251 Speakman Drive
Mississauga, Ontario
L5K 1B2
Tel.: (905) 823-9040
Fax: (905) 403-7379
E-mail: hastingsi@aecl.ca

AECL Website: http//www.aecl.ca

NRC·CNRC
National Research Council Canada
Conseil national de recherches Canada

AECL EACL
Atomic Energy of Canada Limited
Énergie atomique du Canada limitée

Publié aussi en français Printed in Canada
1998 October

Nuclear R&D in the 21st Century

CANADA Vision 2020 and Beyond

The Need for

Nuclear Research & Development

in the

21st Century

Vision 2020 and Beyond:

The Need for Nuclear Research and Development in Canada in the 21st Century

1999 September

A Report of
The R&D Advisory Panel
to
The Board of Directors
of
Atomic Energy of Canada Limited

Publié aussi en français

Canada's investment in nuclear science and engineering R&D has greatly improved the lives of Canadians over the past half century through the production of environmentally friendly and cost-effective electricity as well as through important roles in medicine, agriculture, manufacturing and resource exploitation. Continued investment in nuclear research and development is of vital importance if Canada is to maintain its scientific, technological, commercial and diplomatic standing while continuing to support long-term national goals.

CANADA'S NUCLEAR ACHIEVEMENTS

The excellence of Canadian nuclear science and technology throughout the last half century, under the leadership of Atomic Energy of Canada Limited (AECL), has been recognized internationally for many reasons, including:

- development of the CANDU® power reactor;
- development of the MAPLE research and isotope production reactor;
- development of products that improve the quality of human lives;
- participation in the control of nuclear weapons proliferation; and
- the award of a Nobel Prize in physics.

Despite this international reputation, most Canadians are largely unaware of the extent to which the products of nuclear science and engineering support their daily lives. Many of these are shown in Figure 1 (see page 3).

Tens of thousands of Canadians derive their employment from the investment in nuclear science and engineering R&D, and its main product—environmentally friendly and cost-effective electricity—has helped drive Canada's economy for more than 25 years. Overseas sales of CANDU reactors also contribute substantially to both Canada's economy and to global environmental protection.

The contribution of nuclear R&D through the development and use of radioisotopes is important in many aspects of our lives. Canada is the world's leading producer and supplier of cobalt-60 used in cancer therapy irradiators, a device developed in Canada almost 50 years ago. Canada is also the leading producer and supplier of short-lived radioisotopes for nuclear medicine, which are used to perform 20 million diagnostic tests and treatments a year worldwide. In biology, radioisotopes have made possible the revolution in our understanding of life at the molecular level, which has led to highly effective new treatments for diseases.

Cobalt-60 irradiators, produced in Canada, are also used in such diverse applications as the sterilization of medical devices and products, insect control in agriculture, and the destruction of potentially lethal microbial contaminants in food. Radioisotopes have many other applications, including well-logging in the oil industry, analysis of ore samples in the mining industry, radiography, process control and quality assurance in manufacturing, detection and measurement of industrial pollutants, and smoke detectors in the home.

In 1994, Bertram Brockhouse was awarded a Nobel Prize for work that commenced in the 1950s using the NRX (now shut down) and NRU reactors at AECL's Chalk River Laboratories (CRL). This work led to the neutron scattering techniques that are widely used in many industries, including aerospace, automotive, oil and gas, and manufacturing, to assess the behaviour and properties of materials. This technology is now an essential requirement for the development of advanced materials for a knowledge-based economy, and is an example of the long-term payback that comes from investment in basic research.

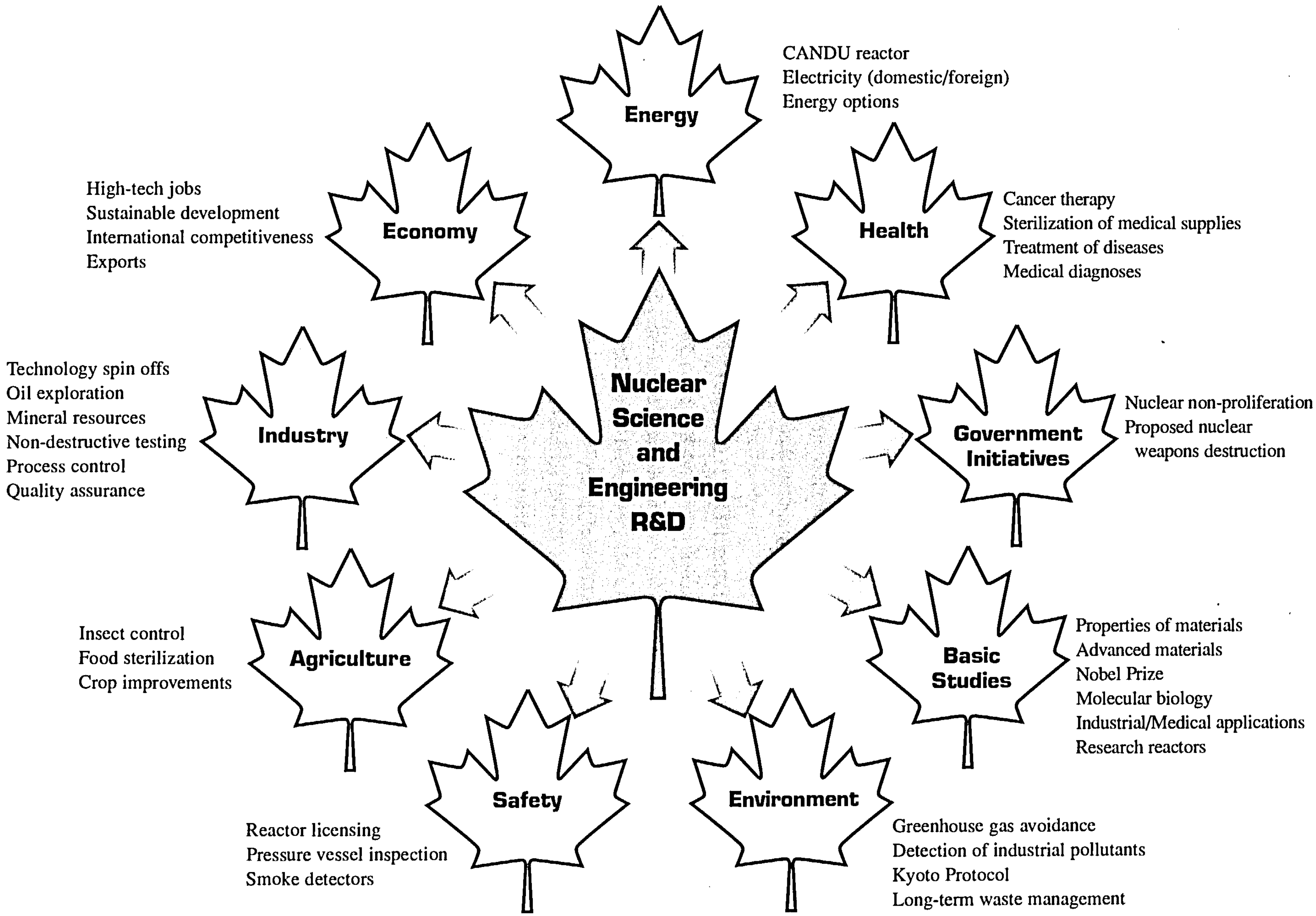


FIGURE 1 : CONTRIBUTIONS OF NUCLEAR SCIENCE AND ENGINEERING R&D TO CANADA

CONTINUING BENEFITS OF NUCLEAR R&D

Government support for R&D constitutes a long-term investment in future technology which private industry, dependent on short-term return on investment, is not able to make. There is ample evidence to show that the benefits still to be realized by government investment in nuclear science and engineering R&D in Canada will be at least as significant as those already achieved. The consequences of not supporting this R&D would be to reduce our industrial competitiveness in both nuclear and non-nuclear sectors. On the other hand, supporting nuclear science and engineering R&D will result in economic, environmental, safety, political and diplomatic, strategic, and technological advantages for Canada in the future, and will allow the government to make choices not available to countries without nuclear R&D.

Economic Development

Historically, the cost of electricity from Ontario's nuclear reactors has been less than that for coal-fired plants.

Maintenance of a high living standard and sustained wealth creation for Canadians require the assurance of an adequate, reliable, diverse and competitive energy supply. Nuclear electricity has contributed significantly to Canada's energy supply through the effective use of nuclear R&D funding. Canada's CANDU reactors have produced more electricity per R&D dollar spent than reactors of any other country with a significant nuclear power program. The contribution of nuclear electricity to GDP was some $28B to 1998, while government support to that date was $5.8B. Nuclear generation currently provides 12% of Canada's electricity and about 48% of Ontario's. By using nuclear fuel, Ontario has saved more than $18 billion in avoiding costs of imported fossil fuel. Historically, the cost of electricity from Ontario's nuclear reactors has been less than that for coal-fired plants, and studies show that electricity generation from existing nuclear plants and from new plants will continue to be competitive.

As existing CANDU plants age, they continue to need R&D support to ensure safe and economic operation and to cope with unexpected events. The speedy resolution, by AECL and the utilities, of problems that emerged at the Darlington and Point Lepreau Nuclear Generating Stations demonstrates the importance of this R&D support in protecting these major capital investments. Maintaining and extending the lifetime of nuclear power plants, a proven cost-effective option, also requires continued R&D support. In the USA, extension of the lifetime of current reactors to 60 years is becoming a competitive reality. For CANDU reactors to achieve similar lifetime targets, additional R&D by AECL and the utilities will be necessary. If R&D funding is curtailed, Canada's investment in nuclear power could be prematurely written off, leading to major expenditures for replacement power, largely from fossil-fired plants. Furthermore, international marketing of CANDU reactors would be seriously jeopardized, since CANDU customers need and expect after-sale R&D support from AECL.

High-tech jobs result from Canada's investment in nuclear science and engineering R&D. About 150 firms and a further 3,000 subcontractors across Canada benefit from each foreign CANDU sale. To ensure that CANDU reactors remain competitive, AECL is developing new CANDU designs with reduced capital and operating costs, improved efficiency and enhanced safety features. In the international market, future CANDU designs must compete against advanced reactor designs of other vendors, based on R&D done in the national laboratories of countries such as the USA, France, Germany and Japan. Canada's international competitiveness will suffer if CANDU does not have strong R&D support.

Environmental Control

Because of adverse global climate changes resulting from the increasing quantities of CO_2 and other greenhouse gases (GHG) in the atmosphere, an international agreement was reached at the Kyoto Climate Change Conference in 1997 to reduce GHG emissions. Canada has committed to a reduction of 6% in GHG emissions below 1990 levels by the year 2010. About 80% of Canada's electricity is generated by hydro and nuclear plants, which do not emit GHG, while only about 20% is generated by fossil fuels, which emit GHG. The lay-up of eight nuclear reactors in Ontario has resulted in increased emissions of GHG and other air pollutants from coal-fired units. If Canada is to meet its Kyoto commitments without severe economic disruption, all the laid-up reactors must be returned to service as soon as possible and operated to 2010 and beyond.

Looking further into the future, to 2020 and beyond, to avoid additional GHG emissions Canada must also build new reactors to replace obsolete coal-fired power plants and to meet increases in electricity demand. While new renewable energy sources have the potential to contribute up to 10% of Canada's future electrical energy supply, only nuclear energy can make the necessary contribution to large-scale energy production while supporting Canada's commitment to GHG reduction.

Its nuclear power program and nuclear R&D expertise also allow Canada political, diplomatic and technological options not available to countries without such expertise.

Environmental pollution is a world-wide problem. Large populous developing countries, such as China, which are heavily dependent on coal, will continue to be among the world's major atmospheric polluters. It is in Canada's and the world's economic and environmental interest to encourage these countries to include nuclear power in their energy mix, as a contribution to sustainable development. Under the Kyoto Protocol mechanisms, Canada may obtain greenhouse gas credits for CANDU exports, to be shared with the customer country. Such arrangements would help Canada meet its Kyoto commitments while gaining economic benefits.

Present practices for nuclear fuel waste management and storage in Canada are safe and economical and these practices could be continued indefinitely. Furthermore, the concept for long-term deep geological disposal of nuclear fuel waste, developed by AECL, has been judged to be safe. Thus, concerns about the safety of nuclear fuel waste management and disposal should not impose constraints on the future growth of nuclear power in Canada.

SAFETY AND REGULATION

Nuclear R&D capability is a requirement for the licensing and safe operation of nuclear power plants. The Atomic Energy Control Board (AECB), the independent federal regulator, requires that licensees have the capacity to perform the R&D essential to safe operation of nuclear power plants in Canada. The facilities of AECL serve as a shared resource for the utilities through which questions from the regulator can be addressed, and the AECB also contracts some research at these facilities. However, the AECB has recently expressed concern about reductions in funding for safety-related research by Canada's nuclear utilities.

This emphasizes the need to provide continuing government support for long-term safety-related research by AECL.

Energy Policy

Energy is one of the most important resources for modern society. Events such as the 1973 oil embargo and the 1997 Kyoto Protocol illustrate the importance of a national policy that will safeguard Canada's energy supply while supporting global objectives. As noted above, Canada's mix of electrical energy sources has benefited the nation by providing economic and reliable electricity with much lower emissions of greenhouse gases and other air pollutants per unit of electricity generated than almost any other industrialized country. Its nuclear power program and nuclear R&D expertise also allow Canada political, diplomatic and technological options not available to countries without such expertise.

International Initiatives

Canada is a member of the G-7, a position from which it can contribute broadly to the development and well-being of the world community and assist in meeting international objectives. Canada's contribution to international safeguards, and foreign policy initiatives, such as the proposal to destroy weapons-grade plutonium in CANDU reactors, are only possible because Canada has a successful nuclear power program.

The World Bank projects that the world population will increase to 7 billion by 2010. Nuclear energy can make significant contributions to impoverished and rapidly growing societies in the future. CANDU reactors could not only produce electricity, but could also be used to provide fresh water from sea water on a scale sufficient for the agricultural, industrial and personal needs of large populations in developing nations.

Advanced Technology

Many countries with successful nuclear programs have National Laboratories, where governments support the laboratory infrastructure and provide direct funding for activities that are in the national interest. Since some of AECL's R&D resources and programs are of interest to government Ministries, the AECB, non-nuclear industries, research organizations and universities, they should be treated as a national asset and funded separately from the commercial activities of AECL. This was the case for AECL's Materials Science Program, which has been reorganized under the National Research Council, and is being considered for its Radiobiology Research Program. It is also the case for the proposed Canadian Neutron Facility (CNF).

The replacement of the now 42-year old NRU reactor by a new research reactor, the CNF, by the year 2005 is a vital element in the continued support of nuclear R&D. The CNF is essential for ongoing support and life extension of current CANDU reactors and the development of future CANDU designs. It will also provide an indispensable tool for probing the nature of materials, a need basic to the industrial base of an advanced technological economy. The CNF can be used to study a wide variety of materials, including alloys, plastics and semi-conductors, and will be influential in opening up new areas of research in biological materials. For these reasons, the National Research Council has joined with AECL in a proposal to the Federal Government for the detailed design and construction of the CNF.

CANDU and the Hydrogen Economy

To ensure that Canada has adequate energy in the 21st Century will require new thinking about traditional means of meeting the various demands for energy. In this respect, an exciting opportunity exists for the future conversion of Canada's transportation system from a fossil-fuel base to an electrolytic-hydrogen base. With the help of federal funding, and other public and private-sector investment, Canada is now well positioned to play a major role, both technical and economic, in a world revolution in GHG-free transportation fuels. CANDU nuclear reactors could produce the electricity for Canadian-developed high-efficiency electrolysis cells, to provide hydrogen for Canada's world-leading fuel cell technology to power cars, buses and trucks. For this to proceed on a large scale, it will be necessary to build additional CANDU reactors and to develop the necessary infrastructure. This revolution would help Canada meet its GHG commitment well beyond the period of the Kyoto agreement.

SUMMARY AND CONCLUSIONS

• To ensure that Canadians continue to enjoy the many benefits of nuclear technology, government investment in nuclear science and engineering R&D must be maintained. There is ample evidence to show that the benefits still to be realized will be at least as significant as those already achieved.

• The generation of nuclear electricity will continue to be economically viable, and it will play an essential role in driving the nation's economy while protecting the environment by avoiding greenhouse gases and other pollutants. Continuing research is needed to support and extend the productive lifetime of existing CANDU reactors in Canada and abroad, and to develop competitive advanced reactor designs.

• Canada's nuclear expertise supports the nation's strategic and diplomatic initiatives, including safeguarding nuclear material and the possibility of destroying weapons plutonium in Canadian reactors. It could also support other initiatives by providing GHG-free electricity and fresh water to developing regions of the world.

• To ensure that the benefits of nuclear technology continue for Canadians we must maintain the research base as a national asset. The immediate requirement is for the Canadian Neutron Facility, a dual-purpose facility that will support both CANDU-related research and the study of advanced industrial and biological materials.

• The use of nuclear power to generate hydrogen fuel would revolutionize transportation and would dramatically curtail the emission of greenhouse gases and other pollutants.

The R&D Advisory Panel to the Board of Directors of Atomic Energy of Canada Limited (AECL)

Dr. David A. Armstrong
Faculty Professor
Department of Chemistry
University of Calgary

Dr. Robin L. Armstrong
Professor Emeritus
Department of Physics
University of Toronto

Dr. David J. Burns
Professor of Mechanical Engineering
University of Waterloo

Dr. Albert A. Driedger
Professor, Faculty of Medicine
University of Western Ontario

Mr. Jon H.F. Jennekens
Jonor & Associates

Dr. John J. Jonas
Birks Professor of Metallurgy and Co-Director, McGill Metals Processing Centre
Mcgill University

Dr. Derek H. Lister
Chair, Nuclear Engineering
University of New Brunswick

Dr. Ernest A. McCulloch
Senior Scientist Emeritus
The Ontario Cancer Institute
Princess Margaret Hospital

Dr. Gilles G. Patry
Vice-Rector (Academic)
University of Ottawa

Dr. J. Terry Rogers
Professor Emeritus
Mechanical and Aerospace Engineering
Carleton University

Dr. Daniel Rozon, Directeur
Institut de génie nucléaire
École Polytechnique de Montréal

Printed in Canada. September 1999. D1322