A CENTURY OF PHYSICS AT THE NATIONAL RESEARCH COUNCIL OF CANADA (NRC)

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BIG IDEAS HAVE HUMBLE BEGINNINGS (1916-1938)

When first established in 1916, the National Research Council of Canada (NRC) was instructed to coordinate and promote scientific and industrial research in Canada. Members of the newly established organization soon realized that few of Canada's companies even had research labs, and those that did had labs so small they were staffed by a single person. Canadian universities presented no better opportunity as fewer than a dozen PhDs in Pure Science had been granted up to that point. In addition, Canadian research in physics was almost entirely published in foreign journals. NRC's members recognized these limitations to be gravely problematic, being a major impediment to the development of an industrializing nation.

NRC would address this compound problem in a few key ways. NRC's first priority became expanding research in Canadian universities through grant programs and scholarships. To ensure research into industrial and social needs would remain paramount in Canada, NRC's second priority was to establish its own laboratories. Interestingly, NRC performed research in rented lab spaces until 1932, when the Sussex Drive laboratories in Ottawa opened.

H.M. Tory, a physicist from the University of Alberta, was appointed as NRC's first full-time President in 1928. In the short span of a year, nearly 600 people worked at the organization and the first edition of the *Canadian Journal of Research* was published, finally providing a forum for consolidating results in a Canadian publication. A few years later, the journal was split into subsections. *Section A*, devoted exclusively to the physical sciences, would eventually evolve into the *Canadian Journal of Physics*.

Hampered by the resource restrictions of the Great Depression, NRC conducted applied research for non-military industrial problems. Physics-related research dealt primarily in acoustics, electrical measurement, radio, radiology, metrology and standards. After A.G.L. McNaughton was appointed NRC's new president in 1935, research efforts began incorporating a more militaristic angle. By 1937, NRC was deep in discussion with the Department of National Defence regarding the possibility of developing aircraft-detecting technology. On the eve of the Second World War, NRC was poised to mobilize national science for Canada's Allied R&D effort.

SUMMARY

From microelectronics to the atmospheres of stars, NRC's achievements in physics have expanded our knowledge and impacted Canadians and the entire world for over a century.

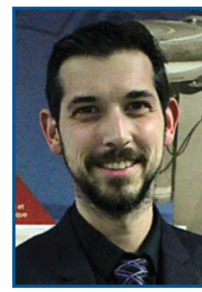
WWII, THE PHYSICIST'S WAR (1939-1945)

The First World War is often considered a chemist's war because of the agents that were used in the manufacture of lethal gases and explosives. If that is so, the Second World War was undoubtedly a physicist's war. With NRC at the helm, Canada's wartime efforts pioneered research and development in radar, nuclear energy, optics and many other technologies.

One of the most important scientific developments of the War resulted from the Tizard Commission to the U.S. and Canada. The Commission divulged British secrets of military science, including the cavity magnetron and the proximity fuse. At the insistence of the British, U.S. and Canadian governments mounted massive programs to develop radar, particularly microwave radar. Canadian researchers improved the designs for the cavity magnetron, and found resources to produce enormous supplies for the war effort, all in absolute secrecy. In total, 12 types of radar were mass-produced, and smaller quantities of 20 other types were manufactured for the military.

By July 1940, Canada established Research Enterprises Limited (REL), a crown corporation in Toronto, to mass produce both optical and radar equipment for the Allied forces. NRC researchers were involved in other projects for the war effort, including the development of a prototype sonar system for defense against acoustic torpedoes, and the development of degaussing countermeasures for ships at the Bedford Basin near Halifax.

In Ottawa, George Laurence began construction of a nuclear pile in the Sussex Drive laboratories, using half a ton of uranium oxide and ten tons of calcined coke. While



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Operations room for ground control radar detection of aircraft during WWII. NRC was the center of Canadian research and development on radar technology such as CHL and GL radars, ASV Mk. II, IFF transponders, height finder radar and microwave-frequency early warning radar. By 1945, NRC had developed about 30 different types of radar for various military purposes. (1943)

unsuccessful due to the lack of quality of the materials, Laurence did achieve Canada's first nuclear fission. Much was learned from this area of research leading to the creation of a joint Canada-U.K. nuclear laboratory in Montreal.

By war's end, NRC provided the foundation for new industries, hi-tech manufacturing and atomic energy.

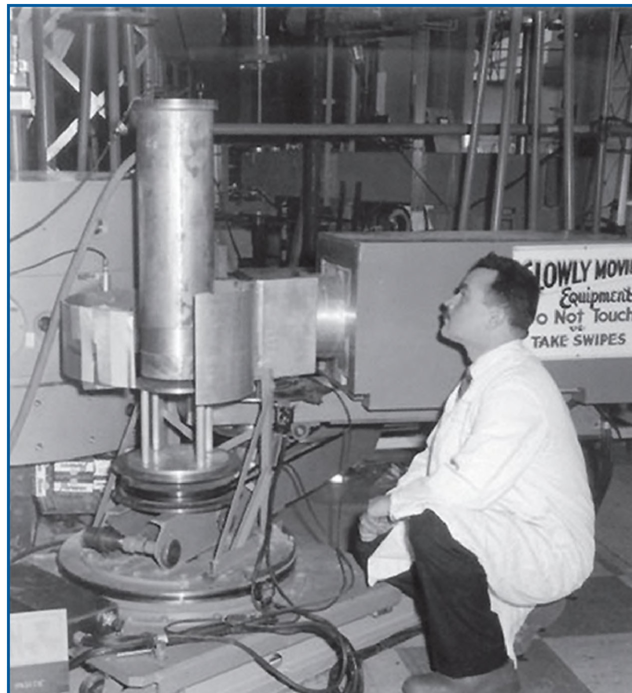
NRC GOES ATOMIC (1945-1959)

The credibility gained by NRC's wartime activities resulted in increased government support for its post-war objectives. Despite having redirected its focus for a time, NRC's original goals were to promote research at Canadian universities, to build research capabilities in Canadian industry, and to grow world-class research excellence in its own laboratories.

During this period, university grants and scholarships grew substantially, and in 1949, NRC began its Post-doctorate Fellowship (PDF) program. Not only did this keep new blood flowing through the NRC labs, it created a pool of qualified young physicists, many of whom moved on to Canadian universities and industry. The Industrial Research Assistance Program (IRAP)—also created during this period—successfully supports Canadian business R&D to this day.

In NRC labs, measurement and standards achieved its research excellence goals, and by 1958, the world's first continuously-operating cesium clock was Canada's primary time standard. As NRC returned to demilitarized research, its early nuclear energy program would form the basis for nuclear medicine.

Canada successfully collaborated with Britain and France to design ZEEP, Canada's first operational nuclear reactor. NRX was developed in 1947, which was the world's top reactor



Dr. Bertram Brockhouse pioneered inelastic neutron scattering, a technique that measures the dynamics of atoms in materials. In this picture Brockhouse is seen working with his spectrometer at NRU (Nov. 1958 - Jul. 1959).

for several years. Its successor, NRU, is today the world's oldest operating reactor. Its ongoing applications include developing and producing medical isotopes to diagnose diseases and treat cancer, testing for reactor fuel and components, designs for CANDU power reactors, and producing neutrons for research.

It is interesting to note that Natural Resources Canada cites nuclear as the second largest contributor of non-emitting electricity, powering 16% of the Country, and 60% of Ontario. As at 2014, this sector provided 30,000 direct jobs to the Canadian economy.

ALL RESEARCH, BIG AND SMALL (1960-1989)

During this period NRC transferred its university granting function to the Natural Sciences and Engineering Research Council of Canada (NSERC), and NRC shifted its first priority to the support of industrial-directed research.

The world's first Microtron, a type of electron accelerator, had been built at NRC in 1947-48, and while it was eventually transferred to the University of Western Ontario, NRC played a substantial role in helping to build a capacity for particle physics in Canada, including major initiatives such as TRIUMF, the Canadian Light Source and the Sudbury Neutrino Observatory (SNOLAB).

The Dominion Radio Astrophysical Observatory in Penticton (DRAO), houses a 26-metre telescope and was one of two observatories to first use Very Long Baseline Interferometry or VLBI to create high-precision images by merging radio signals with another observatory located 3074 kms away in 1967. (Circa 1970)

Dr. Gerhard Herzberg, 1971 Nobel Laureate in Chemistry, analyzing spectrograms at his desk. Herzberg discovered the internal geometry and energy states in simple molecules. One important focus of Herzberg's was the study of methylene, or CH_2, a very unstable molecule known as a "free radical." (Circa 1990)

After assuming stewardship for the Dominion Astrophysical Observatory (DAO) and Dominion Radio Astrophysical Observatory (DRAO) in 1970, NRC took astronomy to new heights with the construction of the Canada-France-Hawaii Telescope (CFHT). CFHT was only the beginning. Its construction led to the creation of other partner observatories, further establishing Canadian firms and engineers as experts in the design, manufacture and construction of instruments and enclosures. While these observatories have reported incredible astronomical discoveries, they have also yielded advances for industry, including high-performance computing systems, stealth aircraft detection and GPS operation.

In 1967, using recording equipment from the Canadian Broadcasting Corporation, NRC astrophysicists were the world's first to successfully merge observations using very long baseline interferometry, or VLBI, across a vast distance with two radio telescopes–DRAO in Penticton, British Columbia, and ARO in Algonquin Park, Ontario.

Canada's pioneer in molecular spectroscopy, Gerhard Herzberg, was awarded the Nobel Prize in 1971. Herzberg explored the energy content and properties of molecules using the new science of spectroscopy to study phenomena outside the visible region of light. Herzberg's pioneering interest was free radicals, and before winning the Nobel Prize, he had determined the properties of more than 30 free radicals, including methyl and methylene.

NRC designed protocols for testing loudspeakers, using an anechoic chamber. Floyd Toole, a psychoacoustics pioneer, worked with Canadian speaker makers in the 1970s to develop and refine tests for clarity, definition, fullness and exactness in sound reproduction, or fidelity. The Audio Engineering Society published Toole's research, which became a worldwide benchmark for audio evaluations.

NRC began researching optical filters in 1956, and moved on to thin-film coatings. That work has been fundamental to technology for communication networks, semiconductor and electronics manufacturing, medical and research instruments based on fluorescence, anti-counterfeiting banknotes, space programs and more.

This was a period of accelerated change, where the various scientific disciplines' naming conventions no longer reflected NRC's growing ties to industry. The Physics Division was transformed into institutes, such as the Institute of Microstructural Sciences, created for solid state physics and optoelectronics to support the semiconductor industry.

By 1989, NRC brought together members from universities, government departments and industry to form the Solid State Optoelectronics Consortium (SSOC), which established wavelength de-multiplexing, a technology at the core of today's optical communications networks.

NRC'S DAYS OF FUTURE PAST (1990-PRESENT)

At the beginning of this period, NRC experienced a heightened awareness of environmental, health and security issues—trumped only by the challenges Canadian industries faced in order to compete globally. NRC would adapt its existing technologies for broader application across industry sectors. For example, NRC developed 3D scanning technology for manufacturing, and honed it for aerospace engineering. An interesting secondary use of the technology enabled blockbuster creatures to come to life for

One of NRC's acoustic labs, an anechoic chamber built to absorb sound and eliminate echo, allowed NRC metrology experts to pioneer science-based methodologies still used today for measuring loudspeaker performance. (Circa 1980)

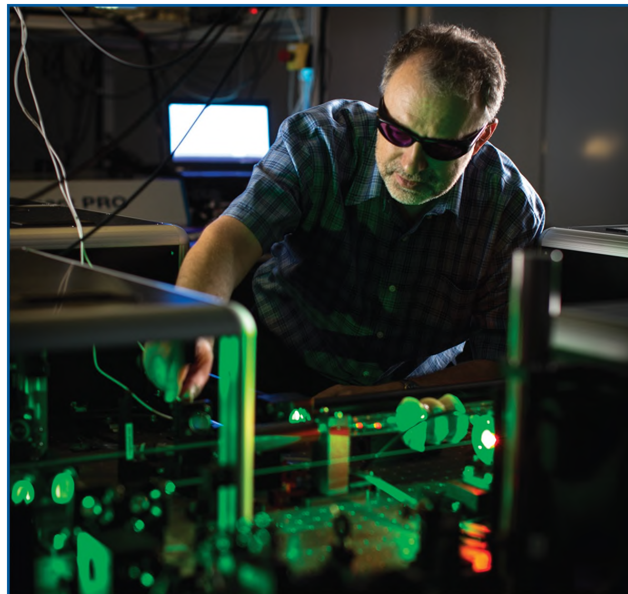
Peter Jackson's *Lord of the Rings* and *King Kong*. Recently, the scanner's microscopic 3D details have even appeared in video games and a U2 music video. These examples show the broad influence and applicability of the work NRC performs.

Members of a multi-year, international astronomy project called the Gemini Deep Deep Survey (GDDS) began peering into our universe's distant past. Working at the Gemini Observatories, NRC and its partners developed a technique that greatly improved long-range observation. What the GDDS team found as a result amazed them. Massive galaxies were discovered dating back from nine to 11 billion years. Until 2003, astronomers believed that only newly-forming galaxies existed during that epoch. GDDS raised fundamental questions about theoretical and cosmological models of the early universe.

In 2005, scientists at the National Institute for Nanotechnology (NINT), an NRC partnership with both the provincial government and the University of Alberta, found a way to create transistors on a molecular scale, which could pave the way for smaller, faster and cheaper microelectronics devices. Switching the current flowing through a single molecule on and off by changing the charge state of an adjacent atom, essentially turned a molecule into a transistor. A technology based on this concept would use much less energy, produce less heat, and run much faster than conventional technology.

Later, NRC researchers developed one of the world's most powerful adaptive-optics systems, known as Altair. Altair, and recent advances in image-processing technology, led an international team of astronomers to reach a milestone in the search for other worlds, capturing the first-ever images of planets circling a star other than the Sun in 2008.

In recent years, Paul Corkum and his team at NRC and the University of Ottawa have received worldwide honours for spectacular advances in probing atomic and molecular reactions. Researchers have created laser pulses as short as 150 attoseconds, or the time it takes an electron to make one orbit around a hydrogen atom. Dr. Corkum's work has opened a window to observe not just the motion of atoms, but the motion of electrons within atoms.



Dr. Andrei Naumov, NRC researcher at the NRC - University of Ottawa Joint Laboratory for Attosecond Science (JASLab), adjusts the calibration on ultrafast laser system that produces 80 million pulses of light every second. Each laser pulse is so precisely controlled it is accurate to 1 part in a trillion. (2007)

Nano-spintronics is a relatively new field in which an electron's spin is used to increase the capabilities of devices and circuits. NRC researchers have found a way to control and detect the spin states of a single electron, an advance that could make it possible for an electron's spin to act as the unit, or "bit", of information. The "single-spin transistor" could revolutionize how information is stored and processed. This research plays a fundamental role in quantum computing.

In Metrology, NRC succeeded in reducing the uncertainty of its watt balance—a device used in the determination of Planck's constant—to 15 ppb, making it the Kibble balance with the least uncertainty to date. That experiment, acknowledged by *Nature Magazine* as one of the hardest known to science, is part of a global, multi-decade effort. NRC's watt balance results pave the way for the kilogram's redefinition in 2018.

NRC has been a part of many of the greatest physical achievements over the last century. A cornerstone of the organization has been its support for science, experimentation and exploration, deeply rooted in social responsibility, to deliver the technologies of tomorrow—a foundational principle that has been true throughout NRC's 100-year history and will remain true tomorrow.