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Abstract/Résumé analytique

Creating a Canadian Profession: The Nuclear Engineer, c. 1940-68

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Canada, as one of the three Allied nations collaborating on atomic energy development during the Second World War, had an early start in applying its new knowledge and defining a new profession. Owing to postwar secrecy and distinct national aims for the field, nuclear engineering was shaped uniquely by the Canadian context. Alone among the postwar powers, Canadian exploration of atomic energy eschewed military applications; the occupation emerged within a governmental monopoly; the intellectual content of the discipline was influenced by its early practitioners, administrators, scarce resources, and university niches; and a self-recognized profession coalesced later than did its American and British counterparts. This paper argues that the history of the emergence of Canadian nuclear engineers exemplifies unusually strong shaping of technical expertise by political and cultural context.

Le Canada, une des trois nations Alliées collaborant au développement de l'énergie atomique durant la Deuxième Guerre mondiale connut une avance précoce dans la mise en application de cette nouvelle connaissance et dans la définition de cette nouvelle profession. À cause du secret de l'après-guerre et des buts nationaux très nets, l'industrie nucléaire fut modelée uniquement par le contexte canadien. Le Canada, dans son exploration de l'énergie nucléaire et dans son abstention d'en considérer les usages militaires, faisait cavalier seul parmi les puissances d'après-guerre; la profession s'instaura à l'intérieur d'un monopole gouvernemental; le contenu intellectuel de la discipline fut influencé par ses premiers praticiens et administrateurs, par la pauvreté des ressources et aussi par les créneaux universitaires; et finalement, une profession consciente d'elle-même se fonda plus tard que ses homologues américains ou britanniques. Dans cet article, nous soutenons que l'histoire de la naissance de l'ingénierie nucléaire canadienne illustre le modelage exceptionnellement marqué de l'expertise technique par le contexte politique et culturel.

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CREATING A CANADIAN PROFESSION: THE NUCLEAR ENGINEER, C. 1940-68[1]

Introduction

The development of atomic energy has been recounted and analyzed in numerous scholarly and popular publications since 1945. The roles of wartime institutions and historical actors in Canada, however, are frequently subsumed within accounts of the Manhattan Project and Anglo-Canadian collaboration. Similarly, the postwar period, during which further exploration of atomic energy and nuclear power was pursued, has also been assessed from predominantly administrative, economic and political perspectives. The historiography of Canadian nuclear energy has ranged from official accounts, to biographies of key scientists, and to national and business histories.[2]

Accounts are nearly silent, however, on the emergence of the new technical specialists of this mutating field, particularly in Canada. Owing to secrecy during and after the war and distinct national aims for the domain, nuclear engineering was shaped distinctively in the Canadian context. Alone among the postwar powers, Canadian exploration of atomic energy eschewed military applications. The occupation emerged within a governmental monopoly, and the intellectual content of the discipline was influenced by its early practitioners, administrators, and university niches. A self-recognized profession coalesced later and in a different form than did its American and British counterparts. Archival sources reveal the unusual degree to which government institutions (particularly the National Research Council and its offshoot, Atomic Energy of Canada Ltd) shaped the new profession. This paper explores the emergence of a distinctively

[1] The funding of this work by the UK Economic and Social Research Council grant RES-000-22-2171, and helpful comments from three anonymous reviewers, are gratefully acknowledged.

[2] For example, Henry D. Smyth, *Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb under the Auspices of the United States Government, 1940-1945* (Princeton, NJ, 1945); Margaret Gowing and Lorna Arnold, *Independence and Deterrence: Britain and Atomic Energy, Vol. I: Policy Making, 1945-52* and *Vol. II: Policy Execution, 1945-52* (London, 1974); C.J. Mackenzie, *The Mackenzie-McNaughton Wartime Letters* (Toronto, 1978); Ruth Fawcett, *Nuclear Pursuits: The Scientific Biography of Wilfrid Bennett Lewis* (Montreal, 1994); Wilfred Eggleston, *Canada's Nuclear Story* (Toronto, 1965); AECL, *Canada Enters the Nuclear Age: A Technical History of Atomic Energy of Canada Limited* (Montreal, 1997).

Canadian breed of nuclear engineer based on a unique conjunction of technical expertise, institutional shaping, academic environment, and national context.

I. Scientific and Wartime Background

Nuclear science in Canada, as in other countries, had attracted researchers from its origins at turn of the century; indeed, the New Zealand physicist Ernest Rutherford and English chemist Frederick Soddy studied radioactivity at McGill University in Montreal. Rutherford received a 1908 Nobel Prize for his Montreal work, which had confirmed that radioactivity signaled the disintegration of atoms and was characterized by a half-life, or typical decay rate for each type of atom. Soddy's own Nobel Prize in 1921 recognized his concept of isotopes as variants of an element having different atomic weights. Both subsequently engaged in research in Britain, and Rutherford's labs nurtured many of the key participants in nuclear fission and its application in Canada, including John Cockcroft and W. Bennett Lewis and Canadians George Laurence, David Keys, and B.W. Sargent.

Serious Canadian involvement in atomic energy was nevertheless a wartime accident. The discovery of the splitting of uranium atoms (later dubbed fission) and the corresponding release of energy, confirmed by experiments and analysis in Germany and published in the British journal *Nature* in February 1939, encouraged rapidly mounted investigations by scientists around the world.[3] At the Collège de France in Paris, the team led by Frédéric Joliot and including Hans Halban and Lew Kowarski demonstrated that this fission usually released two or more neutrons.[4] This detail gave the fission of uranium nuclei not only scientific but also potential engineering interest: the newly liberated particles could cause fission of further uranium nuclei in an exponential expansion, leading to a proportional release of energy. A chain creation — if confirmed — seemed promising for both power generation and munitions.

Small and independent groups of physicists began attempts to create a chain reaction in the laboratory. The National Research Council of Canada (NRC) in Ottawa was the site of early work: there, physicist George Laurence, later assisted by B. W. Sargent of Queen's University, began experiments in March 1940 to investigate the possibility of a nuclear chain reaction. While intensely secret, this was nevertheless a low priority and low-budget project: the acting president of the NRC, Chalmers Jack Mackenzie, initially focused NRC attention and funding on research deemed to be of direct and immediate importance for the war.

[3] Nuclear physics, a rapidly expanding field during the 1930s, was a genuinely international subject by the end of the decade, spread in part by the exodus of scientists from Mussolini's Italy and Nazi Germany. Researchers in Italy (e.g. Enrico Fermi) and Germany (e.g. Lise Meitner, Otto Hahn, Fritz Strassman, Otto Frisch, Rudolph Peierls) evolved compelling interpretations of nuclear fission. In England, Frisch and Peierls wrote a memorandum in March 1940 that convinced the British government to pursue development of a fission bomb; Fermi became the key designer of the Manhattan Project's nuclear reactors.

[4] The group, minus Joliot, was later seminal in defining Canadian nuclear research.

Besides Laurence's in Ottawa, independent experiments began at Columbia University in New York and Imperial College London. Émigré scientists in the UK and USA communicated the potential of the chain reaction to their governments. In Britain, chemist Henry Tizard, responsible for the Scientific Survey of Air Defence, set up a committee (dubbed MAUD) in April 1940 to investigate the feasibility of applying nuclear energy, and visited the USA that autumn to discuss the exchange of military technologies such as radar. Laurence's work was discovered in the first fact-finding tour and soon attracted British funding.[5]

The first MAUD report, provided in March 1941, set the trajectory for British and Canadian involvement in nuclear energy over the following decades. The report judged a uranium-based fission explosive and power generation to be technically feasible. The British report was also crucial in galvanizing American physicists, who campaigned that autumn for an all-out US development programe. That October, a committee of the American National Academy brought together a contingent of physicists and engineers. The American government decision to fund the atomic bomb project was guided by two highly placed administrators who subsequently played an indirect role in defining its Canadian workers and the scope of their activities. Vannevar Bush, directing a new coordinating body, the Office of Scientific Research and Development (OSRD), and James B. Conant, then president of Harvard University and chair of the National Defense Research Committee (NDRC), assumed a wide-ranging set of responsibilities that included the atomic bomb development project. Bush, supported by Conant, reported directly to Franklin Roosevelt and had essentially unlimited access to resources for wartime research and development.[6]

This state-funded scientific project was expanded by a forced marriage. In June 1942, project control was passed to an American Army organization dubbed the Manhattan Engineer District and directed by General Leslie Groves. Most crucially for incubating a new technical elite, engineering development was passed to corporations including Du Pont, General Electric, and Westinghouse. Following a meeting between Winston Churchill and Roosevelt, the two countries agreed to collaborate, with the bulk of research and development to be sited in the USA.

While the American effort was beginning in new secret towns, work continued in British university and industrial labs. The MAUD committee was superseded by a new "Tube Alloys Directorate" in the autumn of 1941, a division of the Department of Scientific and Industrial Research (DSIR) attached to the Ministry of Supply. Even before Groves's call to American corporations, the

[5] John Cockcroft, a physicist and then Assistant Director of Scientific Research in the British Ministry of Supply, took an interest in Laurence's work when in North America during the summer of 1940 as a member of the Tizard mission. Laurence, in return, learned of parallel American work. When Cockcroft returned to the UK, his appeal to Imperial Chemical Industries led to a $5000 grant for Laurence. Thus science was linked intimately to industrial interest even at this early stage.

[6] For careful overviews of activities over this period, see Richard Rhodes, *The Making of the Atomic Bomb* (London, 1986); and Margaret Gowing, *Britain and Atomic Energy, 1939-1945* (New York, 1964).

MAUD committee had recognized the necessity for industrial collaborations. The committee relied on the two British companies that were large enough to support research staff, and to have the knowledge and industrial capacity for the planned work: Imperial Chemical Industries (ICI) and Metropolitan-Vickers.

Unlike its American counterparts, ICI had emphasised the importance of "power production in peace and war," and argued in appendices to the MAUD report that "the present ideas and research work should be developed by a firm in the United Kingdom for the British Empire, whatever may be done in other parts of the world."[7] Its senior managers judged Hans Halban's scheme for a "nuclear energy machine" to be the most feasible, but since it required some 20 tons of heavy-water and an equivalent amount of purified uranium, they argued that Canada, with known supplies of uranium ore, would be a logical partner.[8]

It was equally obvious to administrators that the resources to achieve these goals would be difficult to obtain in wartime Britain, which did not have adequate resources to refine uranium on an adequate scale. Although Tube Alloys initially disdained collaboration with the American groups, the project turned gradually towards complementary and associated tasks with its neighbour. During the preceding year, though, the American groups had made substantial progress and, under the Army's management, were now reticent to accept foreign collaboration, particularly because of suspicion about the involvement of ICI, a major international competitor for American companies. Consequently Canada was needed not merely as partner to provide raw materials, but also host. Negotiations in early 1942 resulted in physicists and engineers at British universities and ICI moving en masse to Montreal under Hans Halban in early 1943. Broadly speaking, then, a Canadian locus was a consequence of British apprehension of invasion, American security concerns, and Anglo-Canadian determination to remain part of the project.

II. Canada and the "Heavy-Water Boiler"[9]

The peculiar wartime context, melding secrecy, high strategic importance, and disparate scientific and engineering expertise, provided the conditions to grow

[7] Imperial Chemical Industries Ltd, "Report by M.A.U.D. Committee on the Use of Uranium for a Bomb, Appendix VII: Nuclear energy as a source of power," in Gowing, *Britain and Atomic Energy*, pp. 433-36.

[8] ICI's own postwar plans for research and power generation are further detailed in "ICI Progress Reports (General Chemistry Division) 1941-43," UK National Archives [formerly Public Record Office, Kew, UK, hereafter cited as NA] AB 1/331. Heavy-water, comprising a heavy isotope of hydrogen (deuterium), had been obtained by Joliot's group in France and was transported to Cambridge, and eventually Montreal, by Halban's team. Heavy-water was expected to yield a more efficient chain reaction than a graphite-based scheme being pursued by Enrico Fermi's group in the USA.

[9] The term used for a nuclear reactor by the Montreal group during the war. See, for example, P.V. Auger, H.H. Halban, R.E. Newell, F.A. Paneth, and G. Placzszek, "Research programs for development of heavy-water boiler," memo, 30 December 1943, Library and Archives Canada [hereafter cited as LAC] RG77 Vol. 283.

both a new subject and a new profession. The emergence of Canadian nuclear research and a distinct definition of nuclear engineers were influenced strongly by the working cultures of the National Research Council of Canada (NRC) and Imperial Chemical Industries (ICI). Both organizations were amenable to a congenial alliance between engineers and scientists. Moreover, the Canadian involvement was overseen and administered by a handful of individuals who combined engineering experience with civil service connections. The shaping of the project, its personnel, and postwar ambitions proved contingent on their backgrounds and interactions.

Just as important, the project was actively supported at the highest government levels. The Canadian government accepted the British request to host aspects of the Tube Alloys Project, offering to pay all project costs except the salaries of its participants from Britain. In the spring of 1942, Canada's Minister of Munitions and Supply, C.D. Howe, himself an engineer, consulted C.J. Mackenzie — also a civil engineer and senior academic before joining the NRC — as the most senior scientific administrator to oversee the work. For Mackenzie, the new project was accepted matter-of-factly as a wartime requirement having potential postwar consequences. It fit well with the Council's mandate of "fostering the scientific development of Canadian industry for Canadian needs and for the extension and expansion of Canadian trade at home and abroad."[10] That autumn, Howe assigned Lesslie R. Thomson, a mechanical engineer and pre-war professor of civil and fuel engineering at two Canadian universities, as administrator and liaison officer.[11]

The personnel staffing the organization were a distinctly twentieth-century collection of scientists, engineers and technicians The effort by specialists to marry scientific research with economically valuable outcomes was becoming familiar in the national standards laboratories that appeared at the turn of the century — the Physikalisch Technische Reichsanstalt in Germany (1887), the National Physical Laboratory in Britain (1900), and the National Bureau of Standards in the USA (1901) — and in industrial laboratories (such as those of General Electric, Kodak, Bell, and Westinghouse in the USA, and GEC, British Thomson-Houston, and Metropolitan Vickers in Britain). In these environments, neither science nor engineering had a permanent position in the hierarchy of status and power: either could assume ascendancy depending on the task at hand.

The administration of the NRC advanced this professional demographic. Neither of Mackenzie's predecessors — Henry M. Tory, an educator responsible for founding several Canadian universities, or General Andrew McNaughton, trained as an engineer and responsible for modernizing the Canadian Army — had engaged in research themselves, but each had a record of promoting it in other contexts. Founded in 1916, the National Research Council had played primarily an advisory role for the Canadian government through the 1920s. During that period, it informed policy, surveyed Canadian research strengths, funding

[10] Commemorative plaque, entrance hall of NRC laboratories, 100 Sussex Drive, Ottawa.

[11] Thomson had earlier been appointed Comptroller and Secretary of the Ministry

committees to investigate specific problems, and provided university fellowships. Although founded ostensibly to coordinate and promote scientific and industrial research, it soon discovered that there was little to promote. Canada, it seemed, was a country focused on application: when the NRC was founded, there were an estimated fifty scientists engaged in so-called pure research.[12]

Under Tory, however, who oversaw the completion of research laboratories in Ottawa in 1932, the organization began to conduct more applied research of its own in the national interest. His "Temple of Science" was populated with some fifty scientists and engineers during the Depression years, working almost exclusively on industrial problems. As a Crown Corporation, the NRC was not a Department of Government, and its staff organization did not always conform to Civil Service norms; indeed, many staff worked without pay during the Depression. Nor was the organization modeled closely on universities. The first reorganization in 1929 created a Division of Physics and Engineering, lumping together fields that in other institutions were held more firmly apart.[13] Under McNaughton's four-year direction to 1939, staff doubled, and working culture remained firmly oriented towards scientific-engineering collaborations. And during his own tenure, when staff reached over 2,000, C.J. Mackenzie sought to maintain "the realistic view which all members of the staff here take. We all feel keenly that unless our endeavours produce equipment and findings … we will not be achieving our fundamental purpose."[14] This merging of scientific and engineering interests was unique, and of particular value for the development of a new field and specialist workers. In the USA, by contrast, the Manhattan Project scientists balked at collaboration with engineers; in Britain, the Tube Alloys work was relatively segregated between university laboratories and the industrial sites of ICI.

Although he knew something of the British nuclear work from previous visits by John Cockcroft, Mackenzie first met Sir George Thomson, Chair of the MAUD committee, and Wallace Akers, the Director of Tube Alloys, in February 1942.[15] He warmed to Akers immediately as an engineer like himself. Mackenzie's diary entries characterize Akers, the Research Director of ICI and now head of Tube Alloys, as "an extraordinarily able and impressive man. He is

12 On the history of the NRC, see Wilfrid Eggleston, *National Research in Canada: The NRC, 1916-1966* (Toronto, 1978); W.E. Knowles Middleton, *Physics at the National Research Council of Canada, 1929-1952* (Waterloo, 1979); and Louise Dandurand, "The Politicization of Basic Science in Canada: NRC's Role, 1945-1976" (PhD diss., University of Toronto, 1982).

13 Paul A. Redhead, "The National Research Council's impact on Canadian physics," *Physics in Canada* 56 (2000), pp 109-21. This union was enduring. The Division became Physics and Electrical Engineering in 1936 and Physics alone only in 1947. It split into separate divisions of Physics and Applied Physics in 1952, when all NRC activities relating to atomic energy were taken over by the new Atomic Energy of Canada Limited, but such disciplinary titles were abandoned in 1990 as too academic.

14 C.J. Mackenzie, *The Mackenzie-McNaughton Wartime Letters* (Toronto, 1978), p.78.

15 Akers' obituary, describing him as a chemist rather than engineer, scarcely mentions his wartime Tube Alloys work. See Lord Waverley and Alexander Fleck, "Wallace Alan Akers. 1888-1954," *Biographical Memoirs of Fellows of the Royal Society*, 2 (1956), pp. 1-4.

sound scientifically and has a very pleasant personality and practical sense. He has extensive industrial experience also." Tube Alloys represented just the kind of project that Mackenzie's NRC aspired to undertake. It promised economic benefits along with a strong component of international science. Mackenzie was correspondingly impressed with the British plans for the project, "talking in terms of very large plants — something in the vicinity of 40 or 50 million dollar plants and if it is successful will be one of the most spectacular things of the war."[16] Following further visits from a half-dozen members of Tube Alloys (Mackenzie referring to "the very hush hush project" alternately in his diary as "the uranium business," "problem S-1," the "U project," "the radiological problem," and "the corrosion project"), Lesslie Thomson began seeking a Canadian base for the operation.

During late 1942, the first few members of the group were accommodated in a Montreal house, but a more suitable location was found March 1943, in an empty wing of the newly constructed hospital of the University of Montreal. Over the following months the Montreal Laboratory was populated with a growing number of technical workers. With the group of French workers came a stock of heavy-water produced in Norway via Joliot's lab, which had been transported to Cambridge in May 1940 after the fall of France.[17] The Montreal Laboratory team was cosmopolitan, consisting of the French and British scientists but also engineers seconded from ICI and equivalent Canadian personnel from the NRC and universities. Still other design engineers were recruited from the Central Register in the UK, but Wallace Akers noted that "the Canadians, who have been found for us, are of a very high standard indeed."[18]

Managing the new cluster of workers nevertheless presented difficulties, with scientists identified as the source of problems rather than solutions. The leaders of the project — C.D. Howe, C.J. Mackenzie, Lesslie Thomson, Wallace Akers, and the scientific leader of the team, Hans Halban — remained embroiled not just in the administrative and political details of the Canadian project through the war, but also its scientific dimensions. And for each of them, all except Halban an engineer by training, the importance of collaboration between scientific research and engineering expertise was a perennial theme. The same insight came to the American administrators, too. Following a meeting with Akers, Mackenzie commiserated,

[16] C.J. Mackenzie, 19 February 1942 diary, LAC MG30-B122 Vol. 1.

[17] That original stock appears never to have been used even in Canada; although a heavy-water reactor was eventually constructed at the end of the war, the supply had been sent for reprocessing at the only heavy-water plant then existing in North America, in Trail, British Columbia, and was eventually repatriated to France in 1948. See Pat Smith, "On the trail of Drum T-7," *AECL Inter-Comm*, 2 June 1989.

[18] "1943 Canadian organization: personnel," NA AB 1/380. By October 1944, when John Cockcroft took control of the Anglo-Canadian project, there were some 140 graduate scientists/engineers, half being Canadian, with twenty-two British, seven New Zealanders and four French; see John Cockcroft, "Montreal staff," NA AB 1/278.

> I gather that things are not going so well in certain parts of the American program as the groups of physicists, particularly at Chicago, do not realize the wisdom of calling in engineers when it comes to plant design etc. These high grade physicists sit around for hours discussing problems which are to be solved in the first chapter of elementary engineering texts. They are beginning to realize that in the States now and are beginning to correct it. In other of the projects engineers from the Kellogg Co. and the Dupont Co. have been called in early in the game and these projects are going very well.[19]

Meeting James Conant of the American NDRC a few weeks later, Mackenzie gained the same perspective:

> Conant was quite concerned about the whole work and said that it was very difficult to get a sound opinion as to the merits of the various projects. He said that his difficulty was to get the opinion of a detached nuclear physicist… He agrees with Akers' contention that it is largely an engineering development or at least the major difficulties will be engineering…They have now a special committee investigating all the projects from an engineering standpoint. The subcommittee is really a group of Dupont engineers.[20]

But where Du Pont was a central, if resented, player in American developments, ICI was accommodated readily into Anglo-Canadian work. An important reason for the difference was the early responsibility allocated to the company by the Tube Alloys Project. By late 1943 Tube Alloys managed 276 research workers: 30 at Birmingham University, 23 at Cambridge, 22 at Oxford, 10 at Liverpool, and 67 at the Montreal Laboratory.[21] ICI staff, accounting for 93 of the total, remained intimately involved, and by September of that year their representatives had joined the Technical Sub-Committee.[22] As the largest and widest-ranging chemical manufacturer in the UK, ICI was involved in every aspect of the early developmental work. Via its fertilizer and synthetic products division at Billingham in the northeast, the General Chemicals and Alkali Divisions in the northeast, and the Metals Division in the Midlands, the company during the war studied production processes for heavy-water, produced the chemicals for the pilot diffusion plant and uranium metal for the first test reactors, supervised the production of special membranes for the model diffusion

[19] C.J. Mackenzie, 19 November 1942 diary, LAC MG30-B122 Vol. 1.

[20] C.J. Mackenzie, 29 November 1942 diary, LAC MG30-B122 Vol. 1.

[21] "1942-1945 Staff, general," NA AB 1/246.

[22] R.W. Clark, *The Birth of the Bomb* (London, 1961), pp. 127-39, 155-58.

units, and operated them.[23] The high proportion of ICI engineers in the Anglo-Canadian program consequently flavoured its working culture.

In the Montreal group, however, scientists initially gained the most influential roles. From March 1943, forty UK-based professionals worked at the Montreal Lab, notably Head of Engineering, Ronald E. Newell; Head of Physics, Pierre Auger; Head of Theoretical Physics, George Placzek, and Head of Chemistry, Friedrich Paneth. However, industrial expertise and science were closely associated in exploring the new field. As Newell summarized it, the assembled group was constructing a new field of expertise — but one closer to engineering than to science:

> Owing to the unusual nature of the work the great majority of the additional staff did not have the full specialized knowledge necessary and a period of training was required. In the case of engineering, for example, this meant development of a completely new branch of engineering... a great deal of new knowledge had to be acquired by the engineers and to some extent this has also applied to the theoretical and experimental physics sections and the chemistry section.[24]

It is not a coincidence that Newell identified the engineering as similar to his own background in industrial chemistry and power generation.[25] This categorization of essential attributes was repeated by other administrators responsible for nuclear specialists through the 1950s. Newell's words were echoed in the war-end summary of the American project:

> Evidently the operation of a full-scale plant of the type planned would require a large and highly skilled group of operators. Although du Pont had a tremendous background of experience in the operation of various kinds of chemical plant, this was something new and it was evident that operating personnel would need special training.[26]

The unusually close collaboration of scientists and engineers in the Canadian context was an important factor in creating a national identity for nuclear specialists. Another was intellectual isolation: the growing nucleus was cloistered. While engineering was identified as central to the Anglo-Canadian

[23] W.J. Reader, *Imperial Chemical Industries: A History* (Oxford, 1975), Vol. 2, pp. 287-96.

[24] R.E. Newell to L.R. Thomson, letter, 11 November 1943, LAC MG30 E533 Vol. 1.

[25] Newell had been chief engineer of the Billingham Power Station in Durham, England, and was introduced to Mackenzie as "a well known specialist on heat extraction and high pressure chemistry" ? see "Organization of Montreal Laboratory," LAC RG77 Vol. 283.

[26] Henry D. Smyth, "A general account of the development of methods of using atomic energy for military purposes under the auspices of the United States Government 1940-1945," 1 July 1945, LAC MG30-E533 Vol. 1.

project, there was relatively little for engineers to do at the Montreal Laboratory. Detailed design work, construction, and testing were in abeyance because, as Mackenzie had suspected, the Americans were reluctant to provide the necessary heavy-water and uranium for Hans Halban's group to build a chain-reacting pile.[27] American administrators continued to distrust the broad European backgrounds at the Montreal Lab; as Mackenzie summarized it,

> the Montreal group… is really not an Anglo-Saxon group, and… they felt there was no guarantee that the various nationals — French, Austrian, Russian, Czecho-Slovakian, German, Italian, etc. could be guaranteed for any length of time. I think there is a great deal to be said for their point of view.[28]

Groves, Conant, and Bush were equally uneasy about UK involvement in what they saw as an American development project. The commercial risks also unsettled them. Wallace Akers, the Director of Tube Alloys, was a senior member of ICI staff; his deputy and senior engineers were all seconded ICI employees, and their company had promoted a potential postwar British nuclear industry in the MAUD report.

As a result, the Montreal group found itself increasingly excluded from American information, with its members pleading for action by the Canadian administrators and pursuing increasingly arcane, but still unverifiable, theoretical studies. As one of the Canadian members recalled, "it was science in a closet. So we worked more or less in our separate corners. Under stress, we could not afford the luxury of seeing the broad picture, and became technicians in our separate cells."[29] Without adequate supplies of uranium or heavy-water, and isolated from experimental findings from the USA, technical workers at the Montreal Lab consequently developed a local Canadian variant of nuclear knowledge, devoting most of their effort to theoretical studies of chain-reactor designs based on heavy-water.[30] Internal security, too, inhibited interdisciplinary collaboration; as one member recalled, "hierarchy prevailed, and the atmosphere was in some ways more military than academic."[31]

Collaboration with the American program improved but remained difficult. The information flow to the American groups was aided by a military liaison officer, except for a brief period in late 1943 when Mackenzie and Akers, exasperated at the stonewalling by Groves, Conant, and Bush, restricted the Montreal

[27] Ironically, the source of heavy-water was an American-owned plant in Trail, British Columbia; ample uranium deposits, too, were available in Canada.

[28] C.J. Mackenzie, 18 January 1943 diary, LAC MG30-B122-Vol. 1.

[29] Philip R. Wallace to M.M.R. Williams, letter, 21 July 2000, SFJ collection.

[30] Michael M.R. Williams, "The Development of Nuclear Reactor Theory in the Montreal Laboratory of the National Research Council of Canada (Division of Atomic Energy) 1943-1946," *Progress in Nuclear Energy* 36 (2000), pp. 239-322.

[31] Philip R. Wallace, "Atomic energy in Canada: personal recollections of the wartime years," *Physics in Canada*, 56 (2000), pp. 123-31; quotation p.126.

group from scientific contact with their American counterparts. A direct discussion between Churchill and Roosevelt at Quebec in August 1943 led eventually to some relaxation of American restrictions. Nevertheless, as Mackenzie fumed a month later, General Groves was "the dominant personality in the US group" and "in effect a dictator" whose "idea of collaboration seems to be to incorporate into the US project such sections of the British team as seem likely to promote a speedier and more certain realization of project."[32] The Montreal-based workers had had frustratingly little contact with their American counterparts until late 1943, during which time American capability had developed rapidly. Isolation thus shaped and consolidated the Canadian work: intellectually segregated, the Anglo-Canadian team diverged increasingly from Manhattan Project goals.

The decision in early 1944 to build a pile and chemical plants in Canada for heavy-water production and plutonium separation therefore was an effort to shift the centre of mass from the USA, and to transfer the project gradually from British to Canadian governance.[33] Like the American wartime installations at Argonne, Illinois (reactor design and testing), Hanford, Washington (large reactors to generate plutonium), Oak Ridge, Tennessee (separation factories to produce the radioactive isotope of uranium), and Los Alamos, New Mexico (bomb design and testing), the chosen Canadian site, Chalk River in southern Ontario, was placed far from population centres both for security reasons and to accommodate the engineering uncertainties of explosion or accidental release of radioactive materials.[34] At Chalk River, physicist John Cockcroft took over from Hans Halban the direction of the British/Canadian team to design the first reactor outside the USA.[35] It became operational in September 1945, four weeks after the Hiroshima and Nagasaki bombs were dropped.[36]

The separation between the American, British, and Canadian goals in the Manhattan Project is illustrated by the bombings of Japan. For the Chalk River group, focused on reactor theory, preparing to test the first Canadian reactor, and

[32] "Letters Re: Personnel - Organization at Chalk River," LAC RG77 Vol. 283.

[33] "1944 Removal of Montreal Laboratory to UK," NA AB 1/149; "1946 Suggested re-organization of the Engineering Branch at Chalk River in the light of present and future responsibilities and the formation of a crown company to administer the Atomic Energy Project," NA AB 2/128.

[34] "It must be pointed out that the Pilot Plant we propose to construct will have an output of approximately 10 times that of the American plant at X [in other words, Clinton, TN]. Furthermore, our proposed plant will be water-cooled and its stability is uncertain under some conditions. For these reasons, the scientists and engineers of the National Research Council are of the definite opinion that, with the present state of knowledge, the plant should not be located closer than 4 miles to the village": B.K. Bolton to C.J. Mackenzie, letter, 18 August 1944, Ottawa, Ontario, LAC RG77 Vol. 283.

[35] Cockcroft was well-suited to the emerging field. He had broad and relevant experience in nuclear physics with a flair for engineering. Having begun university at Manchester as the First World War began and serving as a soldier during the war, he graduated as an electrical engineer and completed a College Apprenticeship at the Metropolitan-Vickers Company. He had had earlier industrial experience during the summer vacation at British Thomson-Houston. Hoping to advance in the industry, he obtained a doctorate at the Cavendish Laboratory under Rutherford ; see Guy Hartcup and T. Edward Allibone, *Cockcroft and the Atom* (Bristol, 1984).

[36] For a detailed narrative of the American side of the Manhattan project, see Richard Rhodes, *The Making of the Atomic Bomb* (London, 1986).

proposing British developments in the months ahead, the use of the bombs was marked by relatively little reaction. Cockcroft had spent the weeks preceding the Japanese events writing a scientific account of chain reacting systems for Lord Cherwell, and the month before that was devoted to a memo outlining postwar possibilities for generating power.[37] On the other hand, more senior administrators prepared to publicize unity of purpose. NRC Director C.J. Mackenzie, on vacation during the bombings in early August, returned to his desk to pen congratulatory letters to Groves, Bush, Conant, and Chadwick.[38] And, also with Mackenzie's drafting, the Canadian government publicized the wartime collaboration within days of the news of the bombings of Japan.[39]

Despite surface collaboration, however, this was clearly an unequal partnership. The American dominance of the Canadian project and influence on its specialist workers is illustrated by actions during the last months of the war. General Groves had complained of a trip by Hans Halban to liberated France in December 1944 during which he met with his colleague Frédéric Joliot, a known Communist. Halban's imperious and secretive manner had ruined his relationships with his Anglo-Canadian co-workers, and the trip seemed to vindicate the decision taken eight months earlier to replace him as project leader. John Cockcroft, his replacement, had a reputation with both the Americans and British as a quietly efficient and tenacious administrator, comfortable with engineering/scientific collaboration and its civil service management.[40]

Groves also was suspicious of later requests by other members of the French contingent, Bertrand Goldschmidt, Lew Kowarski, and Jules Guéron to visit France in April 1945 to discuss their eventual redeployment with Joliot in a postwar French nuclear institution.[41] In September 1945, Groves demanded that the remaining French members of the Montreal Lab/Chalk River team be excluded from what was now a *postwar* project. With only token protest, C.J. Mackenzie complied, and the French departed by the end of the year.[42] James Chadwick, the British discoverer of the neutron, argued to Mackenzie that "this consequence is inevitable" and that he was "not prepared so seriously to prejudice our agreement

37 S.G. Bauer and J. Diamond, "Note on piles for the production of useful power," memo, 4 June 1945, LAC RG77 Vol. 283; John Cockcroft, "The development of chain reacting systems," memo, 30 July 1945, LAC RG77 Vol. 283. Physicist F. A. Lindemann (Lord Cherwell) was the chief wartime scientific advisor to Winston Churchill.

38 For example, "the greatest scientific and technological achievement of all time" (Mackenzie to Conant, 14 August 1945) and "it must have been a great thrill to see the experiment in the desert" (Mackenzie to Chadwick, 23 August 1945), in "Letters Re: Personnel — Organization at Chalk River," LAC RG77 Vol. 283.

39 Department of Reconstruction, "Canada's role in atomic bomb drama," and "Scientists who probed atomic secrets," press releases, 13 August 1945.

40 See, for example, Guy Hartcup and T. Edward Allibone, *Cockcroft and the Atom* (Bristol, 1984).

41 Goldschmidt, as the last assistant of Marie Curie in 1933, was perhaps the only direct link in Canada at the time with the origins of nuclear science.

42 C.J. Mackenzie to G.L. Groves, letter, 26 December 1945, LAC RG77 Vol. 283.

on collaboration with the U. S. in order to relieve a temporary embarrassment."[43] An unsigned memo from one of the senior Chalk River staff, however, complained bitterly about the loss of Goldschmidt, who had led their chemistry research:

> The morale of our chemists has always been adversely affected by the lack of exchange of information. We have been forced to do work which we know has been done already. The "purging" of the leader of the group can hardly be expected to make for improved morale.
>
> In spite of the fact that the chemistry of 49 [i.e. plutonium] was well worked out, we were given little information other than a few vague hints from time to time. The result has been that we have been obliged with a group of about 40 men to do what the Americans did with several thousand….The position therefore is that the "high command" refuse to give us help on 49 Chemistry, and as soon as we are well on the way to doing the job for ourselves insist on firing the man who has directed the work….
>
> Finally, I should like to point out that we have always been treated as the poor relation in this project, and I anticipate great difficulty in attracting good men to the project unless we can reach an international position which enables us to have some self respect.[44]

Jules Guéron, for his part, asked reasonably, if meekly, for "clear cut indications as to the nature and extent of the secrecy regulations to which I am still committed," and what he would be able to take to the new French Commissariat à l'Énergie Atomique.[45] The French program was to remain isolated from work in the USA, Canada, and Britain after the war, largely because of the pro-communist allegiances of key workers such as Joliot. But such security concerns were to remain problematic for Canadian workers, too, inhibiting both collaboration and independence through the 1950s. The American influence thus shaped the composition of Canada's interdisciplinary teams of nuclear specialists.

This administratively-decreed separation helped to create a proto-profession along clearer national lines. In the USA, foreign nuclear workers were quick to adopt American citizenship, particularly in light of suspicions of their allegiances; Eugene Wigner, Edward Teller, Leo Szilárd, and Enrico Fermi were prominent examples between 1937 and 1944.[46] Postwar contributions to nuclear

[43] James Chadwick to C.J. Mackenzie, letter, 8 January 1946, LAC RG77 Vol. 283.

[44] Anonymous to C.J. Mackenzie, memo, 24 December 1945, LAC RG77 Vol. 283.

[45] Jules Guéron to C.J. Mackenzie, memo, 13 December 1945, LAC RG77 Vol. 283.

[46] Some native-born Americans faced equally fervent security scrutiny. The best-known case was Robert Oppenheimer, Director of Los Alamos, who lost his security clearance on weapons projects in 1954 owing to claimed links to communist organizations during the 1930s. See, for example, Jeremy Bernstein, *Oppenheimer: Portrait of an Enigma* (London, 2004).

research and development in Germany, on the other hand, were actively stifled by the prohibition of such activities by the Allied powers.[47]

The episode surrounding the French scientists highlights the issue of respect and comparative judgements of national contributions to the project, which were only hinted at publicly. These, too, influenced national differences in the nascent profession. For example, Arthur Compton, director of the Met Lab which had been responsible for designing American wartime reactors, commented a decade later that "Canada's principal contributions to the atomic project during the war were the mining of uranium ore in the Great Bear Lake region and the supplying of needed uranium materials."[48] The on-again, off-again cooperation, soured by security concerns, mistrust about postwar commercialisation, and dismissive judgements, played its part in accentuating distinct national identities for nuclear engineers.

III. Chalk River for Canadians

At war's end, the Anglo-Canadian project at Chalk River offered the most propitious international site for continued nuclear research. As the Little Boy and Fat Man bombs were dropped on Japan, the first Canadian pile was in its final stages of preparation. The American centres, with their uneasy merging of industrial expertise with academic scientists, had no immediate plans beyond the Manhattan Project; Britain was developing plans for research and atomic bomb development, but as yet had no centres. By contrast, Chalk River was just coming into its own. Despite the repatriation of many of the non-Canadian participants, C.J. Mackenzie was impressed by how easily workers at the National Research Council, and its Chalk River staff, made the transition from wartime to peacetime activities.[49] This continuity, aided by the heterogeneous profile of committed scientific and engineering personnel, undoubtedly gave the Canadians an early postwar advantage over their British and even American counterparts.

Dominated by security concerns, the postwar environment rapidly differentiated the new subject of nuclear engineering in each country. The fitful wartime Manhattan Project collaboration between the UK, USA, and Canada shaped their respective postwar programs. In part to encourage further sharing of information, Anglo-Canadian administrators had given American counterparts unfettered access to information in 1944 and 1945. As administrator Lesslie Thompson reported, a "Special Secret Committee" established in February 1945 allowed "the Trust, US Military Intelligence and the like to have direct information on

[47] In early 1946, Allied Control Law 25 decreed that research in nuclear physics and reactor construction could not be undertaken in Germany or Japan. Although the law was relaxed four years later, experimental research remained off-limits in those countries until 1955.

[48] Arthur Holly Compton, *Atomic Quest: A Personal Narrative* (Oxford, 1956), p. 194.

[49] C.J. Mackenzie, *The Mackenzie-McNaughton Wartime Letters* (Toronto, 1978), p. 144.

what was being done in Canada… In addition, secret reports on the work done in Canadian laboratories on the development and improvements in analytical techniques and so on have been circulated."[50] Yet even this lopsided openness began to disappear within months. A secret cable immediately after the Japanese bombings defined postwar US censorship policy:

> Nothing may be written, discussed or used in any media of publication on the following.
> - Specific processes, formulas and mechanics of operation.
> - Stocks, location of stocks, procurement of stocks and stock consumption.
> - Quality and quantity of production of active material.
> - Physical characteristics of the weapon and methods of using it.
> - Speculation in the future development of the processes for military purposes.
> - Information as to the relative importance of the various methods or plants or of their relative functions or efficiencies.[51]

The policy censored more than bomb-making. In effect, it capped the fragile young field of nuclear engineering. C.J. Mackenzie and John Cockcroft rather helplessly recommended that Canada and the UK follow the same policy.

The 1946 McMahon Act in the USA even more dramatically closed off sources of information and personnel to the new British and Canadian programs. No British or Canadian workers had been permitted to visit the Hanford site — the most secret of American installations — and the design principles and practicalities of its plutonium-producing piles were learned piecemeal and second-hand. Not only was expertise still secret; it had to be reinvented at each national site and passed on by unformalized routes.

The McMahon Act further restricted the formal release of information. Mackenzie complained to C.D. Howe that information flow was in one direction only: the Americans released information to the Canadian company Eldorado about uranium processing in exchange for badly-needed raw ore, but "in spite of a strong case and an active campaign for cooperation on the part of the American group on reactor design, up to the present time we have had no concessions whatsoever."[52]

Canadian access to postwar American sites was further restricted. Beginning in 1948, requests by Canadian scientists to attend training courses on isotopes at Oak Ridge had to be channelled from Chalk River successively to the Department of External Affairs, the Canadian Ambassador in Washington, and the US State Department, which then sought security clearance from the FBI,

[50] L.R. Thomson to C.J. Mackenzie, letter, 1 October 1946, LAC RG77 Vol. 283.
[51] "Statement on US censorship policy," memo, 13 August 1945, LAC RG77 Vol. 283.
[52] C.J. Mackenzie to C.D. Howe, letter, 15 August 1952, LAC MG30-B122 Vol. 3.

because the Americans mistrusted Canadian security procedures.[53] One outcome of the diplomatic and security obstructions was a tightening of security regulations in Canada and at Chalk River in particular. The site retained its wartime status as a closed facility accessible only to cleared visitors. As interest grew, security rose: the Canadian press was refused access, and the editor of *Nucleonics Magazine*, the first American publication in the field, was even more summarily dismissed.[54] The clamp-down apparently surprised and insulted British colleagues, too. David Keys, vice president of the project, was compelled to reassure John Cockcroft that the clearance procedures applied equally to British, Americans, and Canadians.[55]

As a consequence, the postwar context and new forms of technological censorship curtailed international collaboration and accelerated intellectual divergence. In the months after the war, the truly international Montreal Group had been filtered into an Anglo-Canadian team, as French workers were dismissed under American pressure. With the subsequent McMahon Act, American collaboration ceased even before British nuclear workers had all been repatriated from Canada. And as "atomic spy" fears escalated, security restrictions divided even the Canadians and British.[56] The atomic energy projects became increasingly isolated, screwed down, and incestuous on the national scale.

While security threatened to stifle the new field of atomic energy in all three countries, so too did lack of expertise. With the sudden departure of the French workers at the end of the war and the more gradual planned transferral of most of the British workers, the Montreal Laboratory was closed in June 1946, with all remaining employees relocated to Chalk River. Most of those British workers went to the new Atomic Energy Research Establishment at Harwell, directed by John Cockcroft.[57] Despite the appeal of atomic energy, new Canadian workers, deterred by secrecy and relatively underpaid posts, were hard to attract to the geographically isolated Chalk River.

Cockcroft, sounded out about accepting the new post in April 1945, accepted the directorship that October. His sudden recall to Britain led to an anxious

53 "Visits to scientific establishments ? Oak Ridge Institute," LAC RG25-B-2 Vol. 2143.

54 D.A. Keys to Editor of *Nucleonics*, letter, 23 April 1951, LAC MG30 B59 Vol. 4.

55 D.A. Keys to J. Cockcroft, letters, 17 July and 8 August 1951, LAC MG30 B59 Vol. 4. Security nevertheless relaxed considerably from mid-decade; during the 1958-59 business year, for example, there were over 4300 visitors, including some 1500 "business" visitors along with 700 students and members of local clubs.

56 The September 1945 revelations by Igor Gouzenko, a Soviet cipher clerk in Ottawa — which implicated Allan Nunn May (1911-2003) of Chalk River and Klaus Fuchs (1911-1988) of the former Montreal Group and led to the arrest of over three dozen suspects in Canada — were an important precedent for the McMahon Act and in shaping the Canadian reaction to regain American confidence. For an impression of contemporary anxieties, see Bernard Newman, *Soviet Atomic Spies* (London, 1952).

57 For the official history of the British postwar project, see Margaret Gowing and Lorna Arnold, *Independence and Deterrence: Britain and Atomic Energy*, Vol. I: *Policy Making, 1945-52* (London, 1974) and Margaret Gowing and Lorna Arnold, *Independence and Deterrence: Britain and Atomic Energy, Vol. II: Policy Execution, 1945-52* (London, 1974).

search for a Canadian replacement. The best candidate, Walter Zinn, who had worked closely with Fermi in Chicago's Met Lab on reactor design during the war, declined the offer from Mackenzie despite assurances that "the Chalk River project will be completely divorced from petty political interference, and the staff is not under the Civil Service Commission nor its control vested in any department of Government." Mackenzie further confided:

> We are particularly anxious to get a Canadian-born director, as the project is going to be completely Canadian in every respect. We will probably have in the future British teams of scientists who come to us as visitors, but there will be absolutely no administrative control or direction from Britain and the teams will be at Chalk River as guests and we hope teams from the United States will be there in the same capacity.[58]

In reality, the NRC Director was aware of hemorrhaging staff levels at Chalk River and the difficulty of engaging competent replacements owing to salary levels lower than in the USA. The incentives were not merely financial, though: Zinn intimated that "the Americans put terrific pressure on him, pointing out that he was the only man with experience in designing and operating medium-sized piles, that he had been in the American show from the start, knew all the inside dope, and had a responsibility, particularly as he had become a naturalised citizen."[59] Although Mackenzie's claims to Zinn made a strong case for a unique Canadian perspective on atomic energy development, instead he accepted W. Bennett Lewis, a British nuclear physicist who had directed radar work at the Air Ministry Establishment during the war, to succeed Cockcroft as Director of Research.

With the evaporation of the Montreal Laboratory and its unique collaborative team, Chalk River became the home of what was now referred to as the "Atomic Energy Project," under the wing of the National Research Council. The return of some of the wartime scientists to their academic posts meant that Chalk River could more coherently support the integration of science and engineering specialists. For Mackenzie, it fulfilled a desire to model postwar Canadian research on what he saw as wartime British and American models. As Chair of the War Technical and Scientific Development Committee, he had argued in 1943 that "Canada should have strong research groups tied in to the related industries which also should maintain research establishments," and that "the UK appreciates the value of research and has established a large number of research stations under the Admiralty, the Ministry of Aircraft Production, the Dept of Scientific and Industrial Research, etc and has appropriated very large sums for their activities. In the US also very large amounts are being spent on

[58] C.J. Mackenzie to W. Zinn, letter, 17 April 1946, LAC RG77 Vol. 283.

[59] C.J. Mackenzie to J. Cockcroft, letter, 1 October 1947, LAC RG77 Vol. 283.

scientific research." In short, the theme of Chalk River would be government-funded, large scale research — a kind of super powered National Research Council.

In fact, the postwar Atomic Energy Project began to dominate the NRC budget and administration. Moreover, it seemed ripe for transition from research to a more immediate application — even if that application was not yet identified. Mackenzie noted that "atomic energy developments are at the stage where venture money will pay the same sort of dividends as did radar and our other war activities."[60] As a result, in 1952 a new Crown Corporation, Atomic Energy of Canada Limited (AECL), took over the responsibility from the NRC of shepherding these activities. Mackenzie shifted roles, resigning from Directorship of the NRC to lead the new organization until his retirement in 1953. The Canadian government took the opportunity to further consolidate activities: the new president of AECL was W.J. Bennett, Director of Eldorado Mining and Refining, which had been nationalized as a Crown Corporation in 1944 as the principal supplier of uranium to the Allies, and was later to merge with AECL itself.

IV. A Canadian Style of Development

The new organization could more actively promote a new field, new design principles, and new specialists. Chalk River's initial responsibility was reactor design, and the single-minded focus on heavy-water reactors offered a promising development program. The first Canadian reactor, the ZEEP (Zero Energy Experimental Pile), had been conceived in 1944 as a small-scale information-gathering reactor. It provided the experience necessary for a much larger heavy-water reactor, the NRX (National Research Experimental, 1947), which became the most intense international source of neutrons into the 1950s and so an important resource for the British and American researchers, too.[61]

The various trade-offs relied on understandings beyond the ken of conventional engineers. Engineering decisions based on nuclear knowledge had profound effects on design. The Canadian heavy-water reactors highlighted a distinctive design aesthetic that had been inherited from the scarcity of resources and cloistered research during the war: what W. B. Lewis called "neutron economy."[62] He argued that, given the expense and possibly limited supply of urani-

[60] C.J. Mackenzie to C.D. Howe, letter, 15 August 1952, LAC MG30-B122 Vol. 3.

[61] At Harwell, the GLEEP (Graphite Low Energy Experimental Pile, 1947) and BEPO (British Experimental Pile Zero, 1948) research reactors were test-beds for investigating reactor properties. And by 1950, Britain also had two plutonium production piles at Windscale, Cumbria, equivalent to the Hanford facility, but using air-cooling instead of water-cooling. Argonne National Laboratory in Illinois began testing a prototype reactor for submarine propulsion at about the same time and, a year later, the National Reactor Testing Station in Idaho began operating the more innovatory EBR-1 (Experimental Breeder Reactor).

[62] Ruth Fawcett, *Nuclear Pursuits: The Scientific Biography of Wilfrid Bennett Lewis* (Montreal, 1994), pp. 94-95.

um, it was necessary to employ every possible neutron for useful production of fissions, heat, and electrical power.

Design elegance was a luxury that Canadian engineers uniquely could afford. Unlike postwar Britain and the USA, Canada did not pursue atomic energy for weapons development — or at least not directly. As NRC director Mackenzie noted to James Chadwick, "our government has suggested that they are not interested in work on the bomb, and we in Canada have never received a particle of information in connection therewith."[63] Nevertheless, as the wartime Montreal Laboratory members had realized, their heavy-water reactors would generate plutonium at least as well as their American graphite-based counterparts. Plutonium production was the sole purpose for the American Hanford piles and the postwar British Windscale piles. Plutonium could itself be used to power reactors, but it also had a high economic value in the postwar period, when the Americans and British were struggling to produce quantities sufficient for a militarily useful stockpile of atomic weapons. For Canadian designers, even more than their former British colleagues, this value was explicit and readily calculated: Mackenzie, first as president of the NRC and subsequently as president of AECL, secretly negotiated a price for Chalk River plutonium with the Americans, and approved only miserly research samples for the British. The original negotiated deal agreed that the USA would "buy all plutonium produced at Chalk River at a price between $170,000 and $180,000 per kilogram." C.D. Howe briefed the Canadian Finance Minister that "a price of $145,000 per kilogram will permit the government to amortize the new plant over ten years, and… a price of $175,000 per kilogram would allow the Government to amortize past expenditure as well as future expenditures over the same period."[64] Thus the next-generation NRU reactor ("National Research Universal") and plutonium separation plants were designed specifically with the intention of funding their operation and, it was hoped, the entire Canadian program, by sales of plutonium. Awash with research money, Canadian nuclear workers remained ignorant of the supporting economics.[65]

[63] C.J. Mackenzie to J. Chadwick, LAC RG77 Vol. 283.

[64] C.D. Howe to D.C. Abbott, letter, Ottawa, Ontario, LAC RG29-F-2 Vol. 5361. Owing to its American commitments "for all fissile material with the exception of the amount we require for our own use," Mackenzie was hesitant to supply the British program with 2 kg of plutonium as they requested [Mackenzie to Cockcroft, letter, 26 May 1952]. He saw plutonium as a solution to long-term funding of Canadian work: "I am quite sure… that plutonium will always be valuable, and the next plant we plan, after our present production unit [NRX] will be a power production unit with two main products — power and fissile material. On this basis we think the economics will eventually work out satisfactorily": see C.J. Mackenzie to R. Newton, letter, 19 December 1952, LAC MG30-B122 Vol. 3. Britain adopted the same course with its Calder Hall and Chapelcross power stations, which replaced Windscale as plutonium producers.

[65] Because it contradicted the public Canadian policy of abstaining from nuclear weapons work, the plutonium economy of the Chalk River program was confidential. MacKenzie noted, 'I am particularly anxious that all correspondence on the policy level, covering such things as the exchange of Plutonium, barter arrangements of major kind, and any other matters which I should discuss with the officials of the Government or the Control Board, should be sent to my Ottawa office. I do not wish

More openly, Chalk River reactors produced two other products of scientific and economic value. First, they generated intense fields of neutrons, which could be used to irradiate materials to test the effects of radiation and so develop biological and engineering applications for atomic energy.[66] Access to irradiation experiments could be bartered and sold internationally. Second, this irradiation by neutrons generated new radioactive isotopes that could be used for applications such as tracers in medical diagnosis and sources for radiation therapy. Both applications attracted visiting researchers, generated income, and boosted national status.[67]

But who guided the research goals, and to what end? While reactor research was expected to yield fundamentally new scientific information, it fitted poorly with pre-war scientific culture, in which Canadian projects had been small and short-term. Chalk River promoted an open-ended form of science on the industrial scale, but commercial applications initially were unclear. Design principles and scientific insights would remain secret, being disseminated tardily, if ever, in the open scientific literature.[68] How, then, could the Crown corporation serve Canadian science and industry?

Chalk River, like its American and British equivalents, pursued unclear objectives in its postwar atomic energy program. While the prospect of generating useful electrical power was recognized, none of the institutions promoted this as a realistic goal during the immediate postwar years.[69] Instead, in each country the state-funded labs were protected by an umbrella of secrecy and made responsible for investigating the potential of atomic energy. Strategic applications were nevertheless evident. In the USA, the Navy became an early client for propulsion systems, and, in Britain, bomb development absorbed resources. At Chalk River, by contrast, the shunning of military applications and sponsorship placed the Canadian Atomic Energy Project in a more precarious but curiously favoured position, protected by the status afforded by the new field and by the seductive but intangible promises of future applications. Indeed, this period, with little governmental interference and "scientific self-government," was referred to by some Canadian workers as "the Golden Age."[70]

such sensitive matters of policy to get into the general records at the plant' [C.J. Mackenzie to J. Cockcroft, letter, 23 May 1952, LAC MG30-B122 Vol. 3]. See also Wilfred Eggleston, *Canada's Nuclear Story* (Toronto, 1965), pp. 231-3, 241.

66 Neutrons were a key resource for postwar nuclear physicists, and were exploited effectively by Canadian researchers. Bertram Brockhouse (1918-2003), for example, working at Chalk River between 1950 and 1962, eventually was co-recipient of the Nobel Prize for his research on the scattering of neutrons as a probe of nuclear structure and magnetic order.

67 Radioisotopes became a small but profitable by-product of reactors in Canada, where AECL created a Commercial Products Division to market them.

68 On the construction of "atomic secrets," see Gregg Herken, "'A Most Deadly Illusion': The Atomic Secret and American Nuclear Weapons Policy, 1945-1950," *Pacific Historical Review*, 49 (1980), pp. 51-76.

69 Low estimates of raw uranium resources were an important reason for restricted interest in long-term nuclear power generation until the early 1950s.

70 Paul A. Redhead, "The National Research Council's impact on Canadian physics," *Physics in Canada*, 56 (2000), pp. 109-21; quotation p. 112.

Given this unique combination of cosseted yet unfettered research directions, Canadian workers were remarkably diffident in their early predictions. As in the National Research Council from which it sprang, Chalk River technologists and scientists could coexist, exploring both fundamental questions and novel engineering directions.[71] Short-term goals were neither appealing nor pressing. As the vice president and most senior scientific advisor to the project, David Keys damped down the enthusiasm of one correspondent in 1951:

> I believe it will be many years before power will be developed by such a process for commercial uses. When such plants are constructed, they will probably find application in special places where it is difficult to obtain power by any of the usual methods…My personal opinion is that nuclear power will be achieved but will supplement rather than replace any of our conventional sources.[72]

Ideas circulated but without taking root. As C.J. Mackenzie, at the helm of the Canadian activities, mused, it was a matter of confidence and politics as much as technological trajectory:

> Living in a young country where we are inclined to be optimistic, we feel that even with our present piles we are getting valuable operating experience every day, and by the time we have five more years' experience on our production piles and have available the results of development work now under way, we should know a great deal about power units a few years after the first one starts to operate.
>
> I do not believe it is of fundamental importance to try and set the date at which we can say we will enter the atomic power age. In my opinion, any such date can never be identified. The whole development will be a gradual one. In 1952 the most important thing, in my opinion, is to get a power production pile into operation at the earliest possible moment. If our statesmen and politicians get the idea that the useful application of atomic power is still half a century away, it will make it very difficult to get the financial support we need right now.[73]

Mackenzie's proposal to C.D. Howe urging the Canadian government to hail the coming of nuclear power was halted temporarily by the first major nuclear acci-

[71] The term "technologist" became popular in the postwar period, illustrating changing notions of how engineering and science inter-relate.

[72] D.A. Keys to C.C. Cook, letter, 5 September 1951, LAC MG30 B59 Vol. 4.

[73] C.J. Mackenzie to R. Newton, letter, 19 December 1952, LAC MG30-B122 Vol. 3.

dent: the overheating and radioactive breaching of the NRX reactor in December 1952.[74]

Only in 1954 did Chalk River administrators, still focused on the NRX research reactor and its pending successor, the NRU, commit themselves to developing nuclear power generation. David Keys, as scientific advisor to the president of AECL, observed that a feasibility project involving Canadian power companies (notably the Ontario Hydro Electric Power Commission) had begun, and needed to be seen to be in the game:

> In view of the fact that both the Americans and British are proceeding with the construction of plants to produce reasonable quantities of electrical energy from nuclear fission, it is important that Canada should also be considering such possibilities, since our scientists and engineers have made a very successful contributions to nuclear pile operations.[75]

These activities were again prompted, if not directed, by external decision-making. In 1955, exactly a decade after the war's end, the curtain of secrecy was raised: the International Conference on the Peaceful Uses of Atomic Energy was held in Geneva. This was the outcome of a political initiative by President Dwight Eisenhower in 1953, "Atoms for Peace," intended to turn American attention away from the loss of the nuclear weapon monopoly to the USSR and Britain. The Geneva conference, though, represented more than a commemoration or political act; at the level of nuclear workers, it witnessed a collective release of tension that was genuine and uncynical. Security concerns reduced significantly, and international sharing of nuclear knowledge was liberated after a decade of secrecy. It also marked and promoted the first serious attempts to create a new industry. The following year, the Calder Hall power station, the first significant and widely publicized civilian application of nuclear power, was completed next to the Windscale piles in Britain.[76] For each of the former allies, the wide-ranging atomic energy projects were recast as more focused nuclear power programs.

In this more open and commercially-oriented environment, W. B. Lewis became the champion of nuclear power in the Canadian program, later dubbed

[74] Mackenzie was not deterred by the accident: "I do not think anyone ever suggested that all attempts to develop aviation would be stopped by the crash of one plane, and I can see nothing in the incident at Chalk River to prevent our getting on with the development of industrial power. In many ways such accidents, although not very pleasant while they are occurring, do provide experience for future designs which could not be obtained in any other way." See C.J. Mackenzie to R. Newton, letter, 19 December 1952, LAC MG30-B122 Vol. 3.

[75] D. A. Keys, "Monthly report," March 1954, LAC MG30 B59 Vol. 5.

[76] The British achievement, operational over a year before the first American nuclear power station at Shippingport, was not the first example of US nuclear engineers being surpassed. The Board of Governors at Argonne National Laboratory complained in 1949 that "the best research pile is in Canada, and the second best one in England": see "Minutes of Board Meeting, ANL," 7 March 1949, University of Illinois archives, Urbana-Champaign, Illinois, USA, box 19.

CANDU.[77] In early 1962, Canada's first pilot nuclear power station, the NPD ("Nuclear Power Demonstration"), went critical in Rolphton, Ontario, just upriver from Chalk River itself. A joint project of AECL, the Hydro Electric Power Commission of Ontario, and Canadian General Electric, the NPD was the indicator of another phase change: the Atomic Energy Project and AECL had evolved into a new industry with high aspirations and a new type of technical labour.[78]

V. Disciplinary Identity

The preceding sections have discussed the administrative, political, and engineering contexts in which nuclear engineering expertise developed in Canada during and after the Second World War. To establish this new field, however, a supporting occupation and discipline were also required. In effect, the conventional apparatus of intellectual foundations, professional roles, and occupational niches had to be added. These crucial elements slowly emerged during the security-conscious postwar decade, and became hesitantly established in Canada only twenty years after the war's end.

Shielded by the context of isolated research and development, a coherent identity and training for nuclear workers appeared relatively tardily. For instance, in 1948, David Keys, as the chief scientific advisor for the Atomic Energy Project, was asked by the Canadian Navy to suggest appropriate college engineering courses for cadets "interested in the development of atomic power and research in the atomic bomb," and what mixture of "Engineering Physics, Electrical Engineering, Chemical Engineering, pure Physics or Chemistry" would be most appropriate. Keys' answer reflected his own background:

> Mathematics Honours, Mathematics and Physics, Honours Chemistry, or Engineering Physics, in that order. They then should proceed to graduate work in either Physics or Chemistry. Actually a man going into this field should have a good solid foundation in Science and although we have

[77] CANDU ("Canadian Deuterium Uranium"), was a unique technological choice based on the heavy-water reactor designs pursued by the Montreal Group and Chalk River during the war, with a provenance extending back to Joliot's group in pre-war France. Chosen in 1959 as the name of the first large power-generation reactor to be built at Douglas Point on the shores of Lake Huron, Ontario, CANDU was soon adopted as the name of the design type.

[78] The 200 MW CANDU reactor on Lake Huron at Douglas Point, Ontario was the first full scale power station, becoming operational in 1968. Canadian expertise was by then more dispersed: the AECL Nuclear Power Plant Division (NPPD, 1958) in Toronto, Ontario, was responsible for NPD and subsequent reactor designs; at the Whiteshell Nuclear Research Establishment (WNRE, 1963), near Winnipeg, Manitoba, new reactor designs were investigated. Design expertise was transmitted to the C.D. Howe Company, CGE and to India, which designed and constructed a series of power stations based on the CANDU design. On CGE, see Gerald Wynne Cantello, "The Roles Played by the Canadian General Electric Company's Atomic Power Department in Canada's Nuclear Power Program: Work, Organization and Success in APD, 1955-1995," (MA diss. Trent University, 2003).

> Mechanical, Electrical and Chemical Engineers, the research end is performed more by physicists and chemists than by engineers.[79]

Some colleagues were more effusive about new professional territory. B. W. Sargent at Chalk River fielded enquiries in 1953 from would-be engineering students, counselling one that "a graduate nuclear engineer can today practice his profession in Canada" at AECL and the C.D. Howe company (then responsible for building NRU, the latest Chalk River reactor). He envisaged two classes of employment: nuclear power plant operators working for power utilities, and designers and constructors of power plants.[80]

But such certified graduates did not exist and could not be produced. Formal nuclear training in Canada, like its nuclear power-generating program, trailed behind British and American counterparts — neither of which had open academic programs at the time. During the early postwar years David Keys noted a chronic "scarcity of available scientists and engineers in every field"; the availability of craft workers improved, but not for the scientific and engineering professionals.[81] Security concerns, the site's physical remoteness, and limited employment prospects further aggravated the shortage.

Faced with a shortage of skilled nuclear workers, Chalk River, by 1951 established night school classes to teach courses ranging from first-year university classes to the more advanced subjects of calculus, pile theory, and nuclear physics. This was not open training for new careers, however: it was aimed at upgrading existing technician and engineering staff, and was restricted to Chalk River workers who had passed the usual security procedures. Following Harwell's earlier example in England, AECL at Chalk River also employed summer students — some of whom eventually became permanent employees — and began regular training courses for its various professional and craft workers in 1958.[82] A year later AECL began to recruit publicly. Aimed at graduates of chemistry, physics, mathematics, biology, and chemical, mechanical, and electrical engineering — established disciplines, in other words — these efforts highlighted the opportunities in novel areas that still lacked occupational terms such as "operation of nuclear reactors," "biochemistry of nucleic compounds," "technology of reactor operations," "disposal of radioactive wastes," and "statistical studies on mutation rates." In particular, the brochures noted that "reactor

79 D.A. Keys to C.C. Cook, letter, 5 September 1951, LAC MG30 B59 Vol. 4.

80 B.W. Sargent to G.M. Everhart, letter, 4 November 1953, Queen's University archives, Kingston, Canada [hereafter cited as QU] Sargent fonds Series III Box 4 file 4.16. Bernice Weldon Sargent (b1906) had worked with G.C. Laurence in Ottawa on his chain reactor experiments from 1941, and was an early member of the Montreal group.

81 D.A. Keys, "Monthly report," August-September 1947, LAC MG30 B59 Vol. 5.

82 C.J. Mackenzie, LAC RG24 Box 5002 File 3310-50/7. In 1960, AECL further pursued the British model of training by instituting the Chalk River Reactor School, open to international students and making "the basic principles of such reactors available to those qualified engineers and scientists who desire to gain practical knowledge in their design and operation".

research and development presents problems for people with post-graduate training in engineering and nuclear physics and in mechanical engineering."[83] In short, the Chalk River site focused on three distinct tactics to obtain its needed nuclear specialists: upskilling of technical staff, indoctrination of undergraduate science and engineering students, and conversion of university engineering graduates.

Significantly, "nuclear engineers" went unmentioned, because there was nowhere in Canada to obtain suitable university training; technical college courses appear to have been equally absent. In 1953 McGill University had briefly offered an introductory extension course, but only five years later — after the seminal Atoms for Peace conference — Queen's University in Kingston, Ontario (some 375 km from Chalk River and 175 km from Ottawa, the two principal AECL sites), offered a one-year course in nuclear engineering launched by B.W. Sargent. Leading to a Diploma in Engineering (Nuclear), the course centred on "Nuclear Power Reactors, Nuclear Physics, Heat Transfer, Fluid Mechanics, Stress Analysis, Controls, Safety, Metallurgy, and Corrosion."[84] Students could select five courses from five domains: physics, chemistry, metallurgical engineering, electrical engineering, and mechanical engineering. On even stronger lines, McMaster University sought to become the major Canadian university for nuclear research and nuclear engineering training, building the first university reactor in the British Commonwealth in 1959. Significantly, both programs were fostered by men who had been active at Chalk River.[85]

Gaining direct support from Atomic Energy of Canada Ltd was nevertheless difficult. Following visits to AECL President W.B. Bennett and C.J. Mackenzie, one of Queen's organizers admitted "feeling rather depressed":

> I gathered that he had forgotten that he had been openly enthusiastic about our proposal a year or more ago. He now feels that good Nuclear Engineers are produced by experience in the field rather than by any formal training. Dr Mackenzie felt… that it would be much easier to obtain support for a program already under way than to launch a new one.[86]

[83] AECL, "The university graduate and Atomic Energy of Canada Limited," 1959, LAC MG30 B59 Vol. 8..

[84] B.W. Sargent, "file 4.1 Nuclear engineering," QU B.W. Sargent fonds, Series III Box 4. University courses in the USA and UK had begun only a year or two earlier, again triggered by the Atoms for Peace conference.

[85] The postwar university had grown from a Baptist liberal arts college and focused on nuclear topics under the influence of Harry G. Thode. Using the first mass spectrometer in Canada, Thode and his assistants there had contributed isotopic analyzes to the work of the Montreal Group during the war, and focused on radioisotope chemistry thereafter. Besides raising the research aspirations for the institution, Thode became principal of its science college in 1949 and then president of the university, thus establishing an academic base for nuclear science and engineering as a discipline in Canada.

[86] H.G. Conn to P. Mackintosh, letter, 2 January 1958, QU Sargent fonds Series III Box 4.

Not all of these difficulties were attributable specifically to nuclear engineering as a subject; academic ambitions were restrained. Good students had traditionally pursued advanced degrees in other countries. Postwar Canada had twenty-eight universities but, while a number of them offered master's level degrees, only two (University of Toronto and McGill University) had active research programs supporting doctoral degrees. As the pre-war president of the University of Saskatchewan had judged, "the University has no intention of preparing candidates for the Doctor's degree... It would be folly...to add another feeble graduate school to those that encumber the land."[87] By the late 1950s, swollen by war veterans and government funding, university undergraduate enrolment and programs had trebled, but graduate studies still lagged behind. Nevertheless, as nuclear engineering was being mooted as a new subject area in which Canadian inroads were well established, the idea of educating home-grown specialists seemed more plausible.

Not until 1961 did the new Canadian Nuclear Association (an industry-focused organization rather than a professional body) address technical education and training. It noted that a handful of universities now offered relevant courses, but that most were too narrow to accommodate the most suitable candidates — graduates of engineering physics — forcing them to enrol in either physics *or* engineering departments. But the fledgling nuclear engineering courses at Queen's and the University of Ottawa had already been suspended owing to lack of demand; indeed, the proponents at Queen's had been forced to vacate the building that housed their small "low energy pile" because no students at all had registered for the nuclear power engineering course.

There were fewer jobs in the industry than graduates. Both McMaster University and the University of Toronto highlighted the potential of the new field by appointing professors of nuclear engineering but compromised by building course choices around the small number of individual students to make up for their particular educational lacunae.[88] By 1966 an AECL report noted that "because there are so few university graduate students with the appropriate kind of academic training and orientation, the need for staff for the design and operation of nuclear reactors is being met at present by the hiring of graduates from foreign countries."[89]

[87] W. Murray, cited in Mel A. Preston and Helen E. Howard-Lock, "Emergence of physics graduate work in Canadian universities 1945-1960," *Physics in Canada*, 56 (2000), pp. 153-62; quotation p. 155.

[88] Canadian Nuclear Association, "Survey of Nuclear Education and Research in Canadian Universities 1961," QU, B. W. Sargent fonds, Series III Box 4. At the University of Toronto, Boris Davison taught reactor physics during the late 1950s. Davison had joined the Montreal Group in 1944 from the University of Birmingham, moved to Harwell in 1947 and back to Canada in 1954 following security concerns in Britain surrounding his Russian background ; see William J.L. Buyers, "Neutron and other stories from Chalk River," *Physics in Canada* 56 (2000), pp. 145-51. Davison's *Neutron Transport Theory* (Oxford, 1957) became a definitive academic text.

[89] AECL-PD-323, QU, W. B. Lewis fonds Box 12 file 11. As late as 1975, the situation had not changed materially: only the University of Montreal had established a Nuclear Engineering Department authorised to master's level, and the University of Toronto and McMaster University offered nuclear engineering options within their engineering undergraduate and master's degrees.

Unlike their British counterparts, then, Canadian educators defined new specialist programs as "nuclear engineering." But they struggled to define the content of their curricula and faced perennial questions of viability. At best, education and training programs surfaced intermittently to satisfy the unpredictable demand for nuclear workers in Ontario and Quebec.

VI. Occupational Identity

Despite marginal academic success in training nuclear specialists by means of special courses and new university programs, another route was effective in generating a self-aware first generation of nuclear specialists. On-the-job training via AECL and industrial collaborations yielded a peculiarly adept breed of nuclear specialist. With the tardy and irregular availability of university programs, however, the status and uniqueness of engineers and other technical workers was blurred. This mixing of disciplines can be traced to the pre-war NRC heritage, which had encouraged a culture of coexistence between scientists, engineers, and technicians, but was considerably extended by AECL-funded development projects.

During the late 1950s, the planning of nuclear power stations brought AECL workers into contact with traditional engineers in the power industry. The development of power-generating nuclear reactors required expertise that had not developed in the wartime Montreal Lab and postwar Chalk River research cultures. To make the transition to more pragmatic industrial collaboration, Canadian General Electric (CGE) — chosen to embark on the preliminary design of the NPD reactor in 1954 — was staffed with a handful of key AECL engineers to provide key nuclear experience. In a reciprocal fashion, the Ontario Hydro-Electric Power Commission ("Ontario Hydro"), also collaborating with AECL on the NPD demonstration reactor, seconded several of its engineers to CGE. With shared experience gained in design offices, in suppliers' factories, and with reactor prototypes, these conventionally-trained engineers acquired practical expertise to train subsequent industrial workers. Thus electrical, mechanical and civil engineers were reshaped into the first Canadian nuclear engineers.

This specialist experience was also disseminated by fostering new skills and knowledge at the level of companies' competences. By promoting a policy of ensuring at least two suppliers for every nuclear-related component, AECL and Ontario Hydro administrators encouraged technology transfer through development and supply contracts. The addition of these new design, fabrication, and occupational skills was accommodated in new "boundary environments" that brought together traditional technical workers with the AECL-trained counterparts.

Besides this particular context of expanding working cultures and mixed technical environments, Canada differed further from both the USA and Britain in the way it categorized its nuclear workers. American nuclear engineers and scientists had congregated in policy/lobby organizations after the war and a professional society during the early 1950s. British workers, on the other hand, were classed according to wartime Civil Service norms defining technical categories; for them, the "nuclear engineer" did not exist in any formal sense. In neither country was the formation of new trade unions or labour categories officially promoted.[90]

In Canada, by contrast, the National Research Council's Chalk River site encouraged its workforce to unionize; by 1947 many of the rate workers (that is, non-professional tradesmen paid by weekly wage) joined union locals affiliated with the American Federation of Labor (AFL). Following chronic complaints about inadequate wages there was a more concerted effort after the creation of AECL in 1952, and the new organization accommodated most of its workers in existing unions of the Canadian Labour Congress.

Unlike in the UK, though, the Canadian Atomic Energy Project was not averse to distinguishing its employees with fresh identities. Thus the Atomic Research Workers' Union (1952), Association of Atomic Energy Technicians and Draftsmen (1953), Atomic Energy Workers' Union (1957), and Chalk River Nuclear Process Operators' Union were founded to represent AECL employees. They were marked out principally by their circumscribed working locales (initially at Chalk River only, and later with AECL sites at Ottawa and Pinawa, Manitoba) but much less by novel job functions. Where British nuclear craftworkers were accommodated as "general workers," their Canadian counterparts fell into novel, and, one might presume, status-bearing categories. The unique activities and specialists associated with AECL were not in doubt: the Canada Labour Relations Board listed the "nature of the employers' business" as "creation of atomic energy."[91]

Remarkably, however, these seemingly exclusive bodies represented widely disparate skills that were not explicitly tied to the peculiar context of nuclear radiation. Thus the Atomic Research Workers' Union accepted AECL employees classified as "bricklayer, painter, stores counterman, labourer, seamstress, laundry operator, process operator and process trainee, maid and animal attendant, excluding foremen, employees of higher rank, salaried personnel, office staff, scientist staff, guards, fire-fighters and hospital nurses."[92] The Ottawa Atomic Energy Workers — associated with the AECL Commercial Products Division, which focused on radioisotopes — included "carpenter, painter, tool and die maker, electronics technician, lead burner, machinist, trades helper, welder, shop boy, labourer, stores counterman, inspector, sheet metal worker, truck driver" — indeed, all those employees who were not numerous enough to be fitted readily into an existing union. AECL, in conjunction with union representatives, was

[90] Sean F. Johnston, "Implanting a discipline: the academic trajectory of nuclear engineering in the USA and UK," *Minerva*, 47 (2009), pp. 51-73

[91] "Atomic Research Workers Union, No. 24291, Applicant ? and Atomic Energy of Canada Limited, Respondent," LAC RG145 Vol. 114 File 766:336:52.

[92] "Ottawa Atomic Energy Workers, Local No. 1541 (CLC), Applicant - and Atomic Energy of Canada Limited, Ottawa, Ontario, Respondent (Commercial Products Division)," LAC RG145 Vol. 160 File 766:811:57.

careful not to usurp the territory of existing craft unions. In short, the Canadian labour groupings that were most clearly tied to nuclear craft-work had the weakest occupational identity and yet probably the highest prestige to outside eyes.

Such labelling was slower to develop for specialist salaried technical workers at AECL. The Association of Atomic Energy Technicians and Draftsmen split in the mid-1950s to form a separate craft union for draftsmen. The technicians, dissatisfied with their representation by the American Federation of Technical Engineers and impelled by "a feeling of national pride in the atomic Energy Project and a resultant preference for a Canadian union," petitioned in 1956 to form a Canadian Association of Nuclear Energy Technicians and Technologists. Their occupational uniqueness was not in doubt: they were "all employed at Chalk River in the following fields of nuclear energy: (1) Biology and Health Physics; (2) Chemistry and Metallurgy; (3) Physics Research; (4) Reactor Research and Development; (5) Operations Division (Reactors NRX and NRU); and, (6) Engineering."[93] Through these respective roads to union representation, then, Canada highlighted but did not always clearly characterize its nuclear workers, while Britain, on the whole, hid them.

If government-mediated identities of nuclear specialists were distinct and nuanced, public understandings were more easily directed to monochrome views. While the hype of atomic energy was evanescent and ultimately uncon-

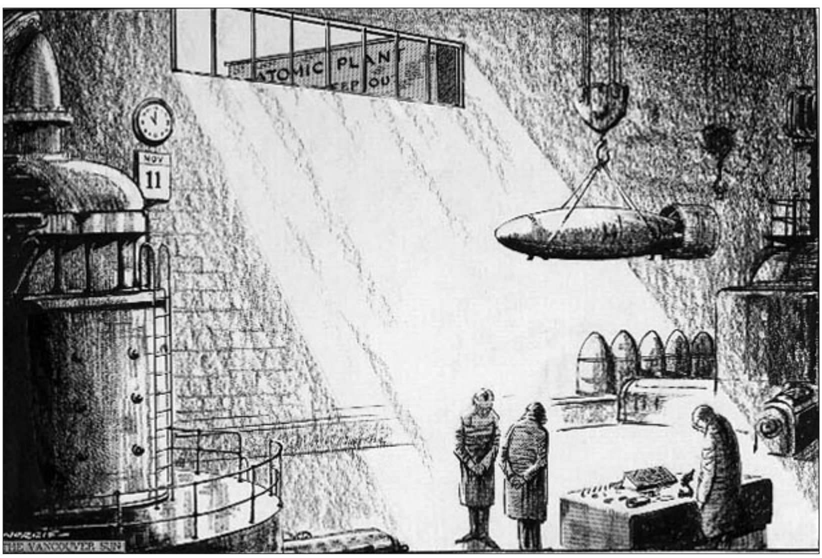

Figure 1: Guilt by perceived association for atomic workers [L. Norris, *Vancouver Sun*, 10 November 1954.] Credit: Library and Archives Canada, Acc. No. 1988-243-30. Copyright: Estate of Leonard Norris. Published by permission.

[93] "Canadian Association of Nuclear Energy Technicians and Technologists, Local 1568, CLC, Applicant — and Atomic Energy of Canada Limited, Chalk River, Ont., Respondent (Technicians)," LAC RG145 Vol. e identification of Biology as a significant discipline also contrasts with British organization of the UKAEA, which employed few biologists.

vincing, the demonstrated dangers of atomic weapons provided a readily absorbed identity. While the American and British governments acknowledged their programs of nuclear weapon development, they and Canada were decidedly less forthcoming about the purpose of their research and development facilities at Argonne, Oak Ridge, Harwell, and Chalk River. Bomb-making or not, public understanding of the Canadian nuclear project was that its secretive nature allied it to military interests and activities (Figures 1 and 2).

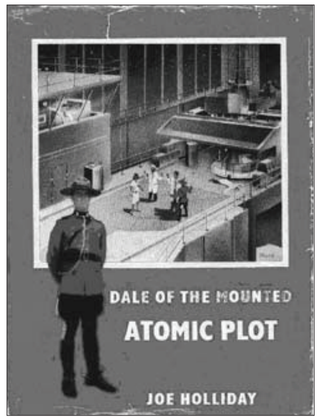

Figure 2: Atomic espionage for popular consumption [Joe Haliday, *Dale of the Mounted: Atomic Plot*. Toronto, Thomas Allen Ltd. (1959)]. Reprinted by permission of the publisher, Thomas Allen, Limited.

VII. Conclusion: Canadian Engineers for the Canadian Context

I have argued that the early environments of nuclear development shaped a distinct national trajectory of design and professional identity in Canada. Thus key researchers, moving from France to Britain and thence to Canada, brought with them a preoccupation with one reactor concept: the heavy-water reactor. The Montreal Lab was founded on the heavy-water brought from France via Norway; its proximity shaped the group's goals. But Anglo-Canadian efforts at the wartime Montreal Laboratory and Chalk River were also shaped by lack of resources, notably of graphite and enriched uranium, owing to American security concerns within the Manhattan Project. Both during and after the war, then, the growing body of knowledge and particular technical expertise shaped and narrowed options for further research, making heavy-water and "neutron economy" the enduring central threads of the Canadian nuclear experience.

Engineering designs were also influenced critically by economics, which was specific to national contexts. British reactor feasibility was determined, for example, by its cost relative to coal-generated electricity. If nuclear power could be forecast as being marginally cheaper or available for longer than coal, then power plant design, construction, operation, and maintenance were judged worthwhile. The relative cost included considerable uncertainty: materials in nuclear reactors were being operated in novel conditions of temperature and irradiation. Unfamiliar dangers, such as degradation of materials or accidents of radiation release, were acknowledged but as yet largely unpredictable. And the adjustable parameter in that economic equation was the sales cost of the plutonium produced by the reactor, dubbed the "plutonium credit" in Britain. In Canada, such economic concerns included additional energy options, and the plutonium credit was a significant hidden variable in determining the design options pursued.

Just as Canadian reactor designs were a defining national feature, so too were the characteristics of the nuclear workforce. Nuclear workers were isolated by international secrecy in atomic energy and shaped by particular national forces. The institutional cultures of the National Research Council and Imperial Chemical Industries both strongly flavoured wartime Canadian nuclear engineering. As an NRC project and then a spun-off Crown Corporation under the unusually single-minded direction of C.J. Mackenzie, and then W.B. Lewis and David Keys, the atomic energy project fostered a relatively comfortable collaboration between engineers and scientists to meet changing national goals. Chalk River, as the isolated nucleus of the discipline and occupation in Canada, also promoted goals distinctly different from, and more coherent than, its wartime allies. Government policy decreed that Canadian nuclear workers in the postwar years could concentrate on scientific and engineering research founded on reactor development, neutron properties, and radioisotopes instead of bomb fabrication and development. Canadian university engineering departments sought to expand into academic territory guaranteed by a new national industry. In close association with Chalk River personnel, they launched degree-granting programs during the late 1950s and early 1960s to define new academic terrain. Canadian labour laws, interpreted in an environment in which atomic energy represented expertise that boosted national status, permitted the self-definition of these new technical specialists. The result of these disparate factors — uniting limited resources, isolated knowledge, and an active but atypical pool of technical workers in a unique working context — was a distinct national field.

Sean Johnston is Reader in History of Science and Technology at the University of Glasgow. His research interests focus on the history of relationships between science, technology, and technical communities, especially the emergence of new technical professions and the consolidation of new scientific knowledge.