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THE ORGANIZATION OF SCIENCE FOR WAR:

THE MANAGEMENT OF CANADIAN RADAR DEVELOPMENT, 1939-45*

David Zimmerman**

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The effective utilization of advanced science by the Western Allies during the Second World War was an important factor in the defeat of the Axis Powers. It has been recognized that Allied success in adapting scientific knowledge to military requirements was more the result of management and organizational techniques than of any technological superiority. While both British and American wartime scientific organization has been examined, there has been little or no work done on the Canadian scientific management structure.

The radar programme was in size and scope the most important of Canada's scientific contributions. The institutional development necessary to manage the increasing team of scientists, engineers, politicians, soldiers, workers and businessmen set trends that governed all other scientific endeavours. An examination of the evolution of the radar programme's management structure shows the increasing importance of the civilian of the civilian scientist in the military and the services' reaction to it. It also forces the re-evaluation of the role of individuals such as C.J. Mackenzie, and of institutions like the National Research Council of Canada (NRC), the Department of Munitions and Supply and the Chiefs of Staff Committee. Most significantly, this study also points to the need for a major revision of the current interpretation of the success of Canada's scientific war. Historians have tended to be non-critical with their praise, and part of their difficulty has been the failure to recognize the bureaucratic structures that were created to administer the radar programme. As we shall see, this provides vital insights into understanding the root causes of the difficulties in research, development and production of radar within Canada.¹

The origins of the radar programme can be traced no further than March 1939 when Great Britain asked the Dominions to each send a physicist to learn of the top secret device's existence. The Department of National Defence (DND) did not have a physicist nor much else in the way of technical staff. All three services had been crippled by extremely

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small budgets and relied almost completely on the British for their technical and scientific requirements. What little military research that had been undertaken within Canada was done under contract with the National Research Council, the government civilian research centre, and it was to this institution that DND turned to enable it to share British knowledge.²

By 1939 DND-NRC relations were extremely close. The extensive cooperation between the RCAF and the council's aeronautical laboratories and the creation of military/NRC advisory panels are the best examples. The strongest bond between DND and NRC was through the President of the latter, Major-General A.G.L. McNaughton, who had been Army Chief of Staff just prior to assuming his duties in June 1935.³

While this close Council-Defence Department relationship was undoubtedly the primary reason NRC was chosen, another factor was that it was also the only scientific institution in the country familiar with military security procedures. The British had stressed to DND the need to preserve secrecy. Since 1938 NRC physicists of the Radio Branch had been engaged in classified research on Cathode Ray Direction Finding (CRDF), a radio navigation aid.⁴

McNaughton sent to Great Britain the head of the Radio Branch, Dr John T. Henderson. It was a good choice, for Henderson was probably the best qualified Canadian for the mission. A research physicist, Henderson had extensive experience with the CRDF, a technological cousin of radar, and thus was familiar with the basic hardware and security procedures. Upon his arrival in April, Henderson, along with his RCAF assistant S/L F.V. Heakes, sent back a series of enthusiastic letters and reports outlining the fundamental principles of radar and its possible use in the defence of Canada. Henderson realized that the NRC would play a major role in the introduction of radar into the Canadian arsenal, a role made more important by blunt warnings that no British radar equipment would be available.⁵

McNaughton realized the gist of Henderson's messages better than did Henderson himself and saw the need to clearly define NRC-DND relations. For this purpose he met with the Chief of Air Staff, Air Vice-Marshal Croil, in July 1939. McNaughton later summarized his ideas on NRC-DND relations to Henderson:

... the part which the National Research Council might usefully play in aid to the Department of National Defence was the organization and training of a small nucleus staff to the point that they could be available to the Defence Department to undertake research work required to fit the English proposal to Canadian conditions; that this staff would act as consultant to the Defence Department, undertaking research on problems as they developed. This staff could also assist the Defence Department in the

installation of the apparatus when received from England.⁶

Croil accepted the general's proposals and they were formalized in an NRC report of 25 July which became the basis of DND-NRC relations during the war.⁷

Despite these early organizational moves there was little progress in Canadian radar development before the spring of 1940. Prewar financial restrictions stymied early radar research. After an initial allocation of \$18,600 in September 1939, no more funds were available until the following May. Only preliminary experimental work could be undertaken.⁸

Perhaps the most important event of this early period was the appointment of C.J. Mackenzie to the post of acting NRC President. Formerly the Dean of Engineering at the University of Saskatchewan, Mackenzie came to the Council to replace McNaughton who rejoined the army to head the First Canadian Division. He was no stranger to the NRC, having been a member of the council and several advisory committees and had at least one friend in Cabinet, the future Minister of the Department of Munitions and Supply, fellow engineer C.D. Howe. Building from the prewar power base left him by McNaughton, Mackenzie became the mandarin of wartime science, but he was not a fully competent administrator. He tended to concentrate his efforts on transforming the council into a scientific centre of international standing rather than an effective military research and development laboratory -- the two not necessarily being the same thing.⁹

The fall of France thrust Canada into the role of senior partner to a beleaguered Britain. Freed from prewar financial restrictions the radar program quickly took several vital steps forward. In July the first operational set, the Halifax Harbour defence set 'Night Watchman,' was completed and the first British-built equipment arrived at the NRC. By the end of the year more than sixty people were employed on radar work at the NRC. This exponential growth continued until the end of 1942 when more than 200 civilians worked on the project.¹⁰

This growth was more than matched by the increased military demand caused by the expanding war effort and the greater utility of radar. All three services overtaxed the research facilities by making uncoordinated demands and by August 1940 it was apparent that some formal procedures were needed to manage the programme. On 3 August the Army Chief of Staff, General Crerar, wrote to Mackenzie:

... More should be done to coordinate the requirements of the Navy, Army and Air Force in this regard and I have accordingly suggested to the Chief of the Naval Staff and the Chief of the Air Staff that a committee consisting of the representatives of the three services and the National Research Council, should be

formed for this purpose.¹¹

Crerar's proposal resulted in the establishment of a sub-committee of the Chiefs of Staff Committee, The Interservice Committee of Electrical Fire Control. It was organized as Crerar had suggested with representatives from each service, NRC and Research Enterprises Limited (REL), the crown corporation established to manufacture radar. At its first meeting on 16 November the chairman, F.V. Heakes, now a group captain, outlined the committee's mandate:

... To ensure that each service was clear as to the others responsibilities, intentions and plans in using RDF equipment in order that overlap and duplication of effort should be eliminated.¹²

The committee had no executive authority and only worked by consensus, something that was found difficult to obtain with the junior officers that were assigned to it. This organizational flaw became apparent in the spring of 1941 as the production component of the program began to come on stream.

The decision to begin mass production of radar in Canada was not taken until July 1940. Considering the state of the Canadian electronics industry, it was a bold step indeed. There were few companies of any note and they tended 'to be manufacturing units only, dependent for their engineering and design on their American principals.'¹³ The task of establishing a radar manufacturer was seen as a matter of necessity in the summer of 1940. Unable to rely on British sources of supply or on still neutral America, Canada had to produce sets for its own and for Imperial needs.¹⁴ On 16 July representatives of the NRC, the three services and the new Department of Munitions and Supply met to determine how this manufacturing miracle was to be organized. W.C. Woodward, the department's representative, outlined a plan that was accepted as the basis of this new scheme:

To preserve the secrecy of the equipment, the apparatus for any given application could be built as a number of separate units by different firms. The assembly of these units, together with the construction of such secret parts as aerials, should be done at a central plant under government supervision....

... Mr. Woodward then remarked that he would recommend that a company be formed at once to operate under government supervision (similar to C.I.L.) for the sole purpose of producing equipment not previously obtainable in Canada.¹⁵

In September Woodward's proposal was slightly modified and the responsibility for radar production was given to a new crown corporation, Research Enterprises Limited.¹⁶

REL was originally established in July to produce precision optical equipment and it seemed a logical step to add radar because of the high technology and top secret nature of both items. In the autumn of 1940, however, REL was still just an administrative superstructure but it had a Board of Directors and senior executives already in place who could quickly begin the planning for the new 'Radio' factory. One of the original members of the board of the new company was Ontario industrialist W.E. Phillips, who from 30 November was the president. Phillips became a key player because of his determination to bring order to the management of the radar programme and his opposition to total NRC control.¹⁷

First priority was attached to the definition of the working relationship between REL and the NRC. In the first week of October, Professor E.F. Burton, a University of Toronto physicist and REL director, met with Henderson. They agreed that REL was to have control of manufacturing and the NRC of research, the two sharing responsibility for development.¹⁸ Burton, however, secretly confided to REL's directors that the manufacturer should '... be in a position to foresee future trends and should recommend to NRC authorities lines along which REL thinks research should be directed.'¹⁹ Clearly Burton wished REL to be the senior partner in this relationship, a theme that would be echoed in the years ahead.

REL began detailed planning for radar production in the spring of 1941 and found that the Fire Control Committee's lack of executive authority had resulted in a total breakdown in coordinated planning. The services 'were placing orders for practically the same equipment but with slightly different specifications.'²⁰ To make matters worse, the services almost daily issued new specifications and made verbal commitments to orders that did not result in firm contracts. By April the REL was overwhelmed by these problems.²¹ On 19 April Phillips met with C.D. Howe's assistant, E.P. Taylor, to express his concern over the confusion and was requested to submit a formal report. The REL staff took only four days to write their memorandum which called for the formation of a new, more powerful committee to be controlled by one forceful civilian chairman:

The question of sound organization in this field of electrical fire control is one of great importance and it has been apparent for some time that any lack of centralized direction in this field would inevitably lead to confusion. In a sense the position we have established for ourselves brings home to all the conflicting issue which must be solved *before we can produce*

It seems that the reason for the present situation, which in our view will increase rather than diminish confusion, is to be found in the failure of the Interservice Committee on Fire Control to *function effectively in the executive sense*. The tendency of the three services as represented in this Committee has been to

accentuate their differences rather than reconcile them....

... A chairman of considerable outside experience, even though he have no connection whatever with the Services, would substantially increase the effectiveness of this Committee and that it would then, with sufficiently wide membership, be the exclusive co-ordinating authority....²²

In his covering letter Phillips nominated O.M. Biggar, another REL director, for the new position.²³

Taylor passed the company's complaints on to Howe, perhaps the most powerful member of Mackenzie King's war Cabinet and the minister who had direct responsibility for the high technology crown corporation. On 29 April he wrote to J.L. Ralston, the Minister of National Defence, expressing his strong support for both REL's recommendations and Phillips' nomination.²⁴ Ralston consulted with his colleagues in the air and naval services and they ordered the Chiefs of Staff committee to reform the subcommittee on radar along the lines suggested by REL. Ralston, however, proposed that C.J. Mackenzie be given the chairmanship. Mackenzie and Howe had been friends since before the First World War, and the service chiefs were probably much more comfortable with a man with whom they already had extensive contact. The only people unhappy with the choice were those at REL.²⁵

The Chiefs of Staff approved a restructured Fire Control Committee, to be known as the RDF²⁶ Committee, and Mackenzie's appointment on 6 May. Each service, REL and the NRC, was to appoint one senior-level administrative officer to complete the committee's composition. Its powers were also outlined:

Co-ordination of development, design requirement and production of RDF apparatus for the fighting services. This to include the determination of types, quantities and future requirements, and the preparation of all necessary production specifications.²⁷

Both the committee and, 'in case of fundamental differences of opinion,' the chairmen were empowered to consult directly with the Chiefs of Staff.²⁸

Mackenzie was determined from the outset to bring order to the radar programme. Abandoning the failed *ad hoc* methods of the Fire Control Committee, he used his executive authority to ensure that there would be no duplication or contradictions. He was backed to the utmost by the Chiefs of Staff who came to rely on and trust Mackenzie completely and would support him against all opposition to his authority.²⁹

Colonel F.C. Wallace was appointed the committee's secretary. A British army officer and industrialist, he had

arrived in North America in the summer of 1940 as a member of the Tizard mission. Staying on to assist and observe the Canadian scientific and industrial mobilization, he displayed a talent for organization and management along with a firm technical understanding of radar. In the spring of 1941 Wallace joined the Radio Section to assist Henderson who had proved to be a less-than-adequate administrator.³⁰

At the committee's first meeting, held at the NRC on 4 June, steps were taken to ensure that it would be the centrepiece of the management structure (See Figure 1). It was ordered that 'no specifications or alterations would be sent direct' to REL or the NRC but must instead be first approved by the committee. On 16 June, at the second meeting, the secretary was made the central coordinator of all specifications. At the same meeting each service added a junior-level radar officer to assist with the technical requirements.³¹

While in these first few meetings Mackenzie's committee brought a semblance of order to the radar programme, certain problems proved extremely difficult to cure. One concerned the poor management within the NRC's Branch Section which was not settled until January 1942 when Henderson was replaced by Wallace.³² This purely internal NRC affair was an easy matter compared to the problems between NRC's Radio Branch and the staff of Research Enterprises, which could not find the correct balance between quantity and quality or deliver sets on schedule. According to W.E.K. Middleton in his study of the Radio Branch, during 1942 both Mackenzie and Wallace became convinced that the source of the problem was the mismanagement of the huge new REL plant by R.A. Hackbusch, manager of the company's Radio Division.³³ Middleton cites as proof of the company's guilt the dramatic confrontation between Wallace and Hackbusch that occurred on 12 November 1942 in Phillips' office but fails to adequately assess the reliability of the only surviving account of the incident which is found in Mackenzie's diary, a source that must be used with caution.³⁴

According to Mackenzie's account, Wallace began the meeting by accusing Hackbusch of allowing sets to leave the plant that were not inspected and that contained parts that did not meet specifications. Hackbusch denied the allegations and called in the plant's superintendent to document his case. Under cross examination by Wallace, however, the superintendent broke down and admitted that all of the charges were true.³⁵ Relying on later diary entries, Middleton asserts that Phillips appeared to have lost confidence in Hackbusch but refused to dismiss him. It took nearly another year for Mackenzie and Wallace to force Hackbusch to resign. Within a week Wallace was brought in as his replacement, while retaining his position at the NRC and in this unique double role was able to integrate research and production fully.³⁶

It is impossible, however, to accept this account at face value. While there were unquestionably serious problems at REL, the company's difficulties were compounded by NRC

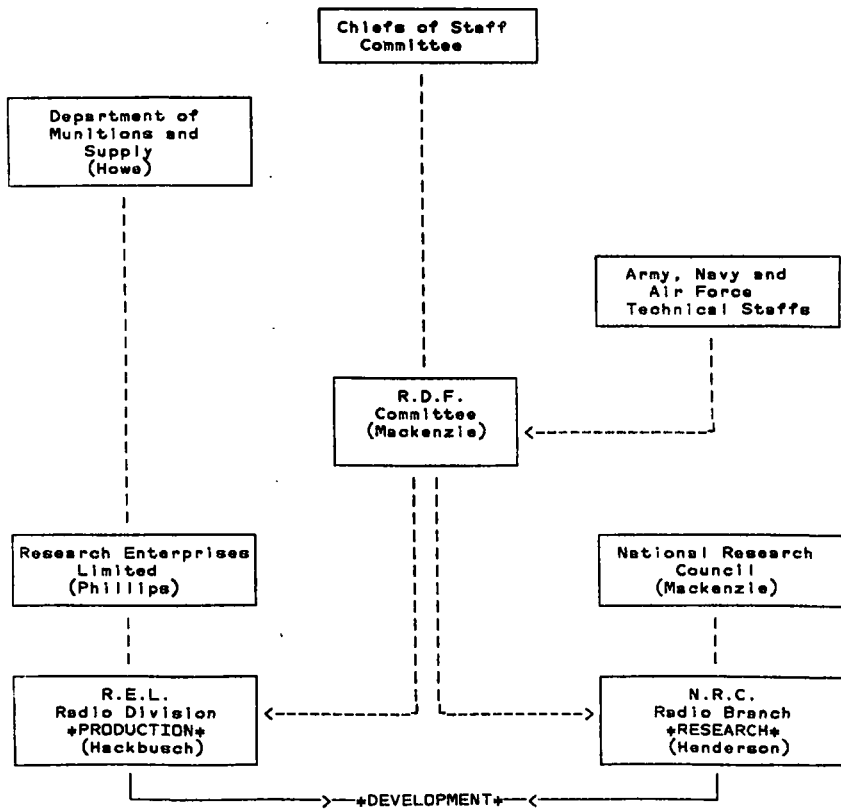


Figure One: Canadian Radar Organization, July 1942

design failures and frequent requests by the services for alterations during the tooling-up phase of a project. The pre-production model of the RX/C radar, for instance, was delivered to REL by the Council in an incomplete state without, as the Radio Branch staff in charge of the project admitted, 'such matters as shock mountings, adequate cooling units, use of component parts to suit production specifications, rigid rack construction, special wiring methods, etc. ...'³⁷ From November 1942 to May 1943, the Navy requested more than a dozen design changes, many of them major, to the RX/C.³⁸

As Chairman of the RDF Committee, Mackenzie was responsible for finding a mutually-acceptable solution to the production problems, but he proved incapable of doing so because of the conflict of interest with his position at the NRC. As his diary indicates, Mackenzie refused to admit any council culpability and as a result the issue was allowed to fester until the spring of 1943 when Howe was asked by Ralston to resolve it. Ralston's letter of 28 April 1943 summarized a lengthy report on the radar manufacturer written by Mackenzie two weeks earlier which accused the company, among other things, of incompetence, deceit and giving Allied orders for radar higher priority than those of the Canadian services.³⁹

On 12 May Phillips and the REL staff responded angrily to Ralston's and Mackenzie's accusations. After comparing the company favourably with the radar manufacturers in the United States and the United Kingdom, Phillips launched into a vicious assault on the services and the NRC's technical competence. He felt that the military 'quite unconsciously think of us as a special section of the Department [of National Defence], with the power to work miracles in production and to have at our command special facilities which enable us to produce complicated equipment without either prototypes or drawings and specifications.'⁴⁰

Typically, Howe sought a way to quickly diffuse the issue and assigned H.J. Carmichael, the Chairman of the Department of Munitions and Supply's Production Board, to investigate. Carmichael's report recommended that DMS establish a Radar Coordination Committee under the chairmanship of A.H. Zimmerman, the director of the Signals Production Branch with Wallace, Phillips and one representative from each service as members.⁴¹ This committee acted as the production planning authority, although it gave certain powers to technical subcommittees, the most important being the Radar Components Committee established in March 1944.⁴²

By intentionally excluding Hackbusch or one of his staff from the membership of the new committee, Carmichael indicated that the REL radio manager's days at the company were numbered. It is still uncertain if Hackbusch was simply a scapegoat, sacrificed rather than the well-connected Phillips or Mackenzie, or the real villain; however, it is more than likely that all three men were to blame. Whatever the answer, the results were closer control of REL by the NRC and in September 1943, Wallace took over the Radio

Division at REL while retaining his position at the Radio Branch.

The formation of the Radar Co-ordination Committee did not seriously weaken Mackenzie's position because Zimmerman was directed to report to the Chiefs of Staff via the Radar Committee. Wallace, who was the NRC President's right-hand man on radar, sat on the committee, and it is possible that Mackenzie was not a member simply because he was already overwhelmed by the multitude of tasks he was already undertaking. Mackenzie's Radar Committee, while surrendering the direct control of REL to the Co-ordination Committee, continued to be the most important single management and planning body until its dissolution in November 1945 (see Figure 2). Ultimately the programme did produce creditable accomplishments, just one example being the development of the Type 268 radar, one of the most advanced centimetric sets in the Royal Navy during the last year of the war.⁴³ These accomplishments, however, were greatly overshadowed by dramatic failures of entire elements of the programme. A major cause of these failures was the inability throughout the war to coordinate research and development with Canadian service requirements, the resolution of which was definitely within the mandate of Mackenzie's committee.

The first detailed study of any of the service's experience with the Canadian radar programme clearly illustrates this problem.⁴⁴ From mid-1941 to the end of the conflict, the Royal Canadian Navy's escort vessels suffered from a lack of adequate modern radar, and in large part this was the result of mismanagement of the technical and manufacturing elements of the programme. The most dramatic of the failures led certain officers to attempt to wrest control of the radar programme from the civilians.

In the spring of 1944 the Royal Canadian Navy was forced to withdraw from service the brand-new ten-centimetre set, RX/C. It was found that the set, although sound in the laboratory, could not be maintained at sea.⁴⁵ The failure convinced the senior naval radar officer, G.A. Worth, Director of Signals, there was a serious administrative problem which he blamed on NRC control of a naval project.⁴⁶ Worth was determined to end the dominant role of the NRC in military science and to place Mackenzie's Committee under the control of the services' new technical staffs. On 8 April 1944, at the meeting of the Chiefs of Staff Joint Communications Subcommittee, Worth proposed that the Radar Committee be made a technical subcommittee of the JCC.⁴⁷ Worth believed that now that the military had the ability to manage its own scientific programmes, no civilian should have control over operational and technical requirements. He accused Mackenzie of gearing 'the progress of radar to NRC tempo when exactly the reverse of wartime requirements.'⁴⁸

Worth's attack was thwarted by the complete trust that the Chiefs of Staff had in Mackenzie. When considering Worth's argument, they simply referred the whole matter to the NRC

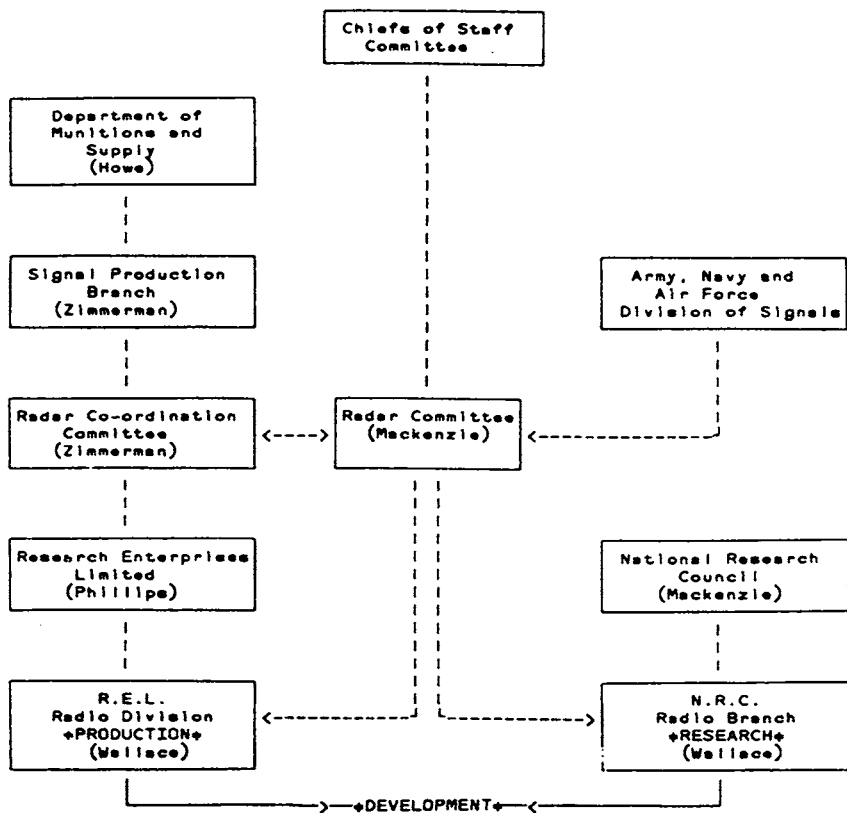


Figure 2: Canadian Radar Organization, July 1944

president.⁴⁹ Mackenzie rejected Worth's proposal and hinted that if the JCC were to gain control of the radar programme, the administration would collapse once again because of inter-service rivalries.⁵⁰ Worth attempted four more times to supplant the Radar Committee but met with no greater success. The debate between Mackenzie and Worth became a heated one and, from June 1944, the latter forbade naval officers from attending committee meetings. The fact that Worth remained unsuccessful is an indication of the power and prestige of Mackenzie.⁵¹

The Radar Committee continued to operate until 19 November 1945 by which time the programme had been dramatically reduced in scope.⁵² The NRC, as Mackenzie had planned since at least 1943, quickly abandoned military research and returned to peacetime pursuits with a greatly enlarged and improved physical plant and staff.⁵³ REL was sold to a variety of firms, including Corning Glass and Rogers Majestic Limited. Only a small radar assembly plant was maintained by the government under the auspices of Canadian Arsenals Limited, a new crown corporation established to provide 'a small peacetime munitions industry for research purposes and for supplying the Armed Forces.'⁵⁴ Small-scale radar manufacturing continued at this plant until the early 1960s when production was terminated in favour of private industry.⁵⁵

The management structure that was developed for the radar programme gave the Council control of the largest single scientific project undertaken by Canada during the Second World War. Although there were several challenges to this power by REL and later by the Navy, Mackenzie and Wallace remained firmly in charge despite strong evidence of mismanagement. How they were able to avoid a serious inquiry into the radar programme is still open to some doubt since an adequate study of work undertaken for either the Air Force or Army is yet to be done, but a recently completed examination of the Navy offers several possibilities. Mackenzie, as he was able to do in his dispute with Worth, raised fears of inter-service rivalries which gave him the support of the Chiefs of Staff. The NRC president's close friendship with C.D. Howe cannot be ignored since the only serious examination of the programme was carried out by the senior staff of the Department of Munitions and Supply. Of course the council cannot be assessed all of the blame for there were serious problems within Research Enterprises and the services' technical staff. It was Mackenzie's responsibility, however, as Chairman of the Radar (RDF) Committee to rectify these difficulties, the fact that he was unable to do this cannot be ignored and calls for a significant re-evaluation of his performance as the mandarin of wartime science.

NOTES

1. This view is forcefully expressed by W.E.K. Middleton in *Mechanical Engineering at the National Research*

- Council of Canada, 1929-1951* (Waterloo, 1984); *Radar Development in Canada: The Radio Branch of the National Research Council of Canada, 1939-1946* (Waterloo, 1981); *Physics at the National Research Council of Canada, 1929-1952* (Waterloo, 1979); and by Wilfrid Eggleston, *National Research in Canada* (Toronto, 1978).
2. L.R. Lafleche to the President, NRC, 10 March 1939. Public Archives of Canada (PAC), NRC file S45-2-16.
 3. John Swettenham, *McNaughton*, (Toronto, 1968), I, 319-43.
 4. NRC, 'War History of the Associate Committee of the National Research Council,' (Ottawa, n.d.), 100.
 5. Henderson to McNaughton, 6 April 1939, 19 April 1939. PAC, NRC file S45-2-1V.1; Henderson and Heakes, 'Electrical Methods of Fire Control in Great Britain,' April 1939, NRC, PRA Report 6; Henderson, 'Electrical Methods of Fire Control in Great Britain, Part 2,' June 1939, NRC, PRA Report 7.
 6. McNaughton to Henderson, 19 July 1939. PAC, NRC File S45-2-16 V.1.
 7. 'Co-operation of NRC in RDF Programme of the Defence Department,' *Ibid.*
 8. John T. Henderson, 'Progress Report for Period June 1939 to 1 January 1942,' NRC Radio Section, 1942, 1-3.
 9. For biographical sketch of Mackenzie see Mel Thistle's Forward to *The Mackenzie-McNaughton Letters* (Toronto, 1975), xiv-xviii.
 10. Middleton, *Radar*, 28-30.
 11. Crerar to Mackenzie, 3 August 1940. PAC, NRC file S45-2-16 v.2.
 12. Minutes of the meeting of The Interservice Committee of Electrical Fire Control, *ibid.*, vol. 3.
 13. F.M. Smith (compiler), 'History of the British Admiralty Technical Mission,' (unpublished manuscript in Directorate of History collection, Ottawa, undated but circa 1946), 110.
 14. Chief of General Staff to Chief of Naval Staff and Chief of Air Staff, 12 July 1940. PAC, R.G. 24 V.8086, N.S. 1272-24 V.1.
 15. Memorandum to D.P.D. from W/T Rowley, 16 July 1940, *ibid.*
 16. 'Memorandum on Electrical Fire Control,' PAC, C.D. Howe Papers, V.43, File 5-9-85-7(2).

17. W.E. Phillips, 'Report on the Special Radio Branch Situation,' 9 October 1940, *ibid.*
18. E.F. Burton, 'Memorandum Re: Interview with Dr. Henderson of the Radio Laboratory, NRC, 3-4 October 1940,' *ibid.*
19. *Ibid.*
20. C.G. Power to Howe, 16 May 1941. *Ibid.*, V.30, file 5-9-85(2).
21. REL Staff, 'Memorandum on Electrical Fire Control, 23 April 1941,' *Ibid.*, V.43, file 5-9-85-7(2).
22. *Ibid.* Emphasis provided.
23. Phillips to Taylor, 24 April 1941. *Ibid.*
24. Howe to Ralston, 29 April 1941. *Ibid.*
25. Macdonald to Howe, 6 May 1941. *Ibid.*
26. For Radio Direction Finding. This was the code for the device in the British Empire until the American term radar was adopted in June 1943 at which time the committee became known as the Radar Committee.
27. Minutes of the 108th Meeting of the Chiefs of Staff Committee, 6 May 1941. DND, History Directorate.
28. *Ibid.*
29. PAC, Mackenzie Diary, 7 May 1941.
30. Middleton, *Radar*, 21, 27-8.
31. Minutes of First Meeting of the RDF Committee, 4 June 1941; Minutes of the Second Meeting, 16 May 1941; Minutes of the Third Meeting, 27 July 1941. PAC, Henderson Papers.
32. Middleton, *Radar*, 30-33.
33. *Ibid*, 43-4.
34. PAC, Mackenzie Diary, 12 November, 1942.
35. *Ibid.*
36. Middleton, *Radar*, 44.
37. H.R. Smyth and K.C. Mann, 'Comments on the Report of J.R. Warren, 23 July 1942,' 1/8/42. PAC, RG77 V.173, f.45-2-52 v.1.
38. 'Detailed Reply to Items Raised in the Honourable Mr. Ralston's Letter of April 28th, 1943,' undated but May 1943. PAC, Howe Papers, V.43, f.5-9-85-7 (1).

39. Ralston to Howe, 28 April 1943; Mackenzie to Secretary, Chiefs of Staff Committee, 12 April 1943. PAC, RG24 V.5282, HQ534-7-2 v.3.
40. Phillips to Howe, 12 May 1943. PAC, Howe Papers, V.433, f.5-9-85-7 (1). Also see 'Detailed Reply to Items Raised in the Honourable Mr. Ralston's Letter of April 28th, 1943.'
41. Zimmerman to H.M. Gallagher, 27 June 1943. PAC, RG28, V.160, file 3-R-15.
42. Minutes of the Ninth Meeting of the Radar Co-ordination Committee, 20 March 1944. PAC, NRC, file 3000-12-1.
43. Norman Friedman, *Naval Radar* (Annapolis, 1981), 191.
44. See David Zimmerman, 'Northern Waves: Science, Technology and the Royal Canadian Navy, 1939-45,' unpublished PhD dissertation, University of New Brunswick, 1986.
45. F.R. Park, 'Operational and Maintenance Problems with RX/C Radar,' PAC, RG 77, V.174, file 45-2-52, V.3.
46. Worth's motivation is open to some debate. Unquestionably he was seeking a scapegoat but also had legitimate grievances against Mackenzie and the management of the radar programme. The RX/C failure had only been the last in a series of disasters to befall Canadian naval radar development, including the withdrawal from service in June 1943 of the American-Canadian hybrid RX/U, and faults with the antenna system of the SW2C set from its introduction into service in early 1942. See Zimmerman, *op. cit.*, 89-113, 159-85, 238-67, 330-34.
47. Joint Communications Subcommittee, Item V, 8 April 1944. PAC, RG 24, V.8086, N.S. 1272-24, V.3.
48. Worth to CNS, 20 April 1944. *Ibid.*
49. Minutes of the Chiefs of Staff Meeting, 21 April 1944. *Ibid.*
50. Mackenzie to the Secretary, Chiefs of Staff Committee, 4 May 1944. *Ibid.*
51. Minutes of the 36, 37, and 50 Meeting of the Radar Committee, 15 May 1944, 19 June 1944, 17 September 1944, *ibid*; Worth to CNS, 13 March 1945; Worth to the Secretary JCC, 3 July 1945, *ibid.*, v.4; Minutes of the Meeting of the Chiefs of Staff Committee, 22 March 1945, 8 November 1945, *ibid*; PAC, Mackenzie Diary, 15 May 1944.
52. Minutes of the 51st Meeting of the Radar Committee, 19 November 1945. PAC, RG 24 V.8086, N.S. 1272-24 V.3.

53. D.J. Goodspeed, *A History of the Defence Research Board of Canada* (Ottawa, 1958), 11.
54. Department of Reconstruction and Supply, *Disposal and Peacetime Use of Crown Plant Buildings* (Ottawa, 1948), 20; also see 44.
55. 'Annual Reports of Canadian Defence Arsenals Limited,' No. 1-18 (1946-1965).