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## **Special Study No 9**

# **Chemistry and Chemical Engineering: A Survey of Research and Development in Canada**

Prepared by a Study Group of  
The Chemical Institute of Canada

A. E. R. Westman

Study Director

for

The Science Council of Canada

### ERRATA

- Page ix, paragraph 2, line 2:  
For "that now accounts" read  
"that it now accounts".
- Page 41, paragraph 5, line 6:  
For "p. xxii" read "p. xvii".
- Page 46, paragraph 1, line 6:  
For "p. xxii" read "p. xvii".
- Page 76, paragraph 5, line 3:  
For "Table 9" read "Table 7".

**CHEMISTRY AND CHEMICAL ENGINEERING: A SURVEY OF  
RESEARCH AND DEVELOPMENT IN CANADA**

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## DEFINITION

For the purposes of the C.I.C. survey, Chemistry R. and D. was defined to include “all R. and D. of a chemical or chemical engineering nature, including that coming under the primary classification of analytical chemistry, inorganic chemistry, metallurgy, organic chemistry, physical chemistry, agricultural and food chemistry, biochemistry, chemical engineering and chemistry in the earth sciences and related fields.”

*The term Chemistry R. and D. is used throughout this report to imply the field of chemistry and related disciplines as defined above.*

## FOREWORD

This study was commissioned in November 1966 by the Science Secretariat of the Privy Council Office.

The Chemical Institute of Canada contracted to make "a comprehensive study of research and development in chemistry and the associated scientific and engineering fields in Canada".

The Institute set up a Steering Committee, under the then-chairman of its Board of Directors, Dr. Maurice Adelman, to take overall responsibility for the study and report. The Steering Committee in turn appointed as study director Dr. A. E. R. Westman, then recently retired from the position of Research Director of the Ontario Research Foundation.

The field of study was divided into twenty areas, each having a chairman empowered to select his own study committee. In addition, a statistical survey was undertaken with the aid of The Institute Head Office staff and facilities, and the service of a consultant mathematician.

On November 1, 1968, the Science Council accepted from the Science Secretariat the responsibility for carrying to completion such special studies as had been initiated by the Secretariat and were still being developed. This present study is one of these.

The final report received by the Science Council from the Chemical Institute of Canada consists of four volumes:

- (i) This summary report.
- (ii) The full text of the reports of subcommittees 1 to 10.
- (iii) The full text of the reports of subcommittees 11 to 20.
- (iv) The tabulated data of the Statistical Survey (the table titles of which appear in an Appendix of the Summary Report).

The Summary Report only is being published. Copies of Committee reports and copies of tables in the Statistical Survey may be obtained from the Science Council of Canada, 150 Kent Street, Ottawa.

The opinions expressed in this report are those of the authors and should not be attributed to the Science Council. The conclusions and recommendations of the Science Council will be published separately at a later date.

P. D. McTaggart-Cowan,  
*Executive Director,  
Science Council of Canada.*

## PREFACE

The impact of science and technology on the economic and social structures in our twentieth century society makes it essential that Canadian Governments concern themselves with the problems and challenges associated with scientific research and development. Modern research and development requires very substantial levels of public financial support; good research, wisely planned and properly executed, followed by active development is, nevertheless, a wise investment for a progressive society since it leads directly to many material and cultural benefits. The problems are: how to encourage good research in what fields; and what levels of support for basic research, applied research and development are sensible, in relation to the wealth and productivity of the country?

In this connection, it is a measure of the importance of industry based on chemistry and related sciences and engineering, that now accounts for an estimated 45% of all expenditures on intramural industrial research and development in Canada, and therefore any planning of future R. and D. effort must clearly give major consideration to this area.

The information contained in this survey, representing as it does the current activity of a high percentage of the Chemistry R. and D. performed in all sectors in Canada, should therefore be helpful in the planning of future levels of support by government, and the co-ordination of effort by all sectors to ensure the most effective results, not only for the sciences and engineering but for Canada's economic progress as a whole.

A. E. R. Westman,  
*Study Director.*



## ACKNOWLEDGMENTS

The Steering Committee wishes to express its gratitude to Dr. A. E. R. Westman for undertaking the work of organizing and carrying out this survey; and to the committee chairmen and members for responding with such energy and enthusiasm to the tasks assigned to them by the Survey Director.

Special acknowledgments are also due to the Scientific Activities Surveys Section of the Dominion Bureau of Statistics; the permanent staff of The Chemical Institute of Canada; and the Science Secretariat personnel and advisers for their helpful co-operation.

The Canadian Chemical Producers' Association helped secure a maximum response from its members to the company questionnaire; and the assistance of the many respondents to the survey questionnaire in securing an exceptionally high rate of response in all sectors is gratefully acknowledged.

The Ontario Research Foundation kindly provided an office and other facilities for use by the Survey Director.

M. Adelman, *Chairman,*  
*C.I.C. Steering Committee.*

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## SUMMARY OF MAJOR RECOMMENDATIONS

The first part of this summary presents the general recommendations arising from the overall study of Chemistry R. and D. in Canada; the second part lists the major committee recommendations.

### General Recommendations

#### 1. Overall Science Policy

Although they are not necessarily the only or even the predominant factors, the level and direction of R. and D. activities can nevertheless play a very important role in the economic growth of a country. From the rather broad field covered by the committee reports, the statistical data, and the many comments received in this study, there is an evident need expressed for an overall science policy. This would set the general level and direction of R. and D. activities and ensure their review from time to time.

*The first general recommendation is, therefore, an overall science policy to set national objectives relevant to our level of development, natural resources, environment, health and economic welfare.*

Detailed planning down to individual projects is not contemplated, except where an individual project looms large enough in the general picture, as is seldom the case in the field covered by this study. However, if national objectives are clearly defined, then institutions and to some extent individuals can plan their work with these objectives in mind. Also, government policy on grants, incentives, patents, taxation, tariffs, etc. can be designed, as far as is possible, to promote rather than to obstruct the achievement of these national objectives.

#### 2. Government, Industry, and Universities or Institutes

The study showed much evidence and opinion that there is a lack of co-ordination between the three sectors engaged in Chemistry R. and D. in Canada. *Consequently, our second recommendation is the introduction of more flexibility and interchange between the three sectors—government, industry, and the universities.* This would follow to a considerable extent from the adoption of our first general recommendation; however, some specific action is needed to implement this second recommendation. The objective would be to take the fullest advantage of all the latent talent for research and invention available to Canada, without regard to the particular sector where it happened to be available. Examples of steps that could be taken are consultation; interchange of staff; and the provision of postdoctoral assistants for scientists in government and industry to engage in research which would complement that in the scientists' prescribed area of special endeavour. With suitable safeguards and

supervision, research work outside universities could be considered for advanced degrees. In addition it is recommended that co-ordinating bodies or committees be set up within the R. and D. fields represented by the twenty committees where these do not exist at present. More industrial support of basic research in universities is also considered desirable.

### 3. *Character of R. and D.*

There are statistical evidence and much opinion that the basic research carried out by the government and the universities is not balanced by a sufficient effort on applied research and development in Canada.

*Our third general recommendation is, therefore, that the present effort in basic research be continued, but that this be balanced as much as possible by an increased effort in applied research and development.*

This also would follow to a considerable extent from the adoption of our first general recommendation; however, there is a strong body of opinion that specific action is needed. The present government incentives are considered helpful, but their incremental character and mode of operation are considered to be limiting factors. More industrial participation in decision-making, more direct government contracts to industry, less tariffs and taxes on R. and D. equipment used in industry, simplification of procedures, and other measures are proposed.

### 4. *Co-operative and Contract Research*

The D.B.S. statistics show that the major proportion of the R. and D. in Canada is done by large companies and that the lower level of R. and D. expenditures in relation to Gross National Product compared with the United States is partly a reflection of the smaller size of the companies in Canada. It is important, therefore, that a special effort be made to encourage and make possible the undertaking of R. and D. projects by smaller companies.

*Our fourth general recommendation is, therefore, that co-operative research associations and, particularly, contract research institutes of the provincial council type and other means be encouraged to enable smaller companies to engage in R. and D. without undue risk.*

This would be particularly valuable in the case of Chemistry R. and D. in which numerous small research projects are possible and these might, in some instances, yield high returns. However, highly trained personnel and sophisticated equipment may be required.

### 5. *Concentration of Effort*

With the limited funds available for R. and D. in Canada, the rapid expansion of university and, to some extent, government research, and the overall rapid expansion and increased sophistication of the whole field of science, there is a danger that our R. and D. efforts will become too diffused or diluted. This has been the subject of comment by several committees.

*Our fifth general recommendation is, therefore, that in university and government R. and D. serious consideration be given to the creation of multi-disciplinary institutes or disciplinary centres-of-excellence so as to avoid dispersion of effort.*

A number of such institutes or centres are recommended by the committees. Each needs to be discussed on its own merits and in the context of the report of the committee concerned.

## *6. Invention and Innovation*

The foregoing recommendations referred to R. and D. without any qualifications. However, if a country is to derive the maximum economic and welfare benefits from its R. and D. program, it is necessary that the whole process of innovation be completed. This means its R. and D. efforts must lead to inventions and that these must be developed and commercialized.

If Canada is to reap the full benefits of its R. and D. program, it is essential that everyone associated with that program be encouraged and assisted in using his inventive faculties to the fullest. Every new advance in knowledge, even in basic research, should be examined as possibly leading to worthwhile invention. At the other extreme, market research should be looking for new wants to be satisfied.

*Our sixth general recommendation is, therefore, that every effort be made in Canada to encourage invention in all three sectors—government, industry, and universities or institutes.*

The creation of an atmosphere favourable to invention may also follow partly from the implementation of our first general recommendation. However, more specific steps would be the broadening of the activities of Canadian Patents and Development Ltd.; the granting of assistance to university professors, and to others not supported by a commercial organization, to apply for and obtain patents; and the provision of more grants to universities and other establishments to support R. and D. of a more applied nature.

## *7. Neglected Areas*

In the terms of reference, the study was asked to locate any serious gaps in the pattern of Chemistry R. and D. in Canada and this was kept in mind when designing the statistical survey and in the separate studies made by the committees.

The committees and the questionnaire respondents reported a number of areas in which they considered there was need for expansion of the R. and D. effort, or for more trained personnel and facilities. These are summarized in Chapters III and V. Each of these situations should be studied both in the context of the areas covered by the committee in question and in the context of an overall science policy as outlined in our first general recommendation.

*Our seventh recommendation is, therefore, that serious consideration be given—in the context of the relevant committee areas and in the light of the*

*recommendation of a national science policy—to the question of neglected R. and D. areas, and the availability of specially trained personnel and facilities.*

#### 8. Government Incentive Schemes

There is general agreement in the committees' reports and among the respondents to the Statistical Survey that the present governmental incentives schemes have served a useful purpose. However, there is also a strong opinion expressed that they can be made more effective by modifying the rules under which they operate. *Our eighth general recommendation is, therefore, that the present government research incentive schemes be reviewed with the aim of making them more effective.* The principal objections are to their concentration on incremental research, to the need to disclose commercial information, and to the need to show manufacturing and export possibilities, etc. There is a preference for direct contracts from government to industry.

#### 9. The Future of Chemistry R. and D.

Most of the committees pointed out that there was a need for more Chemistry R. and D. in their particular areas and, in some cases, for more research personnel. However, the rates of increase in R. and D. expenditures forecast by the respondents in the government and industry sectors were actually quite small.

In the past it might have been argued that a considerable increase in R. and D. by government and industry could not be met by the available supply of personnel. However, as shown in Chapter III.4 and Chapter VI.2, the potential rate of graduation of Ph.D.s in Canada would be adequate to serve a more rapid expansion in R. and D. than has been forecast by the respondents in government and industry.

It is clear therefore that there are unresolved problems in reconciling future manpower supply and demand in Chemistry R. and D. in Canada, and these require study beyond the scope of this enquiry.

Our ninth, and perhaps most important recommendation is, therefore, one which ties in with the previous recommendations and it is *that a thorough investigation be made of the dynamics of the production and utilization of research personnel in Chemistry R. and D. in Canada.* All the techniques of systems analysis should be brought to bear on the problem.

### Committees' Recommendations

Study committee recommendations were of two general types: (i) those referring specifically to the area studied by the committee in question; and (ii) those intended to apply more widely than in the committee's own field of interest.

These recommendations are summarized below in the order of frequency with which they were made, as indicated by the numbers in brackets. (More detailed tabulations of specific areas which were considered to be handicapped in respect to effort, personnel, or equipment are given in Chapter V.)



- (i) Recommendations made most frequently with specific reference to the committee's own area, and shown in their order of frequency indicated by the numbers in brackets, were as follows:

- More undergraduate training (17).
- Establishment of a research institute (8).
- A large increase in R. and D. (7).
- More academic research (7).
- Centres-of-excellence (6).
- More graduate studies (6).
- More university chairs (6).
- Centres with sophisticated equipment available on a rental basis (4).
- Encouragement of commercial production (4).
- Larger computers (3).
- More emphasis on synthetic organic products (2).
- A central information centre (2).

- (ii) Committee recommendations which were intended to apply more generally than to the committee's own field of study were as follows:

- An increased effort in applied research and development, particularly with Canadian objectives (13).
- Increased government support (11).
- Increased incentives for industrial research, particularly with no "incremental" aspect (10).
- More direct contracts and grants from government to industry (7).
- More co-operative or group research (5).
- Re-orientation of university research to meet Canadian needs (3).
- More R. and D. in industry (3).
- More academic consultants in industry (2).
- A stronger patent system (2).
- Universities to award higher degrees for industrial and government research (2).
- A.E.C.B. and A.E.C.L. grants to universities (2).

It should be noted that all general recommendations do not apply to every area covered by the committees. For example, committees 5, 16, and 19 recommend more government research rather than more industrial or university research in the areas of fuels, food chemistry, and geochemistry, respectively.

## Chapter I

# THE ROLE OF CHEMISTRY

### I.1 Chemistry and the Other Sciences

Chemistry is one of the physical sciences. As such it is closely related to physics, on the one hand, and to the life and earth sciences on the other.

A distinguishing feature of chemistry is its concern with matter at the molecular level, and from this core it spreads out in many directions. To explain the properties of molecules, determine their structures, and understand their interactions, it was found necessary to deal with parts of molecules and with atoms. In the other direction, to understand minerals and the naturally occurring organic substances of high molecular weight, it was necessary to study the way in which molecules or their parts could be combined to form crystals and macromolecules. Included in the latter are such widely different compounds as the polymers, which are the principal constituents of modern plastics, and the nucleic acids, which carry the genetic code upon which heredity is based.

Studies of the properties of molecules formed from the chemical elements or atoms led, in 1869, to the periodic law of Mendeleev, from which it followed that there must be some underlying structural principle for all the elements. The discovery by the physicists of the electron, and the concept of an atomic structure consisting of a nucleus and orbiting electrons, provided the explanation of the periodic law of Mendeleev. This and subsequent models of the atom were quickly put to good use by the chemists; and since that time there has been a continuous interplay between chemistry and physics which has greatly benefitted both disciplines.

Although the physicist is not as interested in analysis, molecular structure, and synthesis as is the chemist, he is concerned with radiation and its relationship to matter. A systematic exploration of the electromagnetic spectrum and its connection with matter has been the subject of a continuing study. In many cases it was found that the spectra obtained could be explained in terms of the atomic or molecular structure in which the chemist was primarily interested. Again a very productive interplay occurred, with the chemist finding more and more uses for physical methods and the physicist developing more and more accurate and discriminating techniques.

Analyses of materials, and determinations of molecular and crystal structure which were formerly very time-consuming or impossible when chemical methods were used, can now be done expeditiously by physical methods.

Chemical synthesis of naturally occurring or of new compounds unknown in nature can be guided by physical methods, which thus greatly expedite and extend this field of chemistry.

This interplay between chemistry and physics has resulted in the sub-disciplines denoted by the terms physical chemistry and chemical physics. Neither is inter-disciplinary in the usual sense of the word, since the former is primarily chemical and the latter physical in emphasis. Similarly, there are nuclear chemistry and nuclear physics, radiation chemistry and radiation physics.<sup>1</sup>

The chemist's ability to analyze and synthesize, and to deal with chemical reactions, has resulted in the spreading out of chemistry into the life and earth sciences, the former largely through organic chemistry and the latter through inorganic chemistry.

Biochemistry, which links chemistry with biology and through it with medicine, seeks a chemical explanation for life processes. At first such explanations were considered by many to be impossible but Wöhler's synthesis of urea by chemical means in 1828 dispelled this doubt. Today biochemistry is a very important field of research.

There are several links between chemistry and the earth sciences. Inorganic chemistry is closely related to crystal chemistry, and through it to mineralogy and geology. There is also a science of geochemistry, which aids in the classification of geological formations and the location of mineral deposits by chemical methods.

The wide field of application of chemistry in the other sciences is also indicated by the fact that the students from other departments and faculties who are taught chemistry by university chemistry staffs often outnumber their own students.

In the present survey, which included not only chemistry but a number of related disciplines, it was sometimes a difficult matter to decide just what should be included or excluded. In general, the Science Secretariat preferred that there should be some overlapping between the surveys rather than gaps, particularly if the overlap could be identified. Two approaches were possible: one, that only R. and D. performed by chemists and chemical engineers would be considered; the other, that when a chemical explanation or result was being sought, the R. and D. would be judged to be chemical in nature. The former was deemed to be unsuited to modern situations in which a team consisting of people from a number of disciplines is often used on a project. The latter criterion was therefore used throughout this survey, and in general the emphasis was placed on the objective rather than on the type of worker.

---

<sup>1</sup> Not much difficulty was found in this survey in distinguishing chemistry from physics and in avoiding overlap with the corresponding survey of physics. This was achieved largely by taking care in drawing up questionnaire mailing lists; otherwise, beyond the wording of questionnaires and instructions, the matter was left largely to the respondents and the committees concerned. In general the nature and objective of the work governed, rather than the training of the researcher.

## **I.2 Chemistry and Engineering**

Engineering was originally concerned largely with the application of physics to military and civil problems. However, with the advent and growth of the chemical and chemical-processing industries, it became necessary to have engineers who were capable of designing, constructing, and operating chemical-producing and chemical-processing equipment, on both pilot-plant and full production scale. The close contact of the chemical engineers with industry interested them also in improving chemical processes and in producing new products. When working on a laboratory scale, the chemical engineer may find that his work may not differ much from that of a chemist except that the engineer has a greater interest in design and in practical applications. At the pilot-plant and full production scale, however, it is usual for most of the responsibility to devolve upon chemical engineers.

The growth of chemical engineering as a self-contained discipline has been much more pronounced in the United States than in Europe, and in Canada an intermediate path has been followed.

Since the present study was concerned with applied research and development, as well as with basic research, an effort was made to cover all chemical engineering activities of an R. and D. nature in all the committee areas, and not just those concerned with chemical engineering *per se*.

## **I.3 Chemistry and Metallurgy**

Most processes for the extraction of metals from their ores, or from other sources, involve chemical reactions. The discipline which incorporates these processes is generally known as “extractive metallurgy” or “chemical metallurgy”. However, some aspects of extraction—usually the primary stages of mineral beneficiation—are based largely on physical processes.

“Physical metallurgy” deals with the properties and fabrication of metals; the design of alloys; and the integration of structural and performance requirements with metallic properties. It involves both the “physical” and the “chemical” properties of metals, since it is concerned not only with purely physical concepts (thermal and electrical properties, strength, and so on), but with solid state reactions, metallic compounds, etc. Even “metal physics” is not devoid of a chemical content.

The subject of physical metallurgy is becoming closely associated with the more general area of “materials science” or “engineering materials”, which encompasses all materials in their diverse applications and fabrication.

The corrosion of metals, which is fundamentally a chemical process, is usually dealt with under electrochemistry.

## **I.4 Chemistry and Medicine**

Chemistry is related to medical research through biochemistry and such related disciplines as pharmacology, pharmacy, pharmaceutical chemistry, and food chemistry. Pharmacologists study the effect of drugs on the human system. Pharmaceutical chemists develop new drugs and are concerned with

drug manufacture. Pharmacists are concerned with the accurate and safe prescription of drugs. Food chemists study the supply and evaluation of foods.

It is evident that while all these disciplines have a considerable chemical content, they are closely related to medicine and the ultimate result of research and development in these fields is an improvement in the practice of medicine, often with a concomitant expansion of the chemical products industry.

### **I.5 Chemistry and Agriculture**

Agricultural chemistry seeks a chemical explanation of the growth processes which occur in crop plants and the application of that knowledge to increase yields and quality. Without chemical fertilizers and insecticides, even technically advanced countries could not feed their growing populations. Chemistry also assists in other branches of agricultural research. For example, modern methods of chemical analysis such as vapour-phase chromatography permit the analysis of very small samples which can be taken from seeds without affecting their viability. In this way, plant breeding experiments can be greatly accelerated.

### **I.6 Chemistry and Geology**

The earliest chemical research was largely concerned with inorganic analysis, particularly of naturally occurring minerals. Later, phase equilibrium studies, based largely on chemical principles and techniques, were used to study the synthesis of, and relations between, minerals. These studies still continue and they are greatly aided by physical methods such as x-ray diffraction. More recently new analytical methods which permit the detection and estimation of small traces of the chemical elements have been put to good use both in the finding and classification of geologic structures. In this way the separate subdiscipline of geochemistry has been developed.

### **I.7 Chemistry and Industry**

The chemist, and later the chemical engineer, have always been closely associated with industry. For many years physics made its main contribution to industry through engineering; consequently, at that time much of the physics of a laboratory nature was introduced to industry by chemists. With the advent of electronic and similar industries, this situation has changed and physicists are entering industry in much larger numbers.

In discussing chemistry in industry, a distinction should be made between the "chemical and chemical products" industry and the "chemical-processing" industry. The chemicals of the former group are synthesized or extracted from materials which usually bear little resemblance to the final products, while in the chemical-processing industry chemical methods and techniques are commonly used to modify the properties of a natural raw material to make this more useful.

Using the Dominion Bureau of Statistics classification of industry for R. and D. purposes,<sup>2</sup> the chemical and chemical products industry would be

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<sup>2</sup> D.B.S. 13-527 "Industrial Research and Development Expenditures in Canada (1965)".

represented by the classifications "Drugs and Medicines" and "Other Chemical Products"; the chemical-processing industries might include such classifications as "Foods and Beverages", "Rubber", "Textiles", "Paper", "Non-metallic Mineral Products", and "Petroleum Products".

On this basis the preliminary intramural R. and D. current expenditures for 1966, as reported by D.B.S., for the chemical and chemical products and the chemical-process industries would be \$33.2 millions and \$46.4 millions, or 14.3% and 20.0% respectively of such expenditures for all manufacturing industries. Together they account for 34.4% of such expenditures by all manufacturing industries.

In addition, mining and other industries not considered chemical in nature make current intramural R. and D. expenditures which D.B.S. classifies as being chemical or chemical engineering in nature, and these amounted in 1965 to \$6.6 millions.

The primary metal industries are usually classified as metallurgical rather than chemical processing. Their corresponding R. and D. expenditures in 1966 were \$14.4 millions or 6.2% of the total R. and D. for all manufacturing industries, while mining and other industries accounted for another \$8.2 millions of such expenditures of a metallurgical character in 1965.

It will be evident that chemistry and associated disciplines are widely diffused in industry and account for a substantial proportion of all intramural R. and D. current expenditures by industry of all kinds—roughly 45%.

## **I.8 Chemistry and Society**

Because of the spectacular accomplishments of physics, it is customary to call this the atomic age and to discuss the tremendous problems that these discoveries present to society. Chemistry has also had a very large impact on society.

The contribution of chemistry to science, i.e., to man's understanding of his physical self and his physical environment, has released him from his former complete dependence on naturally occurring materials, and contributed in large measure to his food, clothing, shelter, and health.

The advance of chemical knowledge, particularly in the last hundred years, has also been one of man's most stimulating intellectual experiences. Organic chemists in particular have, by purely chemical methods, arrived at structural molecular formulas that have enabled them to classify a very large number of compounds. Modern physical methods have refined these structures materially but have also largely confirmed the ideas developed by organic chemists.

If present trends continue, particularly in biochemical research on genetic codes and similar subjects, chemists will probably confront society with problems similar to those which were presented by advances in physics. The knowledge of, and the power to control these can either greatly benefit or endanger society, depending on how they are used.

On a more everyday plane, chemistry is involved in the many pollution problems which face society. Over many millenia, man has become adapted

to a particular environment and sudden changes to this relationship may have serious consequences. Concern has even been expressed over the possible effects of a diminution in the oxygen content of the atmosphere owing to the large-scale combustion of fossil fuels. Pollution of air, water, food, etc. may be caused by chemical effluents, insecticides, and other chemicals. Here chemistry may present problems, but at the same time it may provide the analytical and other techniques necessary for their solution. One Canadian effort in this field which invites favourable comment is the industry-sponsored air and water pollution control system set up by the chemical-processing industries in the Sarnia area. There, a considerable growth in chemical industry has been accompanied by an overall decline in air and water pollution rather than an increase.

## **Chapter II**

### **ORGANIZATION OF STUDY**

#### **II.1 Origin and Terms of Reference**

This study was initiated by a contract between the Science Secretariat of the Privy Council Office and The Chemical Institute of Canada (C.I.C.).

The terms of reference of the contract, which are reproduced in Appendix II, called for a report on "chemistry research" in Canada from the standpoint of both research and development, and manpower. The former was to be based on a comprehensive survey to be made by the Institute, and the latter on the manpower survey to be carried out by the federal Department of Manpower and Immigration.

"Chemistry research" was given a wide definition in respect to subject matter and this was further amplified in later discussions with the Secretariat. Some overlap between the various surveys being commissioned was to be preferred to the possibility of leaving gaps between the various studies, particularly if the common area could be identified. All research of a basic, applied, or developmental character was to be covered, wherever it could be found in Canada.

#### **II.2 Boundaries and Subdivisions**

Early in the course of the study certain decisions had to be made as to the extent and boundaries of the study, so that the subject areas could be classified for the statistical survey and for the committees which were to make special studies of particular fields of research.

It will be apparent from the discussion in Chapter I on the nature of chemistry and its close relationship with other disciplines, that any decision on classification would be a matter of somewhat subjective judgments. In consultation with the Secretariat staff, it was decided to base both the limits of the study and its subdivisions mainly on the National Science Foundation (N.S.F.) Specialty Classification (1966), but to use the code numbers already adopted for the Manpower and Immigration survey, and to give some of the major divisions code numbers used by the National Research Council of Canada.

The reasons favouring the adoption of what was essentially an N.S.F. classification were: it was being used by the M. and I. manpower survey; it was in extensive use for United States studies, with which comparisons might be required; and it had a certain amount of international acceptance, particularly by the Organisation of Economic Co-operation and Development (O.E.C.D.). However, it was realized at the time that it had several short-



comings, particularly for a detailed study of this kind. For example, a number of the categories were not mutually exclusive and lacked a systematic basis, particularly in the field of inorganic chemistry.

In addition the classification requirements of a Manpower and an R. and D. survey are different. Manpower is more transferable between categories than is information. For example, a chemist doing research on lime could transfer to research on gypsum without much trouble, but research information on lime might have little, if any, application to gypsum. It is one of the underlying difficulties of such R. and D. surveys that to secure the required specificity, a large number of categories would be necessary, but if this were done it would be difficult to define them in a mutually exclusive way. They would therefore meet with resistance from respondents, particularly in industry, where research is necessarily highly competitive. However, on the whole, a certain amount of ambiguity had to be tolerated in some areas although the classification was found to be a useful one.

The complete classification is reproduced in Appendix V. In this system the whole of the study subject matter is broken down into major field, committee, C.I.C. R. and D. area, and M. and I. specialties.

The breadth of this study is emphasized by reference to the above classification list. A stricter definition of "chemistry research" might have excluded metallurgy, agriculture and food chemistry, biochemistry, earth sciences and related fields, and even chemical engineering.

In this connection, particular reference should be made to biochemistry and metallurgy. Almost all the departments of biochemistry in Canadian universities are part of the medical faculties, and were at the same time in the process of being surveyed by the Medical Research Council. The latter body co-operated with the committee on biochemistry, and furnished most of the data on which the committee's report was based. Reciprocally, in the C.I.C. statistical survey, the data on biochemistry were kept separate so that information could be supplied to the biology study of the Science Council, particularly on biochemistry R. and D. in industry.

In the case of metallurgy, an effort was made initially to confine the study to the chemical aspects of the subject. However, this proved to be impractical from a questionnaire point of view, because, of two companies doing approximately the same kind of R. and D., one might consider that none of its research came within the scope of our study, while the other would report all of it. Consequently, the companies were asked to include all metallurgical research and development up to, but not including, metals-fabrication. Even so, it is believed that some metallurgical R. and D. under this broader definition was still not reported.

### **II.3 Study Structure**

The study of Chemistry R. and D., as broadly defined in the previous section, was carried out largely by twenty committees appointed for the purpose, and through a statistical survey based on questionnaires.

### *Committees*

The twenty committee chairmen appointed by the Steering Committee were asked to select their own members; a complete list of the latter is given in Appendix IV. Short summaries of committee reports appear in Chapter IV, and the full reports have been filed with the Science Council, together with historical material, briefs, and appendices which it was necessary to omit for the sake of brevity.

The methods employed were at the discretion of the committee chairmen, and varied partly according to the field covered. They included, to varying degrees: questionnaire surveys, visits, hearings, and solicited comments.

### *Statistical Survey*

Questionnaires were printed in English and French and were distributed to government departments, industrial companies, provincial research councils and foundations, and university departments and non-profit institutes. For the purpose of surveying industry, provincial research councils and foundations (whose R. and D. is essentially industrial) were included with industrial companies but could be totalled separately.

A reporting unit questionnaire for use at an administrative level and project(s) questionnaires were developed for distribution to government departments. These questionnaires requested the reporting of information on a project basis, by using the M. and I. (N.S.F.) categories described above, of which there are 193 in all. It was hoped that the same questionnaires could also be used for industrial companies and university departments. However, discussion with representatives of the Canadian Chemical Producers' Association (C.C.P.A.) showed that two questionnaires and a detailed classification of projects would be unacceptable because of the risk of disclosure of confidential data. A single company questionnaire was therefore developed, based on only 32 categories labelled "C.I.C. R. and D. Areas" and defined by the M. and I. (N.S.F.) categories. A single questionnaire based on these same 32 areas was also developed for university departments and institutes.

The distribution of the government and industry questionnaires, and the receipt of the replies for transmittal to The Chemical Institute of Canada, were undertaken by the Scientific Activities Survey Section of the Business Finance Division of the Dominion Bureau of Statistics, by using the mailing lists employed for its periodical surveys of R. and D. expenditures in these sectors. The university and institutes mailing list was compiled by The Chemical Institute of Canada from yearbooks and other sources, and the mailing and receipt of replies were handled directly by The Institute.

The scrutinizing of all replies was undertaken by a paid consultant (who also undertook the analysis of data), together with The Institute staff; and correspondence and discussion with respondents to clarify and amplify replies were carried on by the survey director and The Institute staff. By arrangement with C.C.P.A., the industrial returns were scrutinized by a small committee under a secrecy agreement provided by the Science Secretariat, and company

identification was removed after the coding of the returns and before their release to data processing.

In all, fifty-nine tables of data were produced from the processing of the returns, and these were distributed to the committees. Their titles are listed in Appendix VI.<sup>3</sup>

Unexpected delays were encountered in the processing of the data. For this reason, and because the committees tended in some instances to place a wider interpretation on the M. and I. (N.S.F.) categories than did the respondents, these tables proved to be less generally useful to the committees than had been hoped.

**Table 1.—Response to Survey Questionnaires**

	Fed. & Prov. Govts.	Companies & Prov. Councils & Foundations	Univ. & Inst.	Total	%
Total Mailings.....	36	440	202	678	
Replies Percentage to Total Mailings.....	69.4	79.8	76.8		78.3
Estimated Coverage <sup>a</sup> .....	95%	99%	88%		95%

<sup>a</sup> Percentage of actual total of Chemistry R. & D. expenditures in each sector, estimated to have been covered in questionnaires received.

The response to the survey is summarized in Table 1. It will be noted that the estimated percentage coverage achieved was much higher than the total response. The unusually high rate of response was ensured by extending the deadline for data processing to about four-and-a-half months from the time of the survey, during which time follow-up letters and telephone calls to larger respondents were found to be effective in securing replies.

Delay in response was attributed in many instances to the number of similar questionnaires which were being dealt with at the same time, and pressure of other business—particularly in universities at the beginning of the academic year.

The most serious shortfall was in the universities and non-profit institutes. Later, an adjustment was made for this on the basis of size, e.g., by taking the number of graduate students, etc. working on projects coming within the survey boundaries, and comparing this with R. and D. reporting by similar institutions.

<sup>3</sup> Plans were made for using the manpower data from the M. and I. manpower survey in order to meet the terms of reference regarding manpower, and to provide an approximate check on some of the data obtained from the C.I.C. survey. However, the M. and I. data were not available in time for these tasks to be accomplished.

### *Hearings, Briefs, and Comments*

An invitation was made to C.I.C. members wishing to present briefs to a meeting of the Steering Committee on June 8, 1967, and this produced one submission. The latter was in the form of a summary of a more detailed brief, "A Canadian Policy for Research and Development" which had been submitted by The Engineering Institute of Canada to the Minister of Industry in January, 1967. It calls for a strengthening of chemical engineering technology by giving priority of support to engineering schools, and the gradual transfer of tax-supported research from government agencies to industry.

A second brief has been received from the Canadian Ceramic Society urging more R. and D. in glass and other ceramics.

Both of these briefs have been filed with the Science Council.

Company and government questionnaires provided an opportunity to comment on R. and D. in Canada, and the responses are discussed in Chapter V.

### **II.4 Definitions**

In general, D.B.S. definitions, form, and nomenclature were used. These specified that all overhead charges and costs of supporting services should be included in current expenditures, but not capital depreciation costs or capital consumption allowances.

Of particular interest were the definitions of the different characters of research as follows:

*Basic Research, Applied Research, and Development.* Research is the process by which new understanding and new concepts are evolved. *Basic research* is research undertaken primarily for the advancement of scientific knowledge, without a specific practical aim in view. ("Oriented" basic research, which is research required in some area to permit further technological or scientific advances, is also included as basic research.) *Applied research* is the same, but with a specific practical application in view. *Development* is the use of the results of scientific research in order to improve existing materials, devices, products, or processes, or to produce new ones.

It will be noted that the definition of "development" is broader than current usage would indicate since laboratory experimentation would be included, although the word "development" usually implies activity on a semi-commercial or commercial scale.

An effort was made to restrict the survey to genuine R. and D., and to consider the objective of the work as the governing factor, rather than the means employed. For example, routine analytical work would not be reported as R. and D. unless it was part of the cost of an R. and D. project having an objective directly related to one of the fields listed above. On the other hand, the evaluation of development or new analytical methods would be considered as R. and D. in analytical chemistry.

Each organization reporting was asked to distribute its R. and D. in accordance with the M. and I. (N.S.F.) categories listed in Appendix V or, in the case of the companies, and universities and institutes, to distribute its R. and D. among 32 groupings of these categories called C.I.C. R. and D. areas.

The C.I.C. survey was restricted to intramural R. and D., or work done within the reporting organization.

Otherwise D.B.S. definitions and practices were followed.

## Chapter III

### STATISTICAL SURVEY

The discussion in this chapter is based largely on the tables of data compiled from the C.I.C. statistical survey of R. and D. in government, industry, and universities and institutes.<sup>4</sup>

Unless otherwise indicated in the text, minor differences between the totals in the tables in Chapter III and the data tables in the Statistical Survey section filed with the Science Council are due to rounding, and (or) the inclusion of late returns.

#### III.1 Distribution of R. and D. Expenditures

##### *A. Performing Sectors and Sources of Funds*

###### *Operating Expenditures*

The distribution found for the total Chemistry R. and D. operating expenditures for the year 1966 (or fiscal, academic 1966-67) between the different performing agencies, and the sources of funds, are shown in Table 2. Industry was the largest performer and source of funds, accounting for about two-thirds of the total expenditures and financing 92% of this with its own funds. Part of the latter expense would be offset by tax and other allowances (but to an extent which was not reported). The federal government, and universities and institutes' expenditures, were approximately equal, if the university total is adjusted for the estimated non-response. Universities and institutes together received approximately the same total amount of funds from the federal government as they contributed from their own funds.

Some two-thirds of all federal expenditures on Chemistry R. and D. was allocated to federal government departments' own intramural research (again disregarding tax allowances and other industrial research incentive allowances).

As in all such surveys as this, there is a considerable variation in the interpretation of the questions and in the completeness of the replies. From a comparison of expenditures and R. and D. technical manpower (Tables 2 and 13), it may be concluded that industrial companies have reported their R. and D. costs more completely than have government departments and universities (Table 3).

It will be noted that the cost per professional was reasonably comparable as between industrial companies and the federal government. However,

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<sup>4</sup> These tables have been filed separately with the Science Council, and their titles are listed in Appendix No. VI. Copies may be obtained from the Science Council.

**Table 2.—Chemistry Intramural R. and D. Operating Expenditures by Sources of Funds  
and by Performing Sectors (1966 or 1966-67)**

Source of Funds	Performed By:					Totals	%
	Fed. Govt.	Provincial		Companies	Univ. & Inst.		
		Govts.	Councils & Foundations				
	\$'000	\$'000	\$'000	\$'000	\$'000	\$'000	
Federal Government.....	24 507		250	4 270	8 722 <sup>a</sup>	37 749	27.4
Provincial Governments.....		211	1 899	7	990	3 107	2.3
Provincial Councils and Foundations.....			235			235	0.2
Companies.....				80 189	837	81 026	58.8
Universities and Institutes.....					8 713	8 713	6.3
Other.....	16		1 177 <sup>b</sup>	3 480	2 171 <sup>c</sup>	6 844	5.0
Totals.....	24 523	211	3 561	87 946	21 433 <sup>d</sup>	137 674	100.0
Percentages.....	17.8	0.2	2.6	63.8	15.6	100.0	

Sources of data: Statistical Survey Report, Tables 3, 25P, 25, and 36, with slight (+0.1%) adjustment for late returns.

<sup>a</sup> Including National Research Council; Medical Research Council and Defence Research Board.

<sup>b</sup> Mostly Industrial contracts.

<sup>c</sup> Including 729 from U.S. agencies.

<sup>d</sup> \$24 331 when adjusted for estimated non-response.

**Table 3.—Chemistry R. and D. Operating Expenditures Per Man-Year, or Full-Time-Equivalent by Performing Sectors (1966 or 1966-67)**

Operating Expenditures	Performed By:				Totals
	Fed. Govt.	Prov. Govts., Councils & Foundations	Companies	Univ. & Inst.	
	\$	\$	\$	\$	\$
Per Professional.....	30 050	25 840	32 750	25 880 <sup>a</sup> 9 510 <sup>b</sup>	30 760
Per R. and D. Worker, Including Technicians.....	15 100	13 190	16 020	7 860 <sup>c</sup>	13 570

Sources of data: Tables 2 and 13, this report.

<sup>a</sup> Based on Full-Time-Equivalents, academic staff plus postdoctoral fellows.

<sup>b</sup> F.T.E., including academics, postdoctoral fellows, and graduate students.

<sup>c</sup> As in (b), but including technicians.

allowance must be made here for a certain amount of compensation of errors; for example, industrial R. and D. respondents were generally better informed on their indirect costs than were some government departments, while, on the other hand, there were, for the latter, examples of large capital expenditures being written off in operating expenditures in a short period of time.

Two reasons are suggested for the low cost per worker in the case of universities. One is the lower cost to the university of graduate students, compared with that of recent graduates to industry and government. In the above calculations, the operating cost in universities is given on three bases: (a) professionals considered as academic staff plus postdoctoral fellows; (b) including graduate students, and (c) including technicians. A better correlation is obtained if graduate students are excluded, and the remaining deficit of cost per professional compared with government and industry is attributed to the fact that universities frequently lack information on, and therefore exclude from their reported operating expenses, indirect and other costs which are normally budgeted by central administration.

In this connection, if the cost factors given in the 1965 report of the Canadian Association of Graduate Schools are applied to 1966-67 for the personnel in Table 13, good agreement is obtained with the operating and capital expenditures shown in Tables 2 and 4.

An alternative means of checking the degree of completeness of the survey is available in the industrial sector.

The Dominion Bureau of Statistics surveys industrial R. and D. expenditures biennially. The D.B.S. report No. 13-527 reports a total current R. and D. Chemistry expenditure of \$93 940 thousands in 1966, for a group of



industries corresponding to those surveyed in this study<sup>5</sup> in which the operating expenditures for Chemistry R. and D. totalled \$87 946 thousands.

An alternative comparison may be made by totalling the expenditures by discipline from the two surveys. The total of chemistry, chemical engineering, earth sciences, metallurgy, agricultural science, biological science, and pharmacy reported in the D.B.S. report for the latest available year, 1965, was \$88 314 thousands. Pro-rated on the rates of 1965/1966 R. and D. expenditures for all manufacturing, this becomes \$93 055 thousands.

It appears, therefore, that there is a reasonable confirmation by two methods, of the completeness of the total operating expenditures on industrial Chemistry R. and D., as defined for the purpose of this survey.

### *Capital Expenditures*

Capital expenditures on Chemistry R. and D. for the year 1966 (or fiscal 1966/67) are shown in Table 4. It will be seen from the percentages of total capital expenditures by performing agency, that these followed a similar pattern to the percentage distribution of operating expenditures in Table 2, and that funds originate to the extent of over 85% from industry and the federal government.

It should be noted, however, that in the case of universities, building structures are largely provided by the appropriate provincial governments, and are not included in the capital expenditures reported. Similarly, universities rely largely on federal government support for the funds to purchase major items of equipment, rather than on their own funds.

In respect to those contributions to university funds from industry, which were reported as being specifically ear-marked for Chemistry R. and D., the proportion used for capital expenditures was very low compared with the income from industry which was allocated to operating expenses.

Reported government estimates of capital outlay may also not, in all cases, include the cost of structures needed for Chemistry R. and D.

### *Operating Plus Capital Expenditures*

The total outlay for Chemistry R. and D. in Canada in 1966 (or 1966/67) was estimated by respondents in all categories to total \$181 623 thousands (see Table 5). Based on the above discussions, and as noted in Table 1, an overall estimate is that this survey picked up operating and capital expenditures of the order of 95% of the true aggregate R. and D. outlay in that year.

Sources of funds, and total expenditures, were divided by percentages as indicated in Table 6.

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<sup>5</sup> Foods and beverages; rubber; textiles; pulp and paper; primary metals, non-metallic mineral products; drugs and medicines; and "other chemicals".

**Table 4.—Chemistry Intramural R. and D. Capital Expenditures by Sources of Funds  
and by Performing Sectors (1966 or 1966-67)**

Source of Funds	Performed By:					Totals	%
	Fed. Govt.	Provincial		Companies	Univ. & Inst.		
		Govts.	Councils & Foundations				
	\$'000	\$'000	\$'000	\$'000	\$'000	\$'000	
Federal Government.....	7 304		10	934	2 371 <sup>a</sup>	10 619	24.2
Provincial Governments.....		32	111	13	365	521	1.2
Provincial Councils and Foundations.....			102			102	0.2
Companies.....				30 340	38	30 378	69.1
Universities and Institutes.....					1 465	1 465	3.3
Other.....	35		470	43	316 <sup>b</sup>	864	2.0
Totals.....	7 339	32	693	31 330	4 555	43 949	100.0
Percentages.....	16.7	0	1.6	71.3	10.4		100.0

Sources of data: Statistical Survey Report, Tables 3, 25, 25P, 36, with slight adjustments for late returns.

<sup>a</sup> Including National Research Council; Medical Research Council and Defence Research Board.

<sup>b</sup> Including 15 from U.S. agencies.

**Table 5.—Chemistry Intramural R. and D. Operating Plus Capital Expenditures by Sources of Funds and by Performing Sectors (1966 or 1966-67)**

Source of Funds	Performed By:					Totals	%
	Fed. Govt.	Provincial		Companies	Univ. & Inst.		
		Govts.	Councils & Foundations				
	\$'000	\$'000	\$'000	\$'000	\$'000	\$'000	
Federal Government. ....	31 811		260	5 204	11 093 <sup>a</sup>	48 368	26.6
Provincial Governments. ....		243	2 010	20	1 355	3 628	2.0
Provincial Councils and Foundations. ....			337			337	0.2
Companies. ....				110 529	875	111 404	61.3
Universities and Institutes. ....					10 178	10 178	5.6
Other. ....	51		1 647	3 523 <sup>b</sup>	2 487	7 708	4.3
Totals. ....	31 862	243	4 254	119 276	25 988	181 623	100.0
Percentages. ....	17.5	0.1	2.4	65.7	14.3		100.0

Sources of data: Tables 2 and 4.

<sup>a</sup> Including National Research Council; Medical Research Council and Defence Research Board.

<sup>b</sup> Including 744 from U.S. agencies.

**Table 6.—Percentage Chemistry Intramural R. and D. Expenditures,  
Operating Plus Capital, by Sources of Funds and Performing Sectors  
(1966 or 1966-67)**

	Percentage Capital Plus Operating Funds	
	Supplied By	Expended By
Federal Government.....	26.6	17.5
Provincial Governments.....	2.0	0.1
Provincial Councils & Foundations.....	0.2	2.4
Companies.....	61.3	65.7
Universities & Institutes.....	5.6	14.3
Other.....	4.3	—
Total.....	100.0	100.0

Sources of data: Tables 4 and 5, this report.

#### *B. By Character and Area of R. and D.*

##### *Character of R. and D.*

Table 7 shows the 1966 (or 1966/67) distribution of Chemistry R. and D. operating expenditures between basic and applied research and development. It will be seen that basic research accounted for nearly one-quarter of the total, while applied research and development shared the balance roughly in equal proportions.

The federal government and industry each spent about half as much on basic research as did the universities and institutes, but the percentages of total expenditures devoted to basic research in these sectors were respectively 33.5%, 9.1%, and 81.6%.

Applied research claimed approximately the same proportion of operating R. and D. expenditures in both federal government and industry (40.2% and 44.4% respectively), but a below-average (14.2%) level in universities.

The proportion of reported development expenditures was, as is to be expected, highest in industry, intermediate in federal government, and quite low in universities (46.5%, 26.3%, and 4.2% of their operating R. and D. costs, respectively).

While provincial governments' R. and D. expenditures (exclusive of research councils and foundations) were relatively small in amount they were divided largely between applied research and development, in similar proportions to industrial Chemistry R. and D.

##### *Areas of R. and D.*

In the statistical survey questionnaire, the respondents were asked to allocate their R. and D. expenditures by subject areas according to the C.I.C. classification (see Appendix V).

**Table 7.—Chemistry Intramural R. and D. Operating Expenditures by Character of R. and D.  
(Basic, Applied, and Development), by Performing Sectors (1966 or 1966-67)**

Character	Performed By:								Totals	%
	Fed. Govt.	%	Prov. Govts.	%	Industry*	%	Univ. & Inst.	%		
	\$'000		\$'000		\$'000		\$'000		\$'000	
Basic.....	8 218	33.5	18	8.6	8 299	9.1	17 000	81.6	33 535	24.5
Applied.....	9 860	40.2	76	36.2	40 621	44.4	2 955	14.2	53 512	39.0
Development.....	6 447	26.3	116	55.2	42 512	46.5	882	4.2	49 957	36.5
Totals.....	24 525	100.0	210	100.0	91 432	100.0	20 837	100.0	137 004	100.0

Sources of data: Statistical Survey Report, Tables 11a, 26, and 39.  
\* Including Provincial Research Councils and Foundations.

The results are shown in Table 8 for each sector surveyed (federal and provincial governments; industry, including research councils and foundations; and universities and institutes) by C.I.C. R. and D. classification areas.

Two comments must be made on the figures shown.

1. It is suspected, that in areas such as "Chemical Engineering" and "General Analytical Techniques" expenditures may have been reported which were actually spent in support of research objectives in other areas, rather than on research and development in chemical engineering and analytical techniques.
2. The total expenditures by reporting sector, given by the addition of expenditures reported by area, do not agree exactly with those reported in Table 2. The differences are insignificant and can be accounted for by rounding in the case of federal government and industrial results, but the difference is substantial in the case of universities, amounting to nearly 3%. The latter discrepancy results from differences in universities' and institutes' returns between funds received and expended. These differences were numerous and mostly small, and were presumably due to unexpended balances and deficits, the former outweighing the latter.

However, the overall agreement within 0.5% for all sectors is considered satisfactory since it is well below the margin or error of 5% which is estimated for non-response.

**1966 (1966/67) Chemistry R. and D. Operating Expenditures**  
**Table 2 Compared with Table 7**  
**\$'000**

	Fed. Govt.	Prov. Govts.	Industry	Univ. & Inst.	Total
Table 2.....	24 523	211	91 507	21 433	137 674
Table 7.....	24 526	211	91 429	20 837	137 003
Difference.....	+3	0	-78	-597	-671

It will be noted, by reference to the totals on the right-hand side of Tables 8 and 9 that the Chemistry R. and D. effort expended on these subject areas varied widely in amount. Seventy-two percent of all expenditures was made in 10 out of a total of 32 areas. These were, in descending order of size: metallurgy; chemical engineering; elastomers, plastics, and resins; biochemistry; pulp and paper; agriculture and food; fuels, etc.; pharmaceuticals; and general analytical techniques.

Expenditures were notably low in the areas of theoretical chemistry, chemical oceanography, organometallics, dyestuffs, and chemical literature and information.

**Table 8.—Chemistry R. and D. Intramural Operating Expenditures by Area and Performing Sectors (1966 or 1966-67)**

R. and D. Area <sup>a</sup>	Performed By:				Totals
	Fed. Govt.	Prov. Govts.	Industry*	Univ. & Inst.	
	\$'000	\$'000	\$'000	\$'000	\$'000
Analytical Chemistry					
011 General Techniques.....	2 007	119	3 821	615	6 562
012 Spectroscopy.....	421	0	1 801	872	3 094
Inorganic Chemistry					
021 General Inorganic.....	993	0	2 652	642	4 287
022 Physical Inorganic.....	175	0	1 388	479	2 042
023 Theoretical Inorganic....	0	0	0	78	78
031 Metallurgy .....	3 288	0	18 580	1 068	22 936
Organic Chemistry					
041 General Organic.....	1 194	0	2 174	2 075	5 443
042 Physical Organic.....	113	0	420	844	1 377
051 Fuels, etc.....	2 393	0	4 823	11	7 227
052 Coatings & Detergents...	98	0	4 349	0	4 447
053 Dyestuffs.....	0	0	264	0	264
061 Pharmaceuticals.....	1 145	0	4 818	665	6 628
071 Elastomers, Plastics, & Resins .....	120	0	12 571	135	12 826
072 Organometallics.....	0	0	45	99	144
073 Fluorine, Phosphorus, Silicon, & Sulphur Organic Chemistry.....	0	0	324	222	546
081 Pulp & Paper.....	360	0	8 042	169	8 571
091 Textiles (inc. Leather)...	119	0	2 606	8	2 733
Physical Chemistry					
101 Chemical Kinetics.....	506	0	200	1 469	2 175
102 Catalysis.....	266	0	778	350	1 394
111 Thermodynamics & States of Matter.....	462	0	197	423	1 082
121 Nuclear & Radiation....	1 506	0	0	546	2 052
131 Electrochemistry, etc....	253	0	1 413	293	1 959
141 High Pressure & High Temperature.....	188	0	217	97	502
151 Crystal Structure & Theoretical.....	251	0	60	488	799
Agriculture & Food Chemistry					
161 Agriculture & Food.....	2 428	25	4 746	893	8 092
Biochemistry					
171 Biochemistry.....	2 510	0	1 786	6 129	10 425
Chemical Engineering					
181 Chemical Engineering....	2 754	20	12 323	1 305	16 402
Earth Sciences & Related Fields					
191 Chemical Oceanography..	10	0	0	57	67
192 Atmospheric Chemistry..	283	0	246	36	565
193 Geochemistry.....	438	47	323	589	1 397
194 Water Chemistry.....	245	0	256	179	680
Literature & Information					
201 Literature & Information.	0	0	206	1	207
Totals.....	24 526	211	91 429	20 837	137 003

Sources of data: Statistical Survey Report, Tables 13, 26, and 37.

<sup>a</sup> The first two digits of an area code number indicate the committee to which that area was assigned.

\*Including Provincial Research Councils and Foundations.

**Table 9.—Chemistry Intramural R. and D. Operating Expenditures by Major Subject Divisions  
and Performing Sectors (1966 or 1966-67)**

Major Division	Performed By:				Totals	%
	Fed. Govt.	Prov. Govts.	Industry*	Univ. & Inst.		
	\$'000	\$'000	\$'000	\$'000	\$'000	
Analytical Chemistry.....	2 428	119	5 622	1 487	9 656	7.0
Inorganic Chemistry.....	1 168	0	4 039	1 199	6 406	4.7
Metallurgy.....	3 288	0	18 580	1 068	22 936	16.7
Organic Chemistry.....	5 542	0	40 437	4 228	50 207	36.6
Physical Chemistry.....	3 432	0	2 866	3 666	9 963	7.3
Agriculture & Food Chemistry.....	2 428	25	4 746	893	8 092	5.9
Biochemistry.....	2 510	0	1 786	6 129	10 425	7.6
Chemical Engineering.....	2 754	20	12 323	1 305	16 402	12.0
Earth Sciences.....	976	47	824	861	2 708	2.0
Literature & Information.....	0	0	206	1	207	0.2
Totals.....	24 526	211	91 429	20 837	137 003	100.0

Sources of data: Statistical Survey Report, Tables 13, 26, and 37.

\*Including Provincial Research Councils and Foundations.



Referring to the relative R. and D. efforts in different areas by the reporting sectors, the following comments may be made.

1. In polymer chemistry (elastomers, plastics, and resins) and metallurgy, both government and university expenditures were low compared with the industrial outlay.

It might be expected that those areas in which industry was heavily committed would receive special attention from government and university laboratories. In the United States, an increase in interest by industry in a particular field of research is soon reflected in a growth of activity in that area by the other two sectors. For example, it was very evident that when the U.S. market for phosphates expanded rapidly, there was a renaissance in the chemistry of phosphates which extended to very theoretical investigations in government and university laboratories.

This situation may reflect a less active communication and interchange in Canada at the interfaces of industry, government, and the universities.

2. Pulp and paper and textiles Chemistry R. and D. is largely carried on by industry, and relatively little effort was reported in other sectors.
3. Biochemistry R. and D., on the other hand, was relatively small in industry, although the associated pharmaceutical research was strongly supported by industry.

Other comments on the relative R. and D. effort in different areas appear in the summaries of committee reports in Chapter IV.

#### *Government Orientation to Industry*

In the survey, government respondents were asked to indicate which projects and what R. and D. expenditures could reasonably be identified with a particular industrial category.

Of 578 R. and D. projects reported by federal and provincial governments, 490 or 85% could be so related. This number involved operating expenditures of \$19.9 millions or 80% of the total R. and D. funds. Details of the distribution of these expenditures are shown in Table 10, and it will be noted that, where identified to a specific industry, these were directed mainly to chemicals and chemical products; foods and beverages; primary metals, in that order. By far the largest grouping was "Other Industries", indicating an emphasis in government laboratories on work relating to smaller industrial groups.

### **III.2 Reported Need for more Personnel, Equipment, and Services**

Government and industry respondents were asked to report the incidence of problems which limited R. and D. effort during the reporting period. The specific factors on which comment was requested were personnel recruitment (directors, professionals, and technicians); availability of sophisticated equipment; and access to computer services. The results are tabulated in Tables 11A and B for industry and governments respectively.

**Table 10.—Federal Government Expenditures in Chemistry Intramural R. and D.  
Related to Main Divisions of Industry<sup>a</sup> (1966)**

Industry	\$'000
Mines, Quarries, & Oil Wells . . . . .	701
Foods & Beverages . . . . .	3 279
Tobacco . . . . .	—
Rubber . . . . .	—
Leather . . . . .	—
Textiles . . . . .	269
Knitting . . . . .	—
Clothing . . . . .	—
Wood . . . . .	440
Paper and Allied Industries . . . . .	35
Primary Metals . . . . .	1 559
Metal Fabricating . . . . .	690
Machinery . . . . .	15
Transportation Equipment . . . . .	35
Electrical Products . . . . .	382
Non-Metallic Mineral Products . . . . .	707
Petroleum and Coal . . . . .	546
Chemicals and Chemical Products . . . . .	3 424
Miscellaneous . . . . .	360
Construction . . . . .	—
Transportation and Other Utilities . . . . .	—
Service Industries . . . . .	79
Other Industry . . . . .	7 258
Total . . . . .	19 779 <sup>b</sup>
Not Related to Industrial Classification . . . . .	4 747
<b>Total . . . . .</b>	<b>24 526</b>

Sources of data: Statistical Survey Report, Table 12.

<sup>a</sup> D.B.S. classification.

<sup>b</sup> For 478 projects out of 556.

It will be seen that both government and industry respondents placed much greater emphasis on the need for professional personnel, technicians, and equipment than on research directors and computer services. Lack of sophisticated equipment was a problem only in the smaller units.

In addition to the above answers to direct questionnaire queries to government and industry respondents, references were also volunteered as to neglected areas of R. and D. and specific needs, both in the general comments accompanying questionnaires, and in committee reports. The incidence of these specific references by the different committees and sectors of respondents is summarized in Chapter V.

### III.3 Manpower

The manpower data provided by this survey are shown in Tables 12 and 13. The former tabulates the man-year effort of all scientists and engineers engaged in Chemistry R. and D. in Canada in the year 1966 (or 1966/67) by reporting sectors, other than universities and institutes; while the latter provides an analysis of all manpower by level of qualification or function, (A) other than universities and institutes and (B) universities and institutes.

Table 11.—Reported Need for more Personnel, Equipment and (or) Computer Service

## (A) By Industry\*

Area of Difficulty	Difficulty Reported By:		Chemistry R. & D. Expenditures Represented by All Respondents Reporting Difficulties		Percentage of Amounts In Expenditures Column Represented By:		
	No. of Respondents	% of Total Industry Respondents <sup>a</sup>	\$'000	% Total Industry R. & D. Expenditures <sup>b</sup>	Biochemistry	Chemical Engineering	Other Chemistry
Recruitment of:							
Directors.....	7	3.8	3 418	3.7	20.0	45.1	41.1
Other Professional Personnel.....	71	38.1	39 679	43.4	16.3	70.5	87.4
Technicians.....	49	26.3	30 906	33.8	5.4	56.6	88.0
Procurement of:							
Sophisticated Equipment.....	42	22.6	8 841	9.7	0.3	53.7	92.5
Computer Services.....	7	3.8	3 026	3.3	—	72.4	98.2

Sources of data: Statistical Survey Report, Tables 30A and 30B.

\* Including Provincial Research Councils and Foundations.

<sup>a</sup> 186 total questionnaires received.<sup>b</sup> \$91 432 thousands total industry expenditures reported.

NOTE: Percentages do not necessarily add laterally or vertically to 100, since any one figure could be as high as 100 per cent.

**Table 11.—Reported Need for more Personnel, Equipment and (or) Computer Service  
(B) By Government Reporting Units**

Area of Difficulty	Difficulty Reported By:		Chemistry R. & D. Expenditures of Units Reporting Difficulties	
	No. of Respondents	% of Total Respondents <sup>a</sup>	\$'000	Government R. & D. Expenditures, % Total
Recruitment of:				
Directors.....	10 <sup>a</sup>	4.5	922 <sup>a</sup>	3.7
Professional Personnel.....	69 <sup>a</sup>	30.8	10 446 <sup>a</sup>	42.2
Technicians.....	38 <sup>a</sup>	17.0	4 523 <sup>a</sup>	18.3
Procurement of:				
Sophisticated Equipment.....	14 <sup>b</sup>	25.9	5 744 <sup>b</sup>	23.2
Computer Services.....	1 <sup>b</sup>	1.9	80 <sup>b</sup>	0.3

Sources of data: Statistical Survey Report, Tables 2, 4, 6, 11, 17, and 18.

NOTE: Percentages do not sum to 100 since any one could be 100.

<sup>a</sup> Out of a total response of 224 project questionnaires and \$24 737 thousands expenditures.

<sup>b</sup> Out of a total response of 54 reporting unit questionnaires and \$24 734 thousands expenditures.

**Table 12.—Chemistry Intramural R. and D. Effort by Government and Industrial Scientists and Engineers in Man-Years (1966 or 1966-67)**

	Man-Years			
	Fed. Govt.	Prov. Govts.	Industry*	Totals
Chemists.....	410.1	4.6	1 412.0	1 826.7
Chemical Engineers.....	69.8	0.3	622.0	692.1
Biochemists.....	99.4	0.9	101.0	201.3
Metallurgists.....	90.3	0.0	189.0	279.3
Physicists.....	33.0	2.7	72.0	107.7
Mathematicians.....	2.5	0.0	24.0	26.5
Other Engineers.....	39.4	0.0	200.0	239.4
Other Scientists.....	97.9	4.0	202.0	303.9
Totals.....	842.4	12.5	2 822.0	3 676.9
Percentages.....	22.9%	0.3%	76.8%	100.0

Sources of data: Statistical Survey Report, Tables 14 and 27.

\* Including Provincial Research Councils and Foundations.

In the other than universities and institutes sector, over 3 600 man-years were reported for scientists and engineers engaged in Chemistry R. and D. in Canada in that year. Of these 49.8% were by chemists, 18.8% by chemical engineers, 5.5% by biochemists, and the balance of over 25% by metallurgists, physicists, mathematicians, and "other engineers and scientists". As is to be expected, the relative percentages of all professionals employed in the main other than universities and institutes sector compared closely with the relative operating expenditures (See Table 14).

Two notable disparities between the two main sectors were that government employed one-half of all biochemists, but only one-tenth of all chemical engineers reported to be engaged in Chemistry R. and D. (Table 12).

University/institute manpower effort (academics, postdoctoral fellows, and graduate students) stated as the full-time equivalent of time devoted to research, amounted to 2 253 man-years on Chemistry R. and D. In support of this were 474 man-years (F.T.E.) from technicians. The overall professional effort on Chemistry R. and D. in Canada was, therefore, 5 900 man-years in 1966, supported by 4 241 man-years by technicians, an overall total of 10 141 man-years.

### III.4 Forecasts

The survey questionnaire, which was mailed in mid-1967, requested actual 1966 (or 1966-67) expenditures, and a four-year forecast to 1970 (or 1970-71) in the case of governments and industry. For universities and institutes, the estimated actual expenditures for the 1966/67 academic year, and a five-year forecast to 1971/72, was requested. The results are tabulated in Tables 15, 16, and 17 for intramural operating, capital, and operating plus capital expenditures respectively.

**Table 13.—Number and Qualifications of Workers Reported in Intramural Chemistry R. and D.**

**(A) In Non-Universities or Institutes, Man-Years, 1966**

Level of Qualification	Performed By:				Total Non-University
	Fed. Govt.	Provincial		Companies	
		Govts.	Councils & Foundations		
Doctor.....	477	3	61	625	1 166
Master.....	114	4	32	410	560
Bachelor.....	225	2	44	1 650	1 921
Technician.....	820	28	114	2 805	3 767
Totals.....	1 636	37	251	5 490	7 414

**(B) In Universities and Institutes, in Full-Time Equivalents (1966-67)**

Level of Qualification	Performed By: Universities & Institutes	
	No.	F.T.E. <sup>a</sup>
Academics.....	1 042	536
Postdoctoral Fellows.....	378	292
Graduate Students.....	2 187	1 425
Technicians.....	598	474
Totals.....	4 205	2 727

Sources of data: Statistical Survey Report, Tables 14, 15, 27, 28, 27P, 28P, 38, and 44.

<sup>a</sup> Full-time equivalents, as estimated by department heads. It should be noted that "man-years" is a unit of employment; full-time equivalent, "F.T.E.", is a measure of work function, i.e., the 1042 academics employed in universities are considered to be equivalent to 536 working full-time on R. and D.

**Table 14.—Comparison of Percentage Professional Manpower and Chemistry R. and D. Operating Expenditures by Other than Universities and Institutes Performing Sectors**

Chemistry R. and D. Sector				
Percentage	Fed. Govt.	Prov. Govts.	Industry*	Total
Operating Expenditures.....	21.1	0.2	78.7	100.0
Employment, Professionals, Man/Year.....	22.9	0.4	76.7	100.0

Sources of data: Tables 2 and 12, this report.

\* Including Provincial Research Councils and Foundations.

**Table 15.—Chemistry R. and D. Actual (1966 or 1966-67) Operating Expenditures and Forecasts (to 1970 or 1971-72), by Performing Sectors**

Year	Performed By:				
	Fed. Govt.	Prov. Govts.	Industry*	Univ. & Inst.	Totals
	\$'000	\$'000	\$'000	\$'000	\$'000
1966 ('66-'67).....	24 523	211	91 507	21 433	137 674
1967 ('67-'68).....	27 242	206	102 868	25 248	155 564
1968 ('68-'69).....	30 926	240	105 563	29 780	166 509
1969 ('69-'70).....	33 518	271	112 643	35 325	181 757
1970 ('70-'71).....	37 469	289	120 175	39 772	197 705
('71-'72).....				(46 421)	
Forecast Totals (1967-'70 or '70-'71 inc.).....	129 155	1 006	441 249	130 125	701 535
Increase (1966-'70)...	52.8%	37.0%	31.3%	85.6%	43.6%
Increase (1966/67 to 1971/72).....				116.6%	

Sources of data: Statistical Survey Report, Tables 2, 24, and 43. Industry data adjusted for late returns (approximately +0.2%).

\*Including Provincial Research Councils and Foundations.

**Table 16.—Chemistry R. and D. Actual (1966 or 1966-67) Capital Expenditures and Forecasts (to 1970 or 1971-72), by Performing Sectors**

Year	Performed By:				
	Fed. Govt.	Prov. Govts.	Industry*	Univ. & Inst.	Totals
	\$'000	\$'000	\$'000	\$'000	\$'000
1966 ('66-'67).....	7 339	32	32 023	4 555	43 949
1967 ('67-'68).....	8 095	36	24 598	8 109	40 838
1968 ('68-'69).....	8 453	189	24 374	11 656	44 672
1969 ('69-'70).....	10 224	41	21 805	10 051	42 121
1970 ('70-'71).....	10 525	45	18 437	15 343	44 350
('71-'72).....				(11 330)	
Forecast Totals (1967-'70 or '70-'71 inc.).....	37 297	311	89 214	45 159	171 981

Sources of data: Statistical Survey Report, Tables 2, 24, and 43. Industry data adjusted for late returns (approximately +1.0%).

\* Including Provincial Research Councils and Foundations.

**Table 17.—Chemistry R. and D. Actual (1966 or 1966-67) Operating Plus Capital Expenditures and Forecasts (to 1970 or 1971-72), by Performing Sectors**

Year	Performed By:				
	Fed. Govt.	Prov. Govts.	Industry*	Univ. & Inst.	Totals
	\$'000	\$'000	\$'000	\$'000	\$'000
1966 ('66-'67).....	31 862	243	123 530	25 988	181 623
1967 ('67-'68).....	35 337	242	127 466	33 357	196 402
1968 ('68-'69).....	39 379	429	129 937	41 436	211 181
1969 ('69-'70).....	43 742	312	134 448	45 376	223 878
1970 ('70-'71).....	47 994	334	138 612	55 115	242 055
('71-'72).....				(57 751)	
Forecast Totals (1967-'70 or '70-'71 inc.).....	166 452	1 317	530 463	175 284	873 516

Sources of data: Tables 5, 15, and 16 of this report.

\* Including Provincial Research Councils and Foundations.

### *Operating Expenditures Forecast*

The total four-year forecast of \$701 535 thousands represents an average annual rate of increase in operating expenditures, in all sectors on Chemistry R. and D. of approximately 10%.

While the time-lapse since these forecasts were made reduces their value for such purposes as the forecasting of manpower requirements, their fairly uniform rate of progression in each sector may permit short-term projection of reasonable accuracy. Forecasting techniques used by various respondents will vary in respect to such factors as estimation of the degree of inflation applicable, and allowance for the impact of cut-backs owing to economic conditions.

The industrial forecast, averaging somewhat less than 8% per annum, is in line with the current rate of increase in the contribution which the same group of industries makes to the Gross National Product. The government forecasts preceded the recent freeze on federal agencies' staff, and is probably optimistic for the years 1969 and 1970. University and institute forecasts appear to be a more or less linear projection of the rate of university expansion in recent years, of nearly 20% per annum in overall growth in registration and expenses.

### *Capital Expenditures Forecast*

The annual rate of capital expenditures on Chemistry R. and D., forecast over the four-year period 1967-1970 inclusive, was in the range of \$40-44 million. However, unlike the forecast operating costs, which increased progressively in all sectors, new investment increases were predicted to fluctuate from year to year in the case of universities and actually to decline progressively in the industrial sector. In the latter group the forecast 1970 capital investment



was over 40% lower than the actual 1966 expenditure. Whether this truly reflects a tendency for investment to decline, in contrast to expansion in R. and D. operating expenditures, or an unwillingness of respondents to predict R. and D. capital projects so far ahead, in view of the current economic climate, is not known. However, it seems most probable that the latter is the chief influence, and the industry estimates must accordingly be considered as conservative.

#### *Operating Plus Capital Expenditures Forecast*

The overall expenditures, operating and capital, reported in this survey for the period 1967–1970 inclusive totalled \$873 516 thousands. For reasons stated in Chapter III.1A, the response to this survey, as summarized in Table 1, was estimated to have been equivalent to a weighted average coverage of 95% of the actual operating expenditures. On the assumption that a similar percentage of the capital expenditures was reported, the grand total of operating and capital funds actually expended and to be spent in the period 1967–1970 (or 1967/68–1971/72), from all sectors, was \$936.3 millions, compared with \$873.5 millions reported. It should be noted that this figure is probably still conservative because none of the forecasts takes into account agencies which had not yet engaged in R. and D. in 1967, but which may now have done so, or will do before the end of the year 1970 or 1971/72.

It is of interest as a measure of the proportion of Chemistry R. and D. expenditures which are expected to come from the various public and private sectors over a period of four years, to compare the four-year forecasts of operating, capital, and total expenditures for the different reporting sectors, as percentages of the total expenditures in each expenditure category.

**Table 18.—Percentages, by Performing Sectors, of Four-Year Total Forecast Chemistry R. and D. Expenditures**

Expenditures	Fed. Govt.	Prov. Govts.	Industry	Univ. & Inst.	Total
	%	%	%	%	%
Operating.....	18.4	0.1	62.9	18.6	100.0
Capital.....	21.7	0.2	51.8	26.3	100.0
Operating plus Capital.....	19.0	0.2	60.7	20.1	100.0

Sources of data: Tables 15, 16, and 17, this report.

#### *Manpower Forecast*

The respondents to this survey were not requested to forecast their manpower requirements, but the four-year forecasts of operating expenditures may be used to make a prediction of the rate of manpower increase in the various sectors and disciplines.

In Table 19, the actual numbers of graduates in chemistry, chemical engineering, biochemistry, and other sciences, employed in Chemistry R. and D. in 1966 (or 1966/67), are projected to 1970 (or 1970/71). The multiplier used for this purpose is the ratio of the respective operating expenditures times 1.12 to allow for attrition by retirement, etc. No allowance has been made for the incomplete coverage noted in Table 1, but this omission does not affect the comparison of rates of increase between the different sectors.

It will be noted that the overall increase in demand for all Chemistry R. and D. professionals in all sectors and disciplines is estimated to be 64.8%. The forecast gain in other than universities and institutes is 52.5% in the period 1966/1970, while for universities/institutes academic staff the gain is estimated to be 108.0% in the four-year period 1966/67–1970/71.

The increase in demand for Ph.D. staff is 56.3% in other than universities and institutes, while the academic staff expansion assumed to be all Ph.D.s is, as noted above, estimated to be 108.0%.

The desirability of any appropriate balance between government, industry, and university research output was discussed earlier in this report. In addition, the balance between the production and utilization of research personnel should be considered. Any acceleration of R. and D. expenditures would require an adequate supply of research personnel to be effective.

The university sector is a source of research manpower for all three sectors, the total new supply in any year being also determined by the net flow of such personnel into and out of the country. The data of Table 19 show that the potential output of research personnel by the universities could be considerably increased if the growth of the university sector were accelerated and the number of graduate students per academic increased materially above the present relatively low level of 2.2 graduate students per academic.

This question is discussed further in Chapter VI.2.

### **III.5 Respondents' General Comments**

At the request of the industrial companies, the company questionnaire provided an opportunity to comment on the R. and D. situation in Canada with respect to the chemical and associated industries. Out of 185 respondents, 58 companies submitted 152 comments, 65 discussing factors limiting R. and D. in Canada and 87 making recommendations. A full set of these comments was distributed to the study committees and another has been filed with the Science Council. A tabulation by subject matter is given in Chapter V.

On the questionnaire for university departments and research institutes, the respondents were asked to indicate areas of strength or weakness and to list those factors thought to be limiting R. and D. effort. Comments were received from 83 respondents, and these were distributed to the study committees for information and filed with the Science Council. They are discussed in Chapter V.

**Table 19.—Forecast to 1970 (or 1970-71) of Chemistry R. and D. Professional Staff by Sectors, Selected Disciplines, and Qualifications, Compared With 1966 (or 1966-67) Actual**

Disciplines and Sectors	1966 (or 1966/67) Actual <sup>a</sup>				Factor <sup>b</sup>	1970 (or 1970/71) Forecast <sup>c</sup>				Increase 1966/70	
	Doctors	Masters	Bachelors	Totals		Doctors	Masters	Bachelors	Totals	No.	%
<b>A. OTHER SECTORS THAN UNIV./INST.</b>											
Chemists											
In Governments.....	284	60	74	418	1.71	486	103	126	715	297	
In Industry.....	445	164	803	1 412	1.47	654	241	1 180	2 075	663	
Totals.....	729	224	877	1 830		1 140	344	1 306	2 790	960	52.5
Chemical Engineers											
In Governments.....	20	13	35	68	1.71	34	22	60	116	48	
In Industry.....	76	100	446	622	1.47	112	147	655	914	292	
Totals.....	96	113	481	690		146	169	715	1 030	340	49.3
Biochemists											
In Governments.....	68	13	20	101	1.71	116	22	34	172	71	
In Industry.....	42	14	45	101	1.47	62	20	66	148	47	
Totals.....	110	27	65	202		178	42	100	320	118	54.0
Other Disciplines											
In Governments.....	127	41	103	271	1.71	217	70	176	463	192	
In Industry.....	123	164	400	687	1.47	181	241	588	1 010	323	
Totals.....	250	205	503	958		398	311	764	1 473	515	53.7
TOTALS IN OTHER SECTORS THAN UNIV./INST.....	1 185	569	1 926	3 680		1 862	866	2 885	5 613	1 933	52.5
<b>B. UNIVERSITY STAFF</b>											
Academics.....	1 042			1 042	2.08	2 167			2 167	1 125	108.0
<b>C. TOTALS</b>											
All Professionals.....	2 227	569	1 926	4 722		4 029	866	2 885	7 780	3 058	64.8

Sources of data: Tables 5 and 27 (Statistical Survey data); and Tables 13B and 15 of this report.

<sup>a</sup>Man-years for non-university staff; actual number of academic staff in universities (assumed to be all doctors).

<sup>b</sup>Factor equals the ratio of 1970 forecast operating expenditures to 1966 actual, that ratio being then multiplied by 1.12 to allow for staff attrition by retirement, etc.

<sup>c</sup>Estimated from (a) and (b). No allowance is made for incomplete coverage in the survey (see Table 1).

**Table 20.—Comparison of R. and D. Expenditures Shown as Percentages of Value Added by Manufacture for Selected Industries, 1964, 1965, and 1966**

Selected Industries	Operating R. and D. Expenditures % Value Added by Manufacture <sup>a</sup>			Operating Plus Capital Expenditures % Value Added by Manufacture <sup>a</sup>		
	1964	1965	1966	1964	1965	1966
Food & Beverages.....	0.22	0.25	0.26	0.29	0.33	0.35
Rubber.....	0.92	1.00	1.09	1.10	1.20	1.16
Leather.....	—	—	—	—	—	—
Textiles.....	0.52	0.60	0.46	0.63	0.79	0.53
Paper.....	1.11	1.07	1.11	1.55	1.87	1.76
Primary Metals.....	1.14	1.15	1.04	1.53	1.44	1.53
Non-Metallic Minerals.....	0.37	0.31	0.33	0.39	0.33	0.46
Petroleum & Coal.....	3.02	4.41	5.66	6.36	8.57	7.79
Chemicals & Chemical Products.....	2.73	2.88	2.94	3.77	3.74	3.64
Totals for above Industries.....	1.02	1.09	1.11	1.47	1.62	1.51

Sources of data: R. and D.—D.B.S. Catalogue No. 13-527, Tables 1 and 3; Value Added—D.B.S. Preliminary Bulletin 6509-503, Tables 1 and 2 and preliminary releases for 1966.  
<sup>a</sup>This comparison is only approximate for some industries, since "value added" statistics are compiled on an *establishment* basis while R. and D. statistics are made up generally from *company* or *enterprise* units. In the case of a large petroleum enterprise, for example, the petrochemicals value added might be credited to Chemicals and Chemical Products, but the petrochemicals R. and D. be credited to Petroleum. Studies indicate that for other industries the discrepancy is relatively small.

## Chapter IV

### ABSTRACTS OF COMMITTEE REPORTS

The reports of the twenty committees represent the results of intensive and detailed studies of the areas assigned to them. The main reports have been filed with the Science Council and brief abstracts are presented in this section.<sup>6</sup> In some instances, the titles of the abstracts have been modified to agree more closely with the actual scope of the assignment covered and do not correspond exactly with the names of the appropriate committees, as listed in Appendix V. An effort was made to include all the recommendations referring to the field covered by each committee. Where a recommendation has a general connotation, a reference is made to the appropriate item number in "General Recommendations".

#### IV.1 Analytical Chemistry

Analytical chemistry is concerned with what substances (elements, compounds, isomers, etc.) are in a given specimen of material; and with their proportions. The activities of analytical chemistry include identification, measurement, separation, evaluation, the study of analytically useful reactions, and the development of analytical methods.

Research and development work in chemical analysis requires a variety of instruments for making physical measurements and for recording and processing their numerical output, and there has become available to the last generation of analytical chemists for this purpose an array of sophisticated instruments virtually undreamed of twenty-five years ago.

A study by the committee of the results of the statistical survey indicated that the level of effort tended to be exaggerated, since respondents found difficulty in distinguishing between analytical activities which constituted true R. and D. in analytical chemistry and those which merely supported other R. and D. having a different objective, e.g., the development of a nuclear power process.

However, it is clear from the survey that, although the supply of technologists appears to be adequate, research and development in analytical chemistry in Canada is currently handicapped by a shortage of personnel capable of exploiting modern instrumentation for analytical purposes. Therefore, Committee 1 recommends **that the training of qualified personnel in analytical chemistry be stimulated**. Increased emphasis should be given to this in both undergraduate curricula and postgraduate training. Short courses

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<sup>6</sup> Copies available at cost from the Science Council, 150 Kent Street, Ottawa, Ontario.

are needed to widen the knowledge of modern analytical developments among practising chemists.

Since standard samples are needed for developing new methods and evaluating known methods, Committee 1 recommends **that a Canadian Bureau of Standards for Chemistry and Physics be established.**

In common with committees dealing with other areas, Committee 1 recommends **that efforts be made to promote more co-operation between the university, industrial, and governmental laboratories.** (See "General Recommendations", number 2, p. xvii.)

## **IV.2 Inorganic Chemistry — Basic**

After nearly one hundred years of neglect, inorganic chemistry has undergone a renaissance. It is now a dynamic science in the academic sphere, is extensively practised in certain governmental and other official laboratories, and is being more widely employed in industry. Nevertheless, there are many phases in which an earnest endeavour is necessary if imbalance and neglect are to be corrected.

The most obvious need is to bridge the gap between academic and industrial research. The theoretical aspects of the subject are practised almost exclusively in universities and the practical aspects in industry. Official and government laboratories are not entirely successful in bridging the gap, but they lean necessarily towards the more practical and resource-based areas of research.

In the field of industrial inorganic chemistry it is particularly important to make a very real effort to take products to a more advanced stage of manufacture to achieve economic advantages. The funds necessary to support this effort might come directly from industry, for use in research by both industry itself and by the universities.

Areas of comparative neglect include the chemistry of glass and ceramics; solid state chemistry; inorganic electrochemistry (see also report of Committee 13); inorganic thermochemistry (see also report of Committee 14); and extreme high temperature plasmas.

As a result of its studies Committee 2 recommends **that an increased emphasis be placed on R. and D. in inorganic chemistry.** This could be accomplished by universities according the same priority and seniority to inorganic chemistry as is accorded other branches of chemistry; by establishing "centres-of-excellence" in specific fields; and by the National Research Council of Canada undertaking more research in inorganic chemistry.

To meet future needs, Committee 2 recommends **that the supply of qualified and supporting personnel be substantially increased.** Higher degrees should be awarded for research done in industry; industry should support more research in universities; university graduates should not be left with the impression that applied research in industry is intellectually inferior to academic research; and more technologists from Institutes of Technology and

Community Colleges should specialize in inorganic chemistry and be offered satisfying careers in industry.

Committee 2 also recommends **that there be more co-operation between the three sectors in an attack on Canadian problems.** University research should be oriented to a reasonable degree towards the Canadian context and concerned with Canadian resources. Industry should make wider use of academic personnel as consultants. (See "General Recommendations", number 2, p. xvii.)

### IV.3 Metallurgy

The field of metallurgy, as defined by Committee 3, includes all aspects of the art and science of extracting metals from their ores and adapting them to use. This sequence starts with the beneficiation of ores and extends to the preparation of metals for fabrication (but does not include fabrication itself).

Products of the metals industry, including metals in ores, concentrates, and simple shapes, accounted in 1965 for nearly 20% of the total dollar value of Canadian merchandise exports.

Committee 3 considers that a vigorous and aggressive program of metallurgical research in Canada is extremely important if this country is to retain and improve its position in world markets and ensure the optimum utilization of Canadian mineral resources.

In 1967 most of the large metallurgical enterprises in Canada had research departments which they considered to be adequate in size and competently staffed. The Canadian government, chiefly through the Mines Branch of the Department of Energy, Mines and Resources, provides laboratories which work on Canada's metallurgical problems and are prepared to assist where required. Most of the provincial research councils and foundations have metallurgical capabilities. Several Canadian universities have departments of metallurgy (or metallurgical engineering) which combine research with teaching.

The estimated operating expenditures on metallurgical R. and D. in Canada for the year 1965 were \$29 030 000 of which 81.6% was spent by industry, 11.3% by the federal government, 3.4% by provincial councils, and 3.7% by universities. The total R. and D. expenditure by the industry in Canada and abroad was equivalent to about 1% of sales of metals industry products. Out of 281 metallurgical engineers employed in industrial research in 1965, only 204 or 73% were employed by the metals industry. These 204 constituted only 36% of the total of 568 scientists and engineers employed in research by the metals industry. Moreover the number of metallurgical engineers currently graduating will hardly replace the loss due to normal attrition. To achieve the increase in research recommended below it would be necessary for the number graduating to be doubled; and for there to be a corresponding increase in the number of scientists and engineers recruited to metallurgy R. and D. from other disciplines.

On the basis of the information provided by the C.I.C. and other surveys; the comments received from informed people; and its own consideration of the

problems of metallurgical research in Canada, Committee 3 makes the following recommendations.

**1. The total effort on metallurgical research in Canada should be increased by about 50%, to not less than 1.5% of the sales value of metals industry products.** This could be done best by encouraging the growth of industrial research through appropriate measures, including the liberalization of the rules and regulations governing cost-sharing programs. (See "General Recommendations", number 3, p. xviii.) It is also considered to be essential that the number and capability of graduates in metallurgy from Canadian technical colleges and universities be markedly increased. It is believed this can be achieved by increased grants to universities; more liaison between universities and industry; attraction of more highschool graduates to metallurgical courses; the recruitment of more graduate students; and combined university and industry training in research management. Particular emphasis should be placed on research on mineral dressing and chemical metallurgy. Formation of research associations should be encouraged by the government.

**2. Metals research in government laboratories should be increased only as the metals industry grows.** Better communication between government and industrial laboratories should be established, and a formal advisory committee should be set up to this end. (See "General Recommendations", numbers 2 and 3, pp. xvii, xviii.)

**3. Metals research in universities should be directed more specifically to Canadian problems, and communication with industrial laboratories should be improved.** The formation of industrial advisory committees for universities, the greater use of university staff as consultants to industry, and the exchange of staffs between universities and industry are also suggested. The Canadian effort should be oriented towards applied research and development. (See "General Recommendations", numbers 2 and 3, pp. xvii, xviii.)

**4. Major projects grants to universities should be used to supplement and perhaps partially to replace the present grants to individuals.**

**5. The Science Secretariat and the Canadian Institute of Mining and Metallurgy should repeat this survey in 1969.** To this end, D.B.S. should be requested to secure more detailed statistical information than is available at present, with particular reference to the branches of chemical and physical metallurgy.

#### **IV.4 General Organic and Physical Organic Chemistry**

The unique character and importance of organic chemistry stem from the astonishing number of compounds that can be formed by the element carbon. In the past one hundred years, more than a million organic compounds have been prepared and their molecular structures determined, and today there are more organic chemists than chemists of any other kind.

General organic chemistry is concerned largely with synthesis and with structure elucidation. Physical organic chemistry, which has developed rapidly in the last thirty years, seeks an understanding of the precise way in which



molecules react and the forces that control the rates and routes of such reactions. Both have been influenced greatly by the rapid rise since World War II of instrumental analysis.

Committee 4 made a survey of publications in organic chemistry and also used data from N.R.C. and C.I.C. surveys.

According to C.I.C. Statistical Survey data, intramural Chemistry R. and D. operating expenditures in 1966 (or 1966/67) in general and physical organic chemistry amounted to \$6 820 thousands. If other areas which have an organic basis are included, the total rises to \$68 723 thousands out of a total for all areas of \$137 003 thousands. This illustrates the widespread influence of organic chemistry.

Organic chemistry is well developed in Canada and the work done, particularly in the universities and at N.R.C., is of a high standard. The amount of organic chemistry research done in the Canadian chemical industry is low, although some improvement has occurred recently. A considerably larger proportion of Canada's R. and D. in organic chemistry is done in government laboratories than is the case in the United Kingdom or the United States.

The distribution of activity according to subject area is similar to that reported for the United Kingdom, but is rather different from that of the United States, where less emphasis is placed on research on natural products and carbohydrates.

Committee 4 recommends **that organic chemistry research in industry in Canada should be expanded**. Industry should be encouraged to take greater advantage of N.R.C.'s research assistance program. Liaison between organic chemists in industry and universities should be improved by seminars, consulting work, and informal conferences. (See "General Recommendations", numbers 2 and 8, pp. xxii, xx.)

With regard to university research, Committee 4 recommends **that support continue to be based mainly on the scientific reputation of the principal investigator**. While this system is favoured over that based on project proposals, it is believed that greater efforts should be made to recognize and reward both exceptional performance and exceptional promise.

In view of the great and growing importance of sophisticated instrumentation in organic chemistry research, Committee 4 also recommends **that the feasibility of setting up instrumentation centres throughout the country be investigated**.

#### **IV.5 Fuels and Explosives; Coatings and Detergents; and Dyestuffs**

Committee 5 was asked to report on Coal; Petroleum, Petrochemicals, and Lubricants; Explosives; Protective Coatings; and Dyestuffs. Since the R. and D. situations in these four fields have little in common, essentially four reports were submitted.

##### *Coal*

Only *chemical* research and development work related to coal was included in the study. Excluded were exploration, geology, mining, economics, transportation, and most of beneficiation.

Chemical research and development on coal is almost exclusively carried on by government agencies in Canada, as it is in other countries. Committee 5 expects no great change in this respect in the next five years, although major oil companies are interested in securing coal reserves as potential sources of synthetic liquid fuel.

The government agencies are the Alberta Research Council, the Fuels Research Centre of the Department of Energy, Mines and Resources in Ottawa, and the Nova Scotia Research Foundation. Each agency is fully independent but broad co-ordination is achieved through the Canadian Advisory Committee on Coal Research.

R. and D. expenditures in this field are less than \$600 000 per annum, corresponding to less than 1% of the annual value of coal sales. Manpower comprised 21 professionals, 21 technicians, and 6 giving administrative support.

The Canadian Carbonization Research Association undertakes research on metallurgical uses of coal at the Fuels Research Centre.

Research in this field may well suffer a severe blow with the proposed dissolution of the Dominion Coal Board, since this body gave financial support to universities and provincial agencies and was empowered to secure cost estimates of specific metallurgical operations which might benefit coal.

Consequently, Committee 5 recommends **that if the Dominion Coal Board is discontinued, the Department of Energy, Mines and Resources assume those responsibilities and powers necessary to conduct the research and development functions formerly exercised by the Board.**

To maintain in Canada an acceptable level of coal expertise related to coal processing for the metallurgical industry, the Committee recommends **that a chair of fuel technology be endowed in the Chemical Engineering Department of the University of Alberta.**

It is essential if the present export market for coking coal to Japan is to be maintained and expanded, **that expert personnel and adequate equipment be maintained at the federal level.**

Since there is no training available in coal science in Canada, it is recommended **that seven training positions be set up at the Fuels Research Centre in Ottawa, and that new and more flexible financial arrangements be examined to enable the Centre to provide more effective training and increased technical aid to industry.**

#### *Petroleum, Petrochemicals, and Lubricants*

The chemical R. and D. activities in the field of petroleum in Canada are carried out mostly by companies owned by international oil companies. Oil companies in Canada are diversifying their interests into petrochemicals and metallurgy in an imaginative manner that deserves encouragement.

The combined current and capital expenditures for intramural research in the Petroleum and Coal Products<sup>7</sup> industry in 1965 were \$22 726 thousands;

<sup>7</sup> Mainly Petroleum Products.

\$17 919 thousands of which were from Canadian and \$4 807 thousands from foreign sources. Extramural R. and D. amounting to \$3 133 thousands was conducted, 66.3% by Canadian subsidiaries, 16.4% by provincial research councils, 6.9% by universities, and the remainder by other educational institutions and government. The dominant industrial emphasis was on application and development.

A total of 273 engineers and scientists was employed, the largest group being 165 chemical engineers and chemists. Current R. and D. expenditures per engineer-year were \$32 800 and per scientist-year \$50 000.

Relatively minor amounts of chemical R. and D. were conducted in government and university laboratories. Out of 600 grants from the American Petroleum Institute, Canadian universities received 17, totalling about \$136 thousands in value.

Petroleum was not the subject of study in any Canadian university and there is no organo-geochemistry taught in Canada. A better understanding of the genesis of oil might enable large areas of sedimentary rocks to be ruled out as prospects for oil discovery, thus avoiding drilling and exploration.

R. and D. on the *production* of petroleum is more advanced, the Petroleum Recovery Research Institute at the University of Calgary expending \$20 and \$90 thousands on operating and capital respectively in 1966.

Federal government petroleum R. and D. is largely carried out in the Mines Branch and the National Research Council. Included are research on the physical and chemical structure of petroleum; some limited organo-geochemical research; and research on hydrogenation, combustion, and the performance characteristics of fuels and lubricants.

In 1966 operating expenditures in this field were estimated at \$400 thousands, or approximately 2% of all federal Chemistry R. and D. expenditures. Forty-one man-years of scientific and other technical labour were involved.

Despite its importance, there is very limited activity in Canada in fundamental research (at N.R.C. and at the University of British Columbia) on the subject of lubrication.

The Committee recommends **that a favourable economic climate be provided, to encourage industry in its search for new products and processes.** Taxation regulations which permit the rapid write-off of losses are believed to be the most equitable method of assisting industry, whether large or small. The present incentive schemes should be continued.

In view of the need for more fundamental research on petroleum, the Committee recommends **that a collective attempt be made by the Canadian petroleum industry to have the grants to Canadian universities increased from the American Petroleum Institute, in the fields of secondary recovery, chemical engineering, and organo-geochemistry.**

The Committee recommends **a closer association between federal government petroleum research and industry.** Students of technical institutes and universities might receive training in government laboratories during the summer.

In view of the urgency of air pollution studies, the Committee recommends **that funds be set aside for postgraduate training in combustion at the Fuels Research Centre.**

In view of the growing importance of lubrication, **means should be developed for graduating 10 to 12 engineers a year from courses oriented towards lubrication engineering.**

### *Explosives*

The production of explosives in 1966 had an estimated retail value of \$40 millions but no estimate is possible of the cost of Chemistry R. and D. in this field.

Industry adopts a multi-disciplinary approach to explosives research and development and a rough estimate of the total manpower involved is 75 bachelors and 40 scientists with higher degrees. Formal training in the field is not available at any Canadian university.

The principal problem is the lack of both communication and facilities.

The Committee recommends **that an effort be made to secure a high-speed framing camera and operating staff to study the propagation of combustion and detonation, if necessary by a pooling of resources.**

### *Protective Coatings*

A very wide range of manufactured goods in Canada is decorated and protected with organic coatings. A vigorous protective coatings industry is essential to other secondary manufacturers in Canada.

Research expenditures in 1967 were \$4.1 millions, and these have increased, as a percentage of sales, from 1.96% in 1963 to 2.09% in 1967. These are estimated to be at the same relative level as are the ratios of R. and D. expenditures to sales in the U.S.A. and the U.K., and it is anticipated that the parity will continue.

Governments in Canada spent \$225 800 of which \$219 500 was federal.

At present most R. and D. effort in protective coatings is in development work. However, in order for the paint industry to remain competitive with other industries which are striving to replace paint materials, and expand into new markets, it needs intensive R. and D. at the concept level. Consequently, Committee 5 recommends **that government funds be made available to conduct concept research for the paint industry at Canadian universities.** Administration could be a function of the Associate Committee on Paint Research of N.R.C. and the Paint Research Institute.

### *Dyestuffs*

Dyestuffs are used in the colouring of textiles, paper, plastics, foods, and other materials.

Retail sales in 1967 were valued at \$17 million. There was no primary dyestuffs production.

Practically all dyestuff companies operating in Canada are foreign-owned and do no basic research.

Current intramural expenditures on R. and D. in 1966 were \$264 200 or about 1-1½% of sales. No expenditures in this field were reported by governments or universities.

#### IV.6 Pharmaceuticals and Natural Products

This represents one of the strongest divisions of organic chemistry in the country, and Canadian chemists in government and university have often excelled in natural products research. The amount of pharmaceutical research in industry has grown considerably in recent years as a result of government incentive programs. Although related work in schools of pharmacy has been uneven, there are a few laboratories carrying out important work in medicinal chemistry and the chemistry of natural products.

According to the statistical survey, intramural R. and D. operating expenditures on pharmaceutical research of a chemical character in 1966 (or 1966/67) amounted to \$6 628 thousands, of which 17.3% was in government, 72.7% in industry, and 10.0% in universities or institutes. It was divided into 32.9% basic, 50.5% applied, and 16.6% development. A surprising feature was that 32.6% of pharmaceutical research in industry was reported as basic. Manpower engaged in R. and D. was 665, of whom 239 were technicians.

D.B.S. data for 1966 indicate that the industry's overall expenditure on intramural (operating plus capital), and extramural R. and D. amounted to the equivalent of 5% of its sales, a proportion which was exceeded by very few other manufacturing industries.

Looking to the future of pharmaceutical and natural products research in Canada, Committee 6 expects that those involved in the allocation of funds will define long-range scientific policies more clearly. More federal funds will be given for research, but these will not necessarily be at the same rate as in recent years. If the present economic incentives are maintained, and if restrictive patent legislation is not enacted, it is to be expected that more industrial pharmaceutical research will be undertaken in Canada. It is also predicted that pharmaceutical research will shift in the direction of more basic studies; that inter-disciplinary groups will form in the universities; and that government will increase its research where interest is lacking in universities or industry (for example, in food chemistry and the chemical aspects of air and water pollution).

It is to be expected that natural products chemists will expand their interests in the area of molecular biology.

Committee 6 points out a number of areas which need more investigation and various deficiencies in instrumentation and personnel supply. For example, there is a shortage of workers trained in lipid chemistry and of biologists for evaluating physiologically active compounds, as well as a general shortage of technicians.

To meet the needs of the situation the Committee recommends **that a Drug Research Institute be established in Canada.** It also recommends **that**

regional centres be set up to make available the expensive equipment necessary for modern research.

Other, more general recommendations include: increased incentives and support by government for industrial research; increased industrial support for basic research in universities; increased collaboration between workers in the various disciplines, and between government, university, and industrial personnel; and more inter-disciplinary grants. (See "General Recommendations", numbers 2 and 8, pp. xxii, xx.)

#### **IV.7 Polymers; Organometallic, and Organo-nonmetallic Compounds, etc.**

Committee 7 was concerned with elastomers, plastics, and resins, organo-metallic compounds, and organo-fluorine-phosphorus-silicon and -sulphur compounds.

##### *Elastomers, Plastics, and Resins*

As a measure of the importance of this field it may be noted that the world plastics industry is growing at a rate of about 10% per annum compared with 3% for the steel industry. In the United States about 40% of the chemists and chemical engineers appear to be employed in some aspect of the macromolecular industry, and about 70% of the graduates in chemistry and chemical engineering going into industry are expected to begin employment in macromolecular-based company divisions.

Rate of growth of research in this field is indicated by a sixfold increase between 1946 and 1966 in the number of abstracts of original articles published annually (30 000 to 180 000).

According to the Statistical Survey, intramural R. and D. operating expenditures on polymers in 1966 (or 1966/67) were \$12 826 thousands. Of this, \$12 552 thousands were spent by industry; only \$135 thousands by universities and \$120 thousands by the federal government. The industrial R. and D. expenditures were distributed: 5.2% to basic; 33.6% to applied; and 61.2% to development. Compared with this the university funds were spent 77.8% on basic and 22.2% on applied research; while government R. and D. was distributed 25% basic and 75% applied.

Thus, there is a great disparity between the interest shown in this important field by industry and by the universities and government.

The estimates of manpower involved in intramural R. and D. on polymers show a similar pattern: 117 in the universities, of which 29 were academics; 8 reported in government; and 807 in industry, including 426 technicians.

While Canadian production of the basic large-volume synthetic elastomers, plastics, and resins is an accomplished fact, there has not been a continuous growth in the new specialty fields. Indeed, not only the numerous new plastics which have risen to prominence—particularly during space-age research in the United States—but some of the older, well-established products are neither being produced nor actively studied in Canada.

Although courses in polymer chemistry are available at universities, degrees in polymer chemistry are not yet granted. In the absence of major

schools of polymer science, there has been no accumulation of experienced polymer scientists. A start has been made at McGill University and the Universities of Toronto and Waterloo, but it is estimated that a sixfold increase in academic research would be required to balance present industrial activity.

Specific polymer instrumentation is meagre, and a major infusion of capital equipment into existing and new centres is required.

There is comparatively little research work on the synthesis of new monomers or polymers upon which future industrial growth can be based, or on polymer complexes of biological interest. Far from developing advanced technology of its own, Canadian industry has not exploited available foreign technology.

Some means must be found to encourage the highly speculative and costly development programs which result from any successful research. The size of the Canadian market does not provide sales large enough to pay for extensive development programs; evaluation, testing, and standardization are extremely expensive.

As a result of its studies, Committee 7 recommends **that a greatly enlarged program of teaching and research on polymer science be developed in the universities**. This could be done by the establishment of endowed chairs, complete departments, or specialized institutes. Highly trained personnel should be obtained on a permanent basis, but if necessary initially as visiting professors. Other means include a massive infusion of new equipment specific to polymer research, the construction of new laboratories, the establishing of undergraduate and graduate programs in polymer science, and provision of a macromolecular research journal.

A second recommendation is **that the expansion of industrial R. and D. on polymers be further encouraged**. Efforts should be made to encourage more companies to engage in R. and D. in this field, and industry should be offered incentives to accept a reasonable ratio of failures to successes in development work. Crown corporations might be used to manufacture products resulting from successful developments until the market could support competition. An idea exchange whereby projects useful to other companies would be made available on a licensing basis should be established. (See "General Recommendations", numbers 3, 6, and 8, pp. xviii, xix, xx.)

Over the broad field of polymer R. and D., Committee 7 recommends **that a governmental body determine national objectives and co-ordinate the effort in the various sectors**. Specifically, a broadly based testing laboratory oriented towards Canadian conditions should be established and made available to all sectors. The activities of R. and D. institutes should be expanded with services available to all, but particularly to small, companies. (See "General Recommendations", number 1, p. xvii.)

The recommendations of the following four subdivisions are combined at the end of this abstract.

### *Organometallic Compounds*

These are defined as those in which the carbon atom of an organic group is joined directly to a metal. Although known for a long time, they have not been studied or produced in Canada as a distinct class, and no major centre of research has emerged. The only commercial production is believed to be lead compounds for anti-knock fluids and aluminum compounds used as catalysts in the production of plastics and elastomers.

R. and D. expenditures in this field in Canada are very small and, even in industry, are largely for basic research. A great expansion of this new and promising field of R. and D. appears possible.

### *Organo-fluorine Compounds*

These are organic compounds in which hydrogen is replaced by fluorine, and they include a vast array of new materials with potentially interesting and useful properties. World emphasis in the field of organo-fluorine compounds has been on plastics, elastomers, and refrigerants, but of these only the last-mentioned have so far been produced in Canada. There may be strong economic reasons for establishing a larger fluorocarbon industry in Canada, but initially, production as well as R. and D. effort might need support.

### *Organo-phosphorus Compounds*

The number of studies in this field appears small in relation to the total phosphorus industry. Canadian production is limited to pharmaceuticals, anti-oxidants, and food additives, and many other compounds in this class are imported. Interest in organo-phosphorus compounds should be aroused not only in the phosphorus-based industry but also in the fabrication and consuming industries.

### *Organo-silicon Compounds*

Despite their commercial importance, these compounds receive little attention in Canada: there is no production and little research. No return can be expected from basic research until industrial activity has been established and more developmental work carried on.

### *Organo-sulphur Compounds*

In more recent years, research on organo-sulphur compounds has expanded greatly. Sulphur is a by-product of natural gas development, and upgrading this to products of higher value would have obvious economic advantages. Utilization of sulphur also reduces pollution problems. Since the organo-sulphur industry appears active, there seems to be a good basis for growth. A good start has been made by Alberta Sulphur Research Limited and the Fundamental Research Group at the University of Calgary.

For the four subdivisions described above, Committee 7 recommends **an expansion in academic research, the development of compounds of possible commercial interest in universities or institutes, the encouragement of commercial production in Canada, and the promotion of industry-university co-operation.** (See "General Recommendations", numbers 2 and 8, pp. xvii, xx.)



## IV.8 Pulp and Paper

Committee 8 defined its field of study to encompass research in the areas of wood chemistry, cellulose chemistry, chemical by-products, and the chemical and chemical engineering aspects of wood products and pulp and paper.

Today Canada is the world's leading producer of newsprint and is second only to the United States in the production of wood pulp. The industry is the largest single contributor to the G.N.P. (4%) and it accounts for 15.8% of total value of Canadian exports and 21.3% of the value of Canadian exports to the United States. However, the industry compares poorly with major Canadian industries in terms of research expenditures as a percentage of sales.

On the basis of the Committee's definition of their field of study given above, operating R. and D. expenditures in 1965 were \$17.7 millions; \$16.2 millions by industry, \$0.9 millions by government, and \$0.6 millions by universities. On the same basis for overhead, etc. the last two figures should probably be doubled.

University graduates or their equivalents engaged in R. and D. numbered 633: 454 in industry and associations, 55 in government, and 124 in universities. Included were 272 chemists, 254 engineers, and 107 of other disciplines.

As a result of its detailed survey and study of available information, Committee 8 concluded that pulp and paper research in Canada has been moderately successful in the past but is not adequately geared for the future.

Consequently, the Committee recommends **that a considerable expansion of R. and D. effort in pulp and paper be envisaged.** This will require a considerable increase in funds and a greater supply of qualified personnel. New policies and incentives are needed to improve university graduate school output and expand industrial research effort to optimum levels. Federal laboratory research programs should be evaluated for potential redirection of effort in favour of the pulp and paper field, but further overall build-up is not an immediate need.

Specific recommendations by the Committee are: **university centres-of-excellence should be established to strengthen research in the pulp and paper field on a sound policy basis.** This should include establishment by industry of suitable endowed or annual-grant chairs. **Future government incentives should be more diversified,** to include contract awards for industrial research on projects of national interest, and financial inducements for greater industry funding of university graduate school activities, such as the above-mentioned. (See "General Recommendations", numbers 3, 4, 5, and 8, pp. xviii, xx.)

## IV.9 Textiles and Natural Leather

The term "textiles" is applied broadly to the product of the knitter and the weaver, and to the various raw materials and processes that are used in the manufacture, dyeing, and finishing of such products. Included also are ropes, twines, felts, and non-woven materials.

The leather industry is concerned primarily with the tanning of hides and the utilization of the leathers thus produced.

Both industries date from antiquity and until the present century they relied on art rather than science. Today, the application of science is recognized as being fundamental to their future.

### *Textiles*

The limited amount of textiles R. and D. in Canada has been performed by comparatively few organizations.

In the year 1966 in this industry total current intramural R. and D. expenditures were approximately three million dollars, equivalent to approximately 1% of total sales of companies reporting R. and D. or 0.2% of all textile company sales. For the United States textile industry the corresponding figure was about three times as high as the latter percentage.

In 1965 textile companies reporting R. and D. spent \$1 353 000 outside Canada for patents, licenses, and technical "know how". This offset, to some extent at least, the lack of research and development in Canada.

Although there are over one thousand firms in the Canadian textile industry, less than 200 of these employ over 100 persons each. Consequently, conducting industrial textiles research on a group basis appears necessary if effective results are to be achieved.

In 1966 universities spent \$8 000 and the federal government \$119 000 on textile research.

Scientific manpower employed on textile R. and D. consisted largely of chemists or chemical engineers. Of these, 1 was engaged in basic research, 7 in applied research, and 87 in development.

There is need for future R. and D. in fibre-forming polymers, dyeing and finishing, and new forming methods for textile structures.

Committee 9 found that the greatest need arises from shortage of funds to conduct research at a level capable of contributing significantly to the progress of the textile industry in Canada. Therefore, the Committee recommends **that alternative schemes to the present incentives offered by government be explored which do not require the disclosure of the details of research ideas and programs to the government.** (See "General Recommendations", number 8, p. xx.)

### *Leather*

A few laboratories are operated privately by various companies in the leather industry but their work tends to be chiefly concerned with supervision and quality control. One industrial laboratory is studying the use of enzymes in tanning and recently some exploratory work has begun on the use of ultra-sonic energy in tanning.

A number of research projects have been suggested by members of the industry, which would place it in a stronger competitive position. Both basic and applied research are involved. There is general agreement that the leather industry needs an independent laboratory to conduct research and deal with

other problems. There are no educational facilities in Canada for training students in leather research and technology.

Consequently, it is recommended **that a joint effort of government and industry be made to establish a small group of qualified persons, preferably at a university, where instruction could be provided and research undertaken on behalf of the leather industry.**

Similar groups exist in many other countries and could serve as models.

#### **IV.10 Chemical Kinetics, Catalysis and Surface Chemistry**

Committee 10 was assigned an assortment of physical chemistry topics, of which some were related and some not. These are reported under three subdivisions: Catalysis and Surface Chemistry; Chemical Kinetics, Molecular Dynamics, Photochemistry, and Energy Transfer; and Polymer Chemistry. The last was concerned with the physical chemistry aspects of polymers and supplements the report of Committee 7.

According to the Statistical Survey, intramural chemistry operating R. and D. expenditures in the field covered by Committee 10 amounted to \$3 569 thousands, being 21.6%, 27.4%, and 51.0% in government, industry, and universities, respectively; and 69.7%, 23.8%, and 7.0% on basic research, applied research, and development, respectively. Manpower employed amounted to 451, of whom 394 were scientists and engineers distributed 9.6%, 8.1%, and 82.2% in government, industry, and the universities, respectively.

##### *Catalysis and Surface Chemistry*

Although catalysis is of prime importance to Canadian industry, there has unfortunately been no continuous and consistent effort on catalysis R. and D. in this country. Research on surface chemistry is also not extensive, and a comparison with other nations shows Canadian R. and D. to be far behind in this field.

Potentially, funds and equipment are not lacking, but a strong "centre of gravity" and positive and identifiable motivation on the part of industry are needed.

Therefore, Committee 10 recommends **that a consensus of opinion be sought among pertinent industries.** The object would be to assess the willingness of industry to support R. and D. in these fields.

The Committee also recommends **that a working group (or institute) be set up.** This might be done at one of the present academic centres or by co-operation between several centres. It should be headed by an outstanding scientist in the field, and government should provide leadership and funds.

##### *Chemical Kinetics, Molecular Dynamics, Photochemistry, and Energy Transfer*

These areas are concerned respectively with the quantitative measurement of reaction rates and the factors which control them; the study of collisions between molecules; and the chemical effects of light and the energy transfer between molecules. Research in these fields increases our basic understanding of chemical reactions.

The present level of activity in these fields is relatively high and will probably remain so. The present level of support in university and government is fair and reasonable, but activity in industry is understandably quite small.

### *Polymer Chemistry*

Committee 10 was concerned with the physical-chemical investigations of natural or synthetic macromolecules, i.e., rheology, morphology, electrical, optical, and other physical properties in bulk and solution. R. and D. in this area is important because it fills the gap between the development of polymers and their use.

The Associate Committee on High Polymer Research of the National Research Council, the Canadian High Polymer Forum, and the Macromolecular Science Division of The Chemical Institute of Canada have co-ordinated efforts in the field within the limitations imposed by commercial secrecy in industrial work.

Industrial activity is at a high level and has produced adequate technology, but there have not been significant major advances which are clearly the result of Canadian research or specific to Canadian needs. Interest in this area of polymer chemistry in universities has been abysmally low and is only just starting to pick up. Effort in government laboratories is sporadic and lacks direction.

Limiting factors are lack of qualified personnel and of sophisticated equipment. A start has been made in correcting the former but **an attack on the latter factor is recommended.**

### **IV.11 Thermodynamics, Colloids, and Ion Exchange**

Statistics from the National Research Council of Canada and the present survey show that research in these three areas is relatively small, amounting to about 2%, 0.2%, and 1.8% of university, industrial, and government research respectively.

The Committee recommendations for these three areas are given at the end of this abstract.

### *Thermodynamics*

This is a basic subject for all science and engineering and is particularly useful in chemistry and chemical engineering. The Committee considers that work in this area in Canada is less than adequate. There are only 15 principal investigators, assisted by staff and graduate students totalling 50. Lack of trained personnel, of specialized equipment, of operating funds, and of community of interest are the principal factors contributing to the present unsatisfactory situation.

### *Colloid Chemistry*

This is an essential discipline for many of Canada's important industries but research activity in it is small. Teaching of, and research in, colloids have nearly disappeared at universities. Lack of academic leadership and trained

personnel outweighs all other problems, such as the need for additional funds and specialized equipment.

### *Ion Exchange*

Ion exchange is a small, specialized subject related to colloid chemistry and chemical engineering. Its potential has not been fully realized by Canadian industry, except in the treatment of natural water. The very small research effort is widely scattered in industry. Whilst the purchase of foreign technology in this small, specialized field may be economically sound, Canada should have a group of chemists and engineers conversant with recent developments and their application to Canadian problems.

In view of the above considerations, Committee 11 strongly recommends **that centres of specialization in universities and government laboratories be established.** (See "General Recommendations", number 5, p. xviii.) Two or three of these are required for thermodynamics research; and one or more for colloid chemistry—of which at least one should have on its staff an ion exchange specialist.

The Committee also recommends **that the supply of trained personnel should be increased in all three areas.** In thermodynamics this can be accomplished by increasing financial support to professors and providing funds to purchase and maintain specialized equipment. All universities should be encouraged to offer courses and research in colloid chemistry, and chairs should be established at several of them. At least two or three chemical engineering departments should provide courses and research in ion exchange.

In view of the urgent need for more thermodynamic data, Committee 11 also recommends **that a government laboratory or research institute be established to maintain a small continuing program concerned with determining and publishing thermodynamic data.**

## **IV.12 Nuclear and Radiation Chemistry**

Although these two disciplines are frequently found in the same organization, they are, in fact, quite distinct. Nuclear chemistry is the study of the properties and reactions of the atomic nucleus, whereas radiation chemistry is the study of chemical reactions induced by absorption of ionizing radiation.

The survey made by Committee 16 showed that 5% of all candidates for higher degrees in Canadian chemistry departments have thesis topics in either nuclear or radiation chemistry.

Nuclear chemistry in government is found mainly at A.E.C.L., with some lesser activity in other federal departments. In 1966/67 nuclear chemistry programs were under way in eight universities, with 12 professionals, 30 graduate students, and 11 postdoctoral fellows. Annual R. and D. operating funds per staff member in 1966/67 amounted to \$20 thousands; average expenditure on major equipment, averaged over five years, was \$21 thousands.

In the year 1966/67 radiation chemistry was well established in Canadian government laboratories (A.E.C.L., D.R.B., and N.R.C.), with a total of 19

professional staff and 18 technicians. In a total of 14 university departments, there were 20 professional staff members and 35 candidates for higher degrees. Per staff member, the annual R. and D. operating funds averaged \$11 600 and the average expenditure per staff member on major equipment over the past five years has been \$8 200.

The balance between government and university activity was judged to be reasonable in both disciplines. No R. and D. was reported by industrial laboratories.

The supply of M.Sc. and Ph.D. graduates trained in nuclear or radiation chemistry in Canada is likely to meet the country's needs, at least for the next five years.

Although support for the above research programs was not considered inadequate, Committee 12 found many instances of insufficient support for young scientists in university departments. The problem seems to be that the timing of the provision of funds to an individual is faulty, rather than that the total funds provided over his working life are inadequate.

The Committee therefore recommends most strongly **that suitable administrative and financial arrangements be devised to afford better support to the young university scientist.**

The scientific content and the technical implications of most of the work in Canadian universities involving nuclear and radiation chemistry lie within the area of special concern of the Atomic Energy Control Board. However, the A.E.C.B. grants program is now restricted mainly to nuclear physics and other accelerator-based physics programs. Consequently, the Committee recommends **that the A.E.C.B. grants program be extended to nuclear and radiation chemistry.** Such grants would supplement the present N.R.C. grants.

Since pulsed radiolysis studies offer exciting opportunities for tackling many of the unsolved problems in radiation chemistry, and because there is not in Canada a single suitable facility which has been built and is being used specifically for this kind of study, Committee 12 recommends **that the situation be examined in more detail.** It is estimated that such a facility, completely housed, would cost approximately \$0.5 million. If built, it should be made available to radiation chemists from at least several co-operating government or university laboratories.

Finally, while Committee 12 does not endorse the view that radiation chemistry has unlimited application, the Committee recommends **that well-conceived applied radiation chemistry programs be sought out and supported more fully.**

#### **IV.13 Electrochemistry**

The report of Committee 13 deals mainly with electrolytic processing, electrochemical energy storage, and electrofinishing. Statements are also included on electrothermics, corrosion, semi-conductor electrochemistry, and biological electrochemistry. Electrothermics was reassigned to Committee 14 on high temperature and high pressure reactions.

Electrochemistry, as defined above, represents an industrial production valued at \$1.6 billion a year; the value added by manufacture, using electrochemical methods, being about one-half of this figure. However, the combined annual growth rate in annual value of production of these industries is currently only 4.6%.

The incomplete data available indicate that R. and D. operating expenditures for the area coming under the same definition are probably only 0.2% of industrial value of production. This is much less than the 3.5% which has been proposed as an objective by development-minded economists. The level of engineering development seems to be sporadic and discontinuous, and much of the published research does not seem to have had clear objectives.

In the past there have been notable Canadian achievements in this field which have been justifiably recognized. However, today, because of much non-Canadian ownership, research or engineering development tends to be done elsewhere. Most of the work which is published in Canada comes from government laboratories or from research done in universities under government sponsorship. The patent positions which are generated by such work are weak, and there is little co-ordinated effort to direct it to Canadian interests.

Opportunities for expansion of electrochemical R. and D. exist in electrofinishing, electrocoating, electrolytic production of metals and chemicals, in fuel cells, and in certain other branches of applied electrochemistry.

The advances made in electrochemistry in the past ten years in the U.S.S.R. have been outstanding, and they provide excellent guidelines for a renewed Canadian effort.

Since the growth rate of this very large contributor to the Canadian economy is low and is subject to predictable, potentially detrimental influences, Committee 13 recommends **that a joint technico-economic study be made by leaders and specialists in government, industry, and universities.** This should consider the probable effects of public ownership of electrical power and of nuclear energy stations; the agro-electrical concept; and the availability of raw materials and new product consumption patterns.

Since courses in electrochemical engineering in Canada are weak or non-existent, Committee 13 recommends **that seven academic chairs of electrochemistry be established.** Four of these could be supported by the electrolytic process industry, and two by the federal government to study electrofinishing and electrochemical energy storage. The seventh would concentrate on theoretical and basic problems.

A channel is badly needed for scientific and technical communication in electrochemistry. Consequently, Committee 13 recommends **that an "Electrochemical Junction Centre" be established.** This could be maintained by joint industrial-governmental support.

Recognized opportunities for growth in the various branches of electrochemistry are set out in the Committee's report. The Committee recommends **that these and other promising branches of electrochemistry be stimulated by the joint public and private support of selected engineering development projects.**

In carrying this out, and presuming that the preceding recommendation is put into effect, the Committee prefers the several centres-of-excellence approach to the central institute idea.

One can predict that the result of the technico-economic study recommended above would show that a level of annual R. and D. expenditure of between 1% and 4% of the \$1 600 millions/year contribution by electro-chemical industries to the G.N.P. would be advisable. In the meantime, the Committee recommends **that private and public funds co-operate in building the industrial engineering development capability and in financing the academic chairs to a level of 1% of G.N.P. contribution, i.e., \$16 million/year.** A program showing how expenditure could be phased in between 1968 and 1973 is presented in the Committee's main report.

#### IV.14 High Pressure and High Temperature Chemistry

Committee 14 was assigned the task of studying several fields of research: Flames and Explosives; Fused Salts; High Pressure Chemistry; High Temperature Chemistry; and Low Temperature Studies.

Intramural chemistry R. and D. expenditures reported to the Statistical Survey in the above areas were: universities \$97 thousands, government \$188 thousands, and industry \$217 thousands. Since the areas are largely concerned with techniques a difficulty arose in defining the field covered. This could either be restricted to R. and D. on the technique itself or it could be extended to include all R. and D. which employed the technique. The field actually surveyed by Committee 14 was in fact much larger than that which is indicated by the survey data. The best selection of D.B.S. data possible also suggested the inclusion of a much wider field.

The most general finding of the Committee was the need for more research in industry. Consequently, Committee 14 recommends **that the Canadian patent system be strengthened** to provide better protection to the Canadian inventor and encourage industrial research in Canada. The second general finding was that there was a lack of communication between research workers in these fields. Consequently, Committee 14 also recommends **that incentives be provided to encourage collaboration between industrial laboratories and universities.** This might be done by riders to research grants. For instance, a regular meeting of research workers in the subdivision of high temperature research might be organized and supported financially. (See "General Recommendations", number 2, p. xvii.)

Other recommendations by Committee 14 dealt specifically with each area as follows.

##### *Flames and Explosives*

A centre-of-excellence should be established for studies in the field of shock, detonation in the gas phase, high temperature kinetics, and hypersonic flow.



### *Fused Salt Chemistry*

The A.E.C.L. should support research in the field of fused salts for atomic energy applications.

The Department of Energy, Mines and Resources, and the extractive metallurgy industry, should support fused salt research in the metallurgical field.

Contact with the Technical University of Norway should be facilitated through visiting or exchange professors and grants for exchange students.

### *High Pressure Chemistry*

A system should be devised to allow graduate students to earn their degrees through research conducted in the high pressure laboratory at the National Research Council.

### *High Temperature Chemistry*

One or more centres-of-excellence should be established in the high temperature field.

Specific graduate and undergraduate courses in high temperature chemistry should be instituted at the universities.

The undergraduate training required for ceramics, glass, and the electrothermics industries should be re-examined.

Travel to meetings of high temperature groups in the United States and abroad should be supported and encouraged.

### *Low Temperature Chemistry*

Research on practical applications related to Canadian conditions such as cold-weather road-patching, de-icing, frost boil, hail prevention, etc. should be expanded.

## **IV.15 Molecular Structure and Theoretical Chemistry**

Committee 15 conducted a survey of scientists in the fields of spectroscopy, x-ray and neutron diffraction, and theoretical chemistry. Recommendations concerned with these fields follow brief discussions.

### *Spectroscopy*

The purely analytical aspects of spectroscopy were excluded from the Committee's study. Since the only N.S.F. category in which spectroscopy was specifically mentioned was under analytical chemistry, the use of the N.S.F. categories by the Statistical Survey resulted in most pure spectroscopy being reported under analytical chemistry. Consequently, the Committee had to rely on its own studies.

Included were infrared, Raman, electronic, nuclear spin resonance, and electron spin resonance spectroscopy, as well as spectroscopy used to determine fundamental properties of molecules.

Research and development in this field provides basic information about molecular structures and electronic configurations that is useful in all other branches of chemistry.

Industrial applications include the development of new laser sources, and assistance in the synthesis of new compounds and polymers, and in applied photochemistry.

In the chemistry departments of universities, 20 faculty members and 100 graduate students are estimated to be engaged primarily in spectroscopic research. In government and industry, there are probably 50 persons engaged in non-analytical research aspects. Expenditures are difficult to estimate, but are probably around \$1 million at present. The number of Ph.D.s graduated annually is about 15; while M.Sc.s number about 5; however, many combine work on spectroscopy with other aspects of molecular structure.

It is expected that the number of qualified persons in this area will double in the next five years, and the expenditure will rise to \$5–10 millions per annum.

There has been little research in the area of spectroscopy in the industrial field in Canada.

### *X-ray, Neutron, and Electron Diffraction*

This report covers the determination of structure on a molecular scale by x-ray, neutron, and electron diffraction—x-ray diffraction being confined to single crystal methods. Information regarding chemical bonding and reactivity can be derived.

Structural crystallography in general provides a useful guide in research and technology in other fields.

There was little activity in electron diffraction in Canada until recently when the first research group was established at the University of Windsor. Neutron diffraction has played a limited role in chemistry in Canada. Lattice vibrations, hydrogen bonding, and ferro-electricity have been studied at A.E.C.L. at Chalk River and McMaster University. Neutron diffraction will always be limited by the availability of a high-flux neutron source. Structural determination by x-rays on single crystals has been actively pursued at the National Research Council for many years, and in universities for five to seven years. Digital computers are reducing the times involved so that more use in industry may be expected.

The present annual expenditures on x-ray crystallography in chemistry departments is in the region of \$230 thousands for personnel and \$120 thousands for research budgets. Annual expenditures could rise to \$2 millions, chiefly because it will be mandatory to acquire automatic x-ray diffractometers at about \$70 thousands each.

### *Theoretical Chemistry*

The purpose of theoretical chemistry is to provide a unified mathematical framework for the prediction, understanding, and interpretation of all chemical phenomena. The mathematical complexity of the problem precludes the attainment of this ultimate goal at present. However, the attainable goals can be of great help to the experimentalist, by allowing him to correlate and interpret existing data and suggest new and pertinent experiments.

Theoretical chemistry is a very young discipline in Canada. In 1959 only five universities listed theoretical chemists. There are now over 30 theoretical chemists, with 33 Ph.D. and 16 M.Sc. candidates. The present yearly operating budget for a theoretical chemist stands at \$25 thousands. Operating expenditures should increase in the next few years by 50% above the present figure of about \$1 million, exclusive of computer costs.

The whole field of theoretical chemistry has been neglected in Canada, particularly in the areas of statistical mechanics and reaction rate theory. Although most chemistry departments have at least one theoretical chemist, there has been a marked reluctance in the past to consider theoretical chemistry as a discipline in itself. This attitude is changing.

Canadian industry carries out no purely theoretical research and probably will not initiate any in the near future. However, it is expected that the demand will come ultimately.

#### *Electronic Computers*

Electronic computers are essential to the development and practice of all the fields covered by Committee 15. What is lacking is a very large computer, of such a size that Canada could probably afford only one or two such installations.

The first recommendation of Committee 15 is therefore **that means be explored for providing a major computer installation in Canada which would be available for use in a number of fields of research.**

In all three fields studied by the Committee there is much to be gained by increasing the rate of growth of both teaching and research. The second recommendation, therefore, is **that means be explored for stimulating all three fields of research and teaching.** In spectroscopy, laser Raman spectra and molecular beams need special emphasis and, in diffraction research, electron diffraction and the provision of a central neutron diffraction facility.

#### **IV.16 Agriculture and Food Chemistry**

Agriculture and food play a major role in the economy of Canada. Chemistry and chemical engineering are essential to the development of a modern agriculture, and to the food processing and distribution industry.

However, when the need for research in a given field or the need for training in a given trade or discipline is considered, world demand as well as Canadian requirements should be taken into account.

The world demand for food and other agricultural products will grow, since the world population is increasing at a rate of nearly 2.2% per annum, and food waste is high in all countries.

Committee 16 experienced difficulty in securing statistical data suited to its purpose but D.B.S., C.I.C., C.A.S.C.C., and Ontario Research Index data were studied. Some idea of the importance of this field and the amount of R. and D. performed can be obtained from the D.B.S. figures for the food and beverage industry. In 1964, this industry had a sales volume of more than \$6.1 billions, and was the largest employer in Canada, with 131 000 employees.

The net R. and D. operating expenditures for the food and beverage industry in 1965 were \$4.53 millions. In the same year the total (operating plus capital) R. and D. expenditures were \$7.94 millions, or at a rate of less than ten cents per hundred dollars of sales.

As a result of its studies, the Committee concluded:

1. Agriculture and food research is multi-disciplinary in character and increase in purely chemical inputs cannot be justified unless accompanied by a corresponding increase in biological effort.

2. Agricultural research is concentrated in government and university laboratories and is well established. Co-ordination of current effort to achieve national goals is most essential (see "General Recommendations", number 1, p. xvii).

3. Food research is in its infancy and deserves more support (see "General Recommendations", number 7, p. xix). The Canadian food industry now relies, with few exceptions, on research and development done in the U.S.A., but the industrial R. and D. effort in Canada is not expected to increase significantly.

Committee 16 recommends:

1. **That central food research laboratories be developed to carry out basic and applied research programs.**

2. **That chemical education include some orientation towards food and agriculture.**

3. **That increased support be directed towards expansion of existing laboratories.** (See "General Recommendations", number 5, p. xviii.)

The purpose of the last recommendation is to avoid fragmentation of manpower and funds among small laboratories which could not cope with the complex nature of food and agriculture R. and D.

#### **IV.17 Biochemistry**

Biochemistry is a new science which is intimately related to the physical sciences, but is also an integral part of the biological sciences. It plays an important role in industry, medicine, and agriculture, and unless Canada can set and maintain a high standard of biochemical research, high quality research in such fields as medicine, agriculture, fish and food processing, etc. will be limited.

In Canada, teaching and research in biochemistry are concentrated mainly in medical faculties, although some biochemistry is associated with departments of chemistry or biology. Biochemical research is also done in other university departments and some government laboratories. Close to 1 500 biochemists are engaged in teaching or research in Canada.

For the future it seems desirable that the teaching be broadened to give greater emphasis to basic training in the physical sciences. By international standards, Canada has no strong centres of biochemistry and few outstanding groups in research. The output of biochemistry graduates is not excessive and should be increased.

Intramural R. and D. expenditures in biochemistry reported by the Statistical Survey were \$10 425 thousands or 7.6% of the total reported for chemistry. These biochemical expenditures were made 58.8% by universities, 24.1% by government, and 17.1% by industry.

The same survey recorded a total of 1 099 biochemical man-years or 9.5% of the total reported for chemistry. Included were 366 technicians. The 1 099 man-years were divided 68.2%, 15.9%, and 15.9% for universities, government, and industry, respectively.

There is a serious imbalance between university and government research, on the one hand, and industrial research on the other. Plant biochemistry and clinical biochemistry are relatively neglected subdivisions of biochemistry.

Committee 17 therefore recommends **that efforts be made to foster applied research in biochemistry, particularly in industrial and clinical laboratories.** (See "General Recommendations", number 3, p. xviii.) This might be done by the government's collaborating with industry in setting up centralized laboratory facilities, by modifying the patent laws, and by increased collaboration between government, university, and industry through a program of visiting and exchange scientists. (See "General Recommendations", number 2, p. xvii.)

The Committee also recommends **that biochemical teaching and research be brought up to international standards.** Methods suggested include:

1. Greater emphasis on basic training in chemistry, physics, and mathematics and better co-ordination of biochemistry with other science departments.
2. The establishing of inter-disciplinary institutes associated with a university.
3. The developing of centres-of-excellence in biochemical teaching and research (see "General Recommendations", number 5, p. xviii).
4. The direction by government laboratories of more of their attention to mission-oriented research, through the organization of strong inter-disciplinary groups having realistic goals which would benefit the Canadian economy.
5. Increasing support to biochemistry outside the medical faculties.

#### IV.18 Chemical Engineering

Industrial chemical engineering research was defined by Committee 18 to include all research in the chemical, process, and resource industries which was of the kind required to develop successful bench-scale experiments into commercial products or processes.

It was estimated that the total number of chemical engineers in Canada was in the neighbourhood of 5 000 of whom at least 50% had graduated in the last ten years.

R. and D. operating plus capital expenditures in process and resource-based industries as defined by Committee 18 climbed rapidly from about \$60 millions in 1962 to \$135 millions in 1965, or at a rate of 20–30% per year. Currently they are growing at about 10% per year, and forecasts reported to the Statistical Survey indicate a growth rate to 1970 of 3.5% per year. However, most directors of research interviewed felt that the engineering part of

their programs would grow at 6–10% per year. Only a few expect difficulty in recruiting the necessary staff.

Federal policies on R. and D. in general, while conceded to be more helpful than they were a decade ago, are considered to be incomplete, or lacking in clear purpose, by most industrial directors of research interviewed.

One characteristic of Canadian industry is the number of large, resource-based companies which have little or no research effort or are just making a modest beginning.

In universities, chemical engineering departments have grown rapidly in the last five years, from an average of 4 faculty members with 2 graduate students each to an average of nearly 8 faculty members with 3 graduate students each. Only about 4% of their financial support comes from industry.

Statistical data indicate that engineering research and development for the benefit of the chemical, extractive metallurgical, pulp and paper, and other resource-based industries represents only a minor portion of federal research expenditures.

The principal recommendation of Committee 18 is **that the federal government greatly increase its support of applied research and development in areas of national economic significance through tax incentives, research contracts, and research grants.** This increase should not occur in federal government laboratories but primarily in industrial research centres, or in provincial research councils, institutes, and university departments in association with industry. (See "General Recommendations", numbers 3, 4, and 8, pp. xviii, xx.)

Present tax incentive programs such as IRDIA should be changed to support the present level of research expenditures, and not only incremental additions. Development subsidization programs should be freed from the restrictions of manufacturing and export capabilities. The government should assume some of the risk in developing commercial applications of new Canadian technology.

Such a government program should be implemented through a new organization not having laboratories of its own. The present N.R.C. support of basic research in industry and universities should be continued at normal growth rates.

Committee 18 recommends **that the balance between basic, applied, and development work carried out in federal laboratories should be re-examined.** In particular, the needs of the process industries based on natural resources should be reconsidered. (See "General Recommendations", number 3, p. xviii.)

An enquiry into the low rate of invention and innovation in Canada is suggested, as well as an improvement in patent services and regulations. Tariff regulations should be used to promote the growth of those industries with the greatest economic potential.

#### **IV.19 Chemistry in Earth Sciences and Related Fields**

Committee 19 was concerned with the following subdivisions of their subject: cosmochemistry; general geochemistry; atmochemistry; hydrogeo-

chemistry; chemical oceanography and limnology; pedochemistry; biogeochemistry; isotopes and geochronology; geochemistry of mineral deposits; geochemical prospecting; mineralogical phase geochemistry; analytical chemistry of rocks, minerals, and fossil fuels; data processing in geochemistry; and education and research in geochemistry in Canadian universities.

No statistical data were found directly applicable to the fields covered, and the recommendations of Committee 19 are based on the intimate knowledge of the subdivisions listed above by experts who prepared a brief for each subdivision.

The Committee points out that it is possible to utilize world-wide chemical knowledge, especially that which relates to industrial chemical processes, with a minimum of research and development. However, in the earth sciences, the Canadian natural environment is unique in many respects and sustained research *in situ* is necessary.

The Committee's assessments of the level of R. and D. activity and requirements for the different subdivisions are as follows.

#### *Cosmochemistry*

Research activity is satisfactory but teaching, especially details of meteorites, is weak at most universities.

#### *General Geochemistry*

R. and D. level is adequate in igneous and metamorphic rocks but not in sedimentary rocks and processes.

#### *Atmochemistry*

R. and D. level is moderate but an increase is needed to cope with air pollution problems. More finance, co-ordination between agencies, and more emphasis in graduate schools are needed.

#### *Hydrogeochemistry, Chemical Oceanography, and Limnology*

R. and D. will reach a satisfactory level in five years but increased teaching is required in various aspects listed in the Committee report.

#### *Pedochemistry*

R. and D. level in *agriculture* is satisfactory; expansion is expected in other applications. The increase in the number of pedochemists required will not tax present staff and facilities. Increased research on *glacial tills and clays* in Canada is needed for the proper interpretation of geochemical prospecting surveys.

#### *Biogeochemistry*

Large gaps in our knowledge that require increased attention are listed by the Committee. Also more synthetic biogeochemical research is strongly recommended.

### *Isotopes and Geochronology*

R. and D. level in general is satisfactory and a bright future is predicted. However, all aspects of stable isotope research should be improved.

### *Geochemistry of Mineral Deposits*

Research continues at a relatively high level in universities and government, but has not kept pace with the expanding mineral production of Canada. More emphasis on teaching and research on the fundamentals of mineral deposits is needed immediately in all geological faculties. The sources of elements comprising mineral deposits, and the concentration and subsequent diffusion of these elements, are subjects of immediate and urgent concern.

### *Geochemical Prospecting*

This is now widely used and is likely to double in the next five years, but its use for petroleum prospecting is negligible. Teaching and basic research have lagged. The Committee recommends the establishing of an **institute for teaching and research in applied geochemistry**, to be supported by the mining industry, the petroleum industry, and government.

### *Mineralogical Phase Geochemistry*

An increase is taking place in high-temperature, high-pressure work and will continue for the next five years, mostly in universities and government. Research on low-temperature, low-pressure processes should be initiated. The Committee recommends **the concentration of research in this field at three centres-of-excellence rather than ten universities; and that a Materials Research Institute be established on an inter-disciplinary basis.**

### *Analytical Chemistry*

The present R. and D. level is satisfactory but a better supply of trained personnel is needed.

### *Data Processing*

A rapid development in the next five years is predicted, with tripling of staffs and quadrupling of costs. The Committee recommends **that geochemists be trained in statistics and computer science at undergraduate and graduate levels, and that supporting staff be trained in technical institute and vocational schools.**

### *Education and Research in Geochemistry*

The Committee concluded that there were obvious deficiencies in organic geochemistry (petroleum and coal); cosmochemistry; chemistry of fresh waters; atmospheric chemistry and geochemical prospecting.

With regard to a frequently proposed National Institute of Geochemistry for Canada, it is suggested that a more effective procedure would be **to expand one of the divisions of the Geological Survey of Canada**, which has many years of background in this field.



#### IV.20 Literature and Information Services

The chemical literature and information services serve as media for the publication of R. and D. results and also as a reservoir of information upon which further R. and D. can be based.

During 1965, 10 850 periodicals and serials were monitored by Chemical Abstracts. Despite this, Committee 20 considered that scientific self-respect, completion of our investment in R. and D., promotion of a sense of scientific community, completion of scientific symposia and conferences, and the raising and maintaining of standards of scientific work in Canada were adequate reasons for its recommendation **that Canada should continue to expand its program of publishing journals in the field of chemistry and chemical engineering.** These journals should be integrated with international information systems and conform to international standards. All major Canadian libraries should subscribe to these journals. In view of the high costs involved, the possibility of centralizing the production of research journals should be fully explored.

In respect to the abstracting and indexing of journals, however, Committee 20 recommends **that Canada should participate in the improvement and extension of existing services but not attempt publication of its own.**

With regard to information retrieval services, Committee 20 recommends **that libraries having access to computers and serving a community of scientists subscribe to magnetic tapes and similar services.** The National Science Library should also make generally available the results of its experiments with mechanized information retrieval systems and the programs generated for those systems.

Finally, since other countries provide incentives for the publication of scientific monographs and much material with Canadian authorship appears in texts and monographs published in other countries, Committee 20 recommends **that means of encouraging the publication of secondary literature (monographs, etc.) should be explored.**

## Chapter V

### NEGLECTED AREAS AND LIMITING FACTORS IN CHEMISTRY R. AND D.

It has been noted in Chapter III.2 that industry and government respondents were invited to report difficulties in securing personnel, equipment, and (or) computer services. The replies have been summarized in Table 11.

In addition the questionnaires going to government departments and to universities and research institutes invited general comments; while the study committee reports also produced a number of both general and specific comments on areas of neglect and factors limiting the effectiveness and amount of Chemistry R. and D. performed in Canada.

These questionnaires and committee comments have been taken into consideration in preparing the general conclusions in Chapter VI and the summary of recommendations preceding Chapter I. They are too lengthy for inclusion in full, but they have been filed verbatim with the Science Council, and are summarized below.

#### V.1 Questionnaire Comments

##### *Industry*

The company questionnaire invited comment on the influence on R. and D. of such factors as economic environment, size of company, tariffs, patents, etc. Out of 185 industrial respondents, 58 companies submitted 152 comments, 65 of which discussed factors limiting R. and D. in Canada and 87 made recommendations. Tabulations, showing the incidence of the various factors and recommendations appear in Table 21 (A and B). The most frequent recommendations were for direct government grants and contracts to industry; more R. and D. institutes; more overall direction with practical results and national interests in mind; more co-operation between government, industry, and universities; and the elimination of tax and duty on major items of R. and D. equipment and materials. Tax incentives should be increased and apply to all R. and D., not just to increments; and the dissemination of scientific and technical information should be modernized.

##### *Universities and Institutes*

In the university and research institute questionnaires the respondents were asked to indicate areas of strengths and weaknesses, and to list factors which were thought to be limiting research effort. The comments, which were received from 83 out of 114 replies reporting R. and D. are shown in Table 22. Comments were distributed to the study committees and filed with the Science

Council. They were, however, so diversified that no pattern emerged. Those factors mentioned most frequently (qualified personnel, equipment, space, and funds) appeared mainly to reflect a need for overall financial support.

## V.2 Committee Comments

An attempt has been made in Table 23 to complement the replies to specific questions in the industry and government questionnaires (summarized in Chapter III, Tables 11A and 11B) by classifying the frequency with which references to neglected areas and lack of personnel and facilities appear in the committee reports.

**Table 21.—Comments from Company Questionnaires**  
**(A) Factors Limiting Effectiveness and Amount of Chemistry R. and D. in Canada**

Factors	No. of Times Mentioned
(1) Character of R. and D.	
(a) Basic, applied, development balance.....	6
(b) "Interest orientation" of university and government research.....	6
(c) University, government, industry balance.....	2
(2) Taxes and Tariffs	
(a) Duty on materials and instruments for R. and D.....	7
(b) Low tariff protection.....	2
(c) Unco-ordinated taxation at different government levels.....	2
(3) Economics	
(a) Profits, present and potential, affected by fiscal policy, cost-price squeeze, tight money.....	5
(b) Foreign control-centralization and limited opportunities.....	5
(c) Marketing and markets.....	3
(d) Company size.....	2
(e) Increasing cost of R. and D. (6%/yr.).....	1
(f) Increasing competition abroad.....	1
(4) Procurement	
(a) Qualified R. and D. manpower (plastics, textiles, etc.).....	6
(b) Access to special instruments and materials.....	3
(c) Access to information (market statistics, etc.).....	2
(d) Large R. and D. salary differential vs. U.S.A.....	1
(5) Neglected Areas	
(a) Industrial organic (pharmaceutical, polymer, pulp and paper, adhesives)	4
(b) Mining and metals.....	3
(c) Industrial physical (high pressure and temperature, catalysis).....	2
(d) Fuels.....	1
(e) Food (milk products).....	1

Sources of data: Statistical Survey Company Questionnaire.

**Table 21.—Comments from Company Questionnaires  
(B) Recommendations for Increasing the Effectiveness  
and Amount of Chemistry R. and D. in Canada**

Recommendations	No. of Times Mentioned
(1) National Organization	
(a) More R. and D. institutes (food, applied wood chemistry), 2; instrumentation, 3; graphic arts, 1; major industrial fields, 1; lignin and bark chemistry, 1; wood microbiology, 1; textile chemistry, 1; industrial organic chemistry, 1.....	12
(b) More overall direction (practical results, national interests).....	9
(c) More co-operation government, university, industry R. and D.....	9
(d) More co-operative R. and D.....	1
(e) A responsibility of the Science Council.....	1
(f) Examine practical results of N.R.C. R. and D.....	1
(2) Taxation	
(a) Eliminate tax, duty, on major R. and D. equipment and materials....	7
(b) Continue R. and D. tax incentives.....	4
(c) Increase, lengthen R. and D. tax incentives, apply to all R. and D., not to increment.....	4
(d) Eliminate tax incentive for work done outside Canada.....	1
(e) Change tariff reference 120.....	1
(3) Manpower	
(a) More graduates in pharmaceutical manufacturing, glass and ceramics, polymer chemistry, chemistry of adhesives.....	4
(b) More industry-oriented graduates, fewer Ph.D.s.....	3
(c) More Ph.D.s in chemical engineering.....	2
(d) More female chemists.....	1
(e) More qualifying extension courses (Toronto area).....	1
(f) More information to high schools.....	1
(4) Economics	
(a) Direct government grants and contracts to industry.....	13
(b) Strengthen patent system.....	2
(c) Review government economic policies.....	1
(d) Study tariffs and economics.....	1
(e) Study problem of small capacity units in remote locations.....	1
(f) Accelerate economic and political integration with U.S.A.....	1
(5) Information	
(a) Modernize dissemination of scientific and technical information.....	3
(b) More detailed D.B.S. statistics to aid marketing studies.....	1
(c) Buy more technology abroad.....	1
(d) More information on sources of R. and D. materials.....	1

**Table 22.—Comments from Universities and Research Institutes' Questionnaires  
Factors Limiting Research**

Factors	No. of Times Mentioned
Qualified Personnel.....	17
Equipment (mostly major).....	14
Space.....	11
Funds for Expansion.....	9
Technicians.....	5
Graduate Students.....	4
Need for Research Institute.....	1
Need for more Applied R. and D.....	1

Sources of data: Statistical Survey University Questionnaire.

**Table 23.—Comments from Committee Reports**  
**(A) On Neglected R. and D. Areas, Personnel, and Facilities**

	Mentioned By Committee No.
<b>(a) More R. and D. Effort</b>	
Exploitation of modern instrumentation.....	1
Glass and ceramics, solid state chemistry.....	2
Applied metallurgy, chemical metallurgy, research by industry.....	3
Industrial organic chemistry.....	4
Metallurgical uses of coal, petroleum chemistry, organo-geochemistry, lubrication, combustion, concept research on paints.....	5
Drug research.....	6
New monomers and polymers, polymer complexes of biological interest, organometallics, fluorocarbons, organo-phosphorus compounds, organo-silicon compounds.....	7
Overall expansion of R. and D. in pulp and paper (13 areas listed).....	8
Fibre-forming polymers, dyeing and finishing; forming methods for textile structures, leather research.....	9
Catalysis, physical chemistry of polymers.....	10
Thermodynamics, colloid chemistry, and ion exchange.....	11
Applied radiation chemistry.....	12
Greatly increased overall effort, particularly electrochemical engineering... Basics of flames and explosions; molten-metal-water reactions; fused salt chemistry; high- and low-temperature chemistry; resource development for Canadian needs, particularly in north.....	13
Laser spectroscopy; Raman spectra and molecular beams; statistical mechanics and reaction rate theory.....	14
Food science, research, engineering, evaluation, food and beverage industrial R. and D.; biological engineering; degradation of cellulose; conversion of non-protein nitrogen to protein nitrogen by microorganisms; algae for food; tissue culture for food purposes; biological aspects of pesticide research.....	15
Plant biochemistry, clinical biochemistry, applied biochemistry in industry, biochemical R. and D. outside the medical field.....	16
More applied chemical engineering R. and D., particularly for resource-based industries.....	17
Glacial tills and clays; fundamentals of mineral deposits; Canadian coal basins and enclosing sediments; geochemistry and applications (particularly petroleum); geochemical data on sedimentary rocks and processes, surficial materials; data on trace constituents of natural waters; chemical research on hot and cold springs; synthetic biogeochemistry; data processing.....	18
Production of Canadian monographs and texts in chemistry.....	19
<b>(b) More Training of Personnel</b>	20
More university graduates and highly qualified personnel.....	1
University graduates, technologists.....	2
University graduates.....	3
Instrumentation centres across country.....	4
Fuel training, lubrication training.....	5
Chemists for research in lipids, steroids, antibiotics and polypeptides; biologists for evaluating physiologically reactive substances, organic chemistry technicians.....	6
Undergraduate and graduate training in polymers.....	7
More undergraduates and graduates in pulp and paper.....	8
Personnel trained in leather chemistry.....	9
Graduates, postgraduates, and technicians.....	10
Electrochemical engineers.....	13

**Table 23.—Comments from Committee Reports**  
**(A) On Neglected R. and D. Areas, Personnel, and Facilities (Concluded)**

	Mentioned By Committee No.
Trained personnel in glass and ceramics, and electrothermics.....	14
Food scientists and technicians to meet Canadian and world needs, agricultural technicians.....	16
Postgraduates in atmospheric chemistry, undergraduates in hydrogeochemistry, personnel trained in analytical chemistry.....	19
<b>(c) More Facilities</b>	
Canadian source of standard samples for analysis.....	1
Sophisticated equipment for use on rental basis.....	2
Framing camera for explosives research.....	5
Instrumentation service centres.....	6
Co-operative facilities for complete testing of polymers.....	7
Major equipment, equipment for evaluating polymers.....	10
Specialization centres.....	11
Pulsed radiation facility.....	12
Centres-of-excellence.....	14
Automatic x-ray spectrometers, electron diffraction facility, neutron diffraction facility, ultra-large computer.....	15
Food research centres.....	16
Strong centres of biochemical research.....	17

**Table 23.—Comments from Committee Reports**  
**(B) On Specific Needs and Major Equipment Needs**

	Mentioned By Committee No.
Federal government incentives for treatment and processing in Canada of Canadian raw materials.....	3
More detailed D.B.S. statistics on the branches of chemical and physical metallurgy.....	3
An investigation of the feasibility of instrumentation centres.....	4
A fuel research centre for pilot scale studies.....	5
Facilities and personnel for studying explosives phenomena, particularly a high-speed framing camera.....	5
A central polymer evaluation facility.....	7
An institute for catalysis and surface chemistry.....	10
A thermodynamic data institute.....	11
A facility for pulsed radiolysis.....	12
A central information centre on electrochemistry.....	13
A very large computer.....	15
Large pieces of spectroscopic equipment.....	15
An inter-disciplinary centre for food investigation.....	16
A facility for large-scale testing of functional properties of new foods.....	16
Inter-disciplinary biochemical institutes.....	17
The establishment of a new government body, having no laboratories of its own, for increasing applied research and development in areas of national concern	18
An institute for teaching and research in applied geochemistry.....	19
Subsidies for publication in Canada of monographs, textbooks, etc. in chemistry by Canadian authors.....	20

## Chapter VI

### GENERAL CONCLUSIONS

A very broad field of effort in Chemistry R. and D. was covered by the twenty committees and the statistical survey. Characteristically, this field is largely "little science" rather than "big science", including many small but few large projects. In the few large ones surveyed, e.g., Nuclear Research Establishment of Atomic Energy of Canada Ltd., Whiteshell, Man., the survey was concerned only with the part of the project that could be assigned to Chemistry R. and D. Consequently, the reports of the committees noted in Chapter IV deserve careful study and the recommendations of each committee should be considered in the context of that committee's field of responsibility.

However, a few conclusions emerging from the study have a certain broad application although they are not applicable to every area studied. They are concerned with the present level of Chemistry R. and D. in Canada, and the outlook for the next few years, and they lead to some general recommendations.

#### VI.1 Industrial R. and D.

##### *Present Level of Chemistry R. and D.*

It is usual to discuss R. and D. levels with reference to the United States, where, for the fiscal year 1963/64, 3.4% of the Gross National Product (G.N.P.) of \$639 billions was spent on research and development of all kinds.

In 1963, Canada spent about 1% of the G.N.P. of \$43.5 billions. When such figures became available, there was a tendency to attribute the commercial predominance of the United States to its relatively large investment in R. and D., and to ascribe Canada's lower R. and D. percentage to the foreign ownership of many of its industries.

Further consideration has shown that the above is an over-simplified conclusion. About 60% of the large R. and D. expenditure of the U.S.A. could be ascribed to two large national policy decisions, the nuclear armament and space programs, which resulted in a great increase in the government funds going into industry on R. and D. contracts. Undoubtedly, this had a considerable commercial significance also. Again, to predicate commercial success on one factor alone, namely the level of R. and D., would be to exclude a number of other important factors such as size of home market, management techniques, war-time damage, etc. For example, Japan has achieved a considerable degree of commercial success largely by initially importing technology under license.

Although foreign ownership may, in some cases, be a factor which limits Canadian R. and D. expenditures, this disadvantage is offset to a considerable degree by technology that is received from the United States and other countries at relatively low cost. Moreover there are other factors than ownership which tend to limit R. and D. expenditures in Canada. These include a limited home market and the size of companies.

Statistics show that the bulk of the R. and D. in a country is done by the larger companies. For example, companies with annual R. and D. expenditures of \$100 millions or more accounted for 65% of the United States industrial expenditures on R. and D. in 1965, while companies with less than \$50 thousands R. and D. expenditures accounted for less than one-half of 1% of the total. This illustrates the contention that a viable research program usually requires a minimum expenditure of about \$100 thousands a year, and that even if this represents only 1% of sales or approximately 2% of "value added", about \$10 millions annual sales are required to support such a program. Despite this contention small companies can, by contracting their research to other organizations, undertake modest research programs with a reasonable prospect of success. In a country like Canada where there is a relatively high proportion of small companies, it is important that organizations such as the provincial research councils and foundations, and the industrial institutes set up by the Department of Industry, be adequately supported.

Development expenditures also loom large in the United States industrial picture; basic, applied, and development expenditures for 1965 being in the ratio 1:5:19. In some cases when a new process is discovered in Canada, particularly in the chemical industry, the market in Canada will not support the minimum size of plant needed for economic operation. Consequently, development is shifted to the United States or another country with a larger potential market. If the process is successful, the Canadian market may then be built up by importing requirements until a sufficient volume has been created for the erection of a plant of viable size. This is particularly true for industries such as petroleum refining or the manufacture of chemicals. A tenfold increase in manufacturing scale may halve production costs.

#### *Relationship of R. and D. Expenditures to Value Added by Manufacture*

The most recent final D.B.S. statistics for Canada may be compared with R. and D. expenditures for the same year, as shown in Table 24, on the assumption that the same distribution of companies is made over the various categories in both cases by D.B.S. Table 24 is restricted to classes of manufacturing whose R. and D. might be expected to come largely within this study's definition of Chemistry R. and D.

On the basis of Table 24 for 1964, the groups of companies can be divided into three categories: the R. and D. intensive industries (chemicals and chemical products, and petroleum refining have R. and D. expenditures percentages of value added which are considerably above the national average); those of about average R. and D. intensity (including rubber, paper, and the primary



metal industries); and those of lower intensity (including the food and beverages, textile and non-metallic mineral industries). Preliminary statistics for 1965 and 1966 show the same pattern as for 1964 (see Table 20).

**Table 24.—Comparison<sup>a</sup> of Intramural R. and D. Expenditures by Manufacturing Industries with Value Added by Manufacture; 1964**

Manufacturing Industries	Value Added \$'000	Current Plus Capital R. and D. Expenditures		Current R. and D. Expenditures	
		\$'000	% Value Added	\$'000	% Value Added
Food & Beverages...	2 056 885	6 001	0.29	4 543	0.22
Rubber.....	218 403	2 401	1.10	2 009	0.92
Leather.....	163 812	—	—	—	—
Textiles.....	541 968	3 420	0.63	2 816	0.52
Paper.....	1 296 089	20 136	1.55	14 389	1.11
Primary Metals.....	1 136 495	17 392	1.53	12 960	1.14
Non-Metallic Minerals.....	512 931	1 996	0.39	1 889	0.37
Petroleum & Coal...	286 772	18 238 <sup>b</sup>	6.36	8 655 <sup>b</sup>	3.02
Chemical & Chemical Products.....	949 649	35 864	3.77	25 891	2.73
Totals & Percentages	7 162 954	105 448	1.47	73 152	1.02

Sources of data: R. and D., D.B.S. Cat. No. 13-527, Tables 1 and 3; Value Added, D.B.S. Prelim. Bull. 6509-503, Tables 1 and 2.

<sup>a</sup> This comparison is only approximate for some industries, since "value added" statistics are compiled on an *establishment* basis while R. and D. statistics are made up generally from *company* or *enterprise* units. In the case of a large petroleum enterprise, for example, the petrochemicals value added might be credited to Chemicals and Chemical Products, but the petrochemicals R. and D. be credited to Petroleum. Studies indicate that for other industries the discrepancy is relatively small.

<sup>b</sup> Petroleum only.

## VI.2 General Outlook for Chemistry R. and D.

A number of the committees recommend a very substantial increase in Chemistry R. and D. expenditures in their particular fields. For example, Committee 13, Electrochemistry, envisages an increase of about \$15 millions per annum. It will be evident from Table 24 that large increases in expenditures must come from the government or from the less R. and D. intensive industries.

The industrial R. and D. operating expenditure forecasts reported in Table 15 do not envisage much change in the ratio of R. and D. expenditures to value added by manufacture, assuming a normal rate of growth in the G.N.P. during these years. However, in view of the changes which have occurred in the economy since these forecasts were made, they may actually prove to have been optimistic.

In Chapter III.4, reference was made to the high potential for Ph.D. production which exists in chemistry. In view of the rather limited rate of

expansion of Chemistry R. and D. envisaged in the forecasts, this raises an important problem. On the one hand we have a high potential for the production of research personnel and recommendations from committees for considerably increased expenditures on R. and D.; and on the other, a limited expectation of increases in Chemistry R. and D. expenditures by government and industry. D.B.S. data also show that the chemically based industries are gradually losing ground to such industries as the electrical products industries in respect to the proportion of the total R. and D. expenditures to value added by manufacture. This may be related to the fact that the electrical products industry receives a higher proportion of its funds from the government.

During the past few years the rapid expansion of postgraduate schools has absorbed much of the Ph.D. production, but this has in turn added to our potential output and helped create a possible oversupply situation. In the past, such pressures have been minor and have been relieved by migration, chiefly to the United States. However, with the more critical attitude to R. and D. expenditures which has now developed abroad, such migration may, in future, be difficult.

If this available R. and D. manpower could be put to work on projects which would significantly increase Canada's G.N.P., it would be a solution much to be desired. Although international scientific prestige and the pursuit of knowledge for its own sake are very commendable objectives, their pursuit must in turn depend on an adequate rate of growth in the G.N.P.

Under our system of free competition—and the chemical industry is strongly competitive—companies cannot afford to initiate R. and D. programs, even if various government incentives are available, unless the research shows distinct promise of leading to ultimate profits or royalty returns. Consequently, although a *general* discussion of tariffs and patents is clearly outside the terms of reference of this study, it must be reported that some industrial respondents have raised these subjects. Some point out that certain tariff changes remove the automatic protection hitherto afforded a new product in Canada. It has also been observed that the proposed removal of patent protection from pharmaceuticals may discourage the R. and D. efforts of those companies responsible for a good deal of the present Chemistry R. and D. in Canada.

Since limited funds are available to spend on Chemistry R. and D. in Canada, it is clearly important that these should be employed as effectively as possible, and the character of Canadian R. and D. is therefore of special interest.

#### *Character of R. and D.*

The totals of operating expenditures reported by all respondents for basic research, applied research and development on Chemistry R. and D. are given in Table 9. Ordinarily, one would expect that this proportion of basic research expenditures would generate much more applied and development effort. This supports suggestions made by many of the committees that, while we are very

successful in encouraging basic research in Canada, much more emphasis needs to be given to applied research and development if we are to derive the maximum economic benefit from our R. and D. efforts.

In this connection, it should be pointed out that the term "R. and D." tends to cover up a most important step which must come between research and development to make innovation possible. This is invention.

It is quite generally believed that not only has too little emphasis been placed on the applied side of chemistry but that an atmosphere has been created which encourages pure research and discourages many people from entering applied work. The encouragement of more research in industry by the National Research Council, and the proposal to give recognition to applied research by the Royal Society of Canada, may help to correct this situation.

### **VI.3 Overall Pattern of Chemistry R. and D. in Canada**

The overall pattern of Canada's Chemistry R. and D. appears to be characterized by a rigidity and lack of co-ordination which are the result of the lack of an overall science policy. As mentioned earlier, the United States national policy on nuclear armament and space activities set an overall objective for the science program of that country which was supported by large government funds, so that every institution or organization in some way found itself caught up in the program.

In Canada there has been no explicitly stated overall science policy. Some years ago the National Research Council decided to build strength into the university research effort, particularly on the basic side, and there appears to be general agreement that this has been done quite successfully. Nevertheless, the committee reports and the comments received from many other sources indicate that there is too little interchange and co-ordination between industry, government, and university. It is reported that each of the three R. and D. sectors (government, industry, and the universities) tends to go its own way both in general and in the particular fields of the committees' interests.

This is illustrated by Table 8 where the great interest of industry in polymers contrasts with the small interest of the universities and government. This situation may be compared with that which existed during World War II, when the urgent need for synthetic rubber resulted in a widespread joint effort in industry, government, and university. It may be argued that polymers have now reached the stage where they are of little interest from the point of view of basic research, but does this not mean that the chemical engineering departments should have taken up the challenge?

Another tendency in Canada which is pointed out by the committees is that too many universities select research projects in the same field so that the national research effort becomes diffused; hence the frequent recommendation to create centres-of-excellence and research institutes.

#### **VI.4 Government Incentives for R. and D.**

There was general agreement that the present incentives for R. and D. in industry were very worthwhile but industry itself expresses a preference for simplification, for the removal of the incremental feature, and for direct grants.

Since Canada has a large number of small companies who would find it difficult or too hazardous to mount research projects from their own resources, special attention should be paid to encouraging all types of co-operative and contract research. In Canada we have developed a type of contract research institute exemplified by our provincial research councils and foundations, which have succeeded in finding ways and means of working very closely with industry. They should be given increasing support. The concept of applied research institutes at universities appears to be promising and also merits assistance.

Co-operative research or research associations have not been as successful in Canada, with the exception of the Pulp and Paper Research Institute, and it is interesting to observe that some of the research associations in England now undertake contract research.

# Appendices

## Appendix I

### LIST OF ABBREVIATIONS USED IN THIS SUMMARY REPORT AND THE COMMITTEE REPORTS

AECEB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Limited
CASCC	Canadian Agricultural Services Co-ordinating Committee
CIC	The Chemical Institute of Canada
CARDE	Canadian Army Research and Development Establishment
DBS	Dominion Bureau of Statistics
DDP	Department of Defence Production
DDSP	Defence Development Sharing Program
DEMR	Department of Energy, Mines and Resources
DIR	Defence Industrial Research
DOI	Department of Industry
DRB	Defence Research Board
DRTE	Defence Research Telecommunications Establishment
EJC	Electrochemical Junction Centre
FAO	Food and Agriculture Organisation
FTE	Full Time Equivalent
GIRD	General Incentives for Research and Development (succeeded by IRDIA)
GNP	Gross National Product
ING	Intense Neutron Generator
IRAP	Industrial Research Assistance Program
IRDIA	Industrial Research and Development Incentives Act
LCAO	Linear Combination of Atomic Orbitals
M & I	Manpower and Immigration
MO	Molecular Orbital
NMR	Nuclear Magnetic Resonance
NRC	National Research Council of Canada
NSF	National Science Foundation (U.S.A.)
OECD	Organisation for Economic Co-operation and Development

PAIT	Program for Advancement of Industrial Technology
PDF	Postdoctoral Fellow
R. and D.	Research and Development
SCF	Self-Consistent Field
TRIUMF	Tri-Universities Meson Facility
UK	United Kingdom
USA	United States of America
WHO	World Health Organisation

## **Appendix II**

### **TERMS OF REFERENCE**

(Memorandum of agreement dated November 1, 1966)

The Chemical Institute of Canada will arrange for a study of research and development of Chemistry in Canada (hereinafter referred to as "chemistry research"). For completeness, the statistical locations and broad occupations of all professional chemists will, as far as possible, be recorded.

The study will mainly consist of a comprehensive survey of chemistry research in Canadian universities, industry, and government laboratories; the extent to which it is supported by public and private funds and the location and subject-matter of all significant work; the relative scientific, economic, and social importance of the major activities in chemistry research (under subdivision headings to be agreed); the balance between them with particular reference to locating serious gaps in the pattern; the future of chemistry research in Canada with recommendations on what objectives should be set for the next five years.

The study will use the results of the Government's own (Manpower and Immigration) most recent manpower survey and will not conduct a comprehensive manpower survey of its own.

A comprehensive draft report will be submitted to the Science Secretariat not later than November 30, 1967. The study group will not be required to take the report beyond the stage of a clear typewritten draft.

The Chemical Institute of Canada will appoint a head of study and chairmen of subdivision groups in the specialist subjects, as required. These groups may operate by sending out questionnaires, seeking briefs, holding hearings or informal discussions. Subdivisions of chemistry to be covered include the following (the detailed breakdown of subdivision headings is to be agreed between the contracting parties):

Analytical Chemistry

Inorganic Chemistry

Organic Chemistry

Physical Chemistry

Agricultural and Food Chemistry

Biochemistry

Chemical Engineering

Chemistry in the Earth Sciences and Related Fields.

### **Appendix III**

#### **MEMBERS OF STEERING COMMITTEE**

##### *Chairman*

Dr. M. Adelman, Head, Department of Chemical Engineering and Associate Dean of Graduate Studies, University of Windsor, Windsor, Ontario.

##### *Secretary*

Mr. T. H. G. Michael, General Manager, The Chemical Institute of Canada, Ottawa, Ontario.

##### *Members*

Dr. R. M. Butler, Head, Special Process Development, Engineering Division, Imperial Enterprises Ltd., Sarnia, Ontario.

Dr. P. A. Giguère, Faculté des Sciences, Université Laval, Québec, P.Q.

Dr. J. W. Hodgins, Dean, Faculty of Engineering, McMaster University, Hamilton, Ontario.

Dr. R. H. Manske, Retired Director of Research, Uniroyal Ltd., Guelph, Ontario.

Dr. W. A. E. McBryde, Dean of Science, University of Waterloo, Waterloo, Ontario.

Dr. B. B. Migicovsky, Director-General (Institutes), Research Branch, Canada Agriculture, Ottawa, Ontario.

Dr. I. E. Puddington, Director, Division of Applied Chemistry, National Research Council, Ottawa, Ontario.

Dr. H. S. Sutherland, Vice-President, Gulf Oil Canada, Ltd., Montreal, Quebec.

Mr. A. O. Wolff, Vice-President, Northern Electric Limited, Montreal, Quebec.



## Appendix IV

### COMMITTEE MEMBERS

(with affiliations at time of appointment)

- No. 1 — *Chairman:* Dr. W. A. E. McBryde, Dean, Faculty of Science, University of Waterloo, Waterloo, Ont.  
*Members:* Mr. R. B. Carson, Chief, Analytical Chemistry Research Service, Central Experimental Farm, Ottawa, Ont.; Professor A. Corsini, Department of Chemistry, McMaster University, Hamilton, Ont.; Mr. D. S. Russell, Division of Applied Chemistry, National Research Council, Ottawa, Ont.; Mr. G. W. Taylor, Rubber Division, Polymer Corp. Ltd., Sarnia, Ont.
- No. 2 — *Chairman:* Dr. N. F. H. Bright, Mines Branch, Ottawa, Ont.  
*Members:* Professor R. Rivest, Département de Chimie, Université de Montréal, Montréal, Que.; Dr. J. B. Taylor, Division of Applied Chemistry, National Research Council, Ottawa, Ont.; Mr. A. D. Turnbull, 3614 Cadboro Bay Road, Victoria, B.C.
- No. 3 — *Chairman:* Mr. A. D. Turnbull, 3614 Cadboro Bay Road, Victoria, B.C.  
*Members:* Mr. R. C. Bell, Manager, Technical Research, Cominco Ltd., Trail, B.C.; Dr. N. F. H. Bright, Mines Branch, Ottawa, Ont.; Mr. V. N. Mackiw, Director, Research & Development Division, Sherritt Gordon Mines Limited, Fort Saskatchewan, Alta.; Dr. E. Peters, Associate Professor, Department of Metallurgy, University of British Columbia, Vancouver, B.C.; Dr. W. R. Trost, Vice President (Academic), The University of Calgary, Calgary, Alta.
- No. 4 — *Chairman:* Dr. R. Stewart, Department of Chemistry, University of British Columbia, Vancouver, B.C.  
*Members:* Dr. A. S. Perlin, Prairie Regional Laboratory, National Research Council, Saskatoon, Sask.; Dr. P. Yates, Department of Chemistry, University of Toronto, Toronto, Ont.
- No. 5 — *Chairman:* Dr. D. S. Montgomery, Department of Energy, Mines & Resources, Ottawa, Ont.  
*Members:* Mr. C. H. Bayley, 425 Hinton Avenue, Ottawa, Ont.; Dr. N. Berkowitz, Head, Coal Research, Research Council of Alberta, Edmonton, Alta.; Mr. A. Darling, Explosives Research Laboratory, Department of Energy, Mines & Resources, Ottawa, Ont.; Mr. M. L. Staples, Director, Textile Dept., Ontario Research Foundation, Sheridan Park, Ont.; Mr. D. A. Stevenson, Explosives Research Laboratory, Department of Energy, Mines & Resources, Ottawa, Ont.; Dr. J. W. Tomecko, Director, Industrial Research Institute, University of Waterloo, Waterloo, Ont.; Dr. R. B. Whyte, National Research Council, Ottawa, Ont.; Mr. C. J. Warrington, The Chemical Institute of Canada, Ottawa, Ont.
- No. 6 — *Chairman:* Dr. A. Davis, Ayerst, McKenna & Harrison Ltd., Montreal, Que.  
*Members:* Dr. W. A. Ayer, Department of Chemistry, The University of Alberta, Edmonton, Alta.; Dr. R. Greenhalgh, Defence Chemical, Biological and Radiation Laboratories, Defence Research Board, Ottawa, Ont.
- No. 7 — *Chairman:* Dr. H. L. Williams, Department of Chemical Engineering, University of Toronto, Toronto, Ont.  
*Members:* Dr. A. G. Brook, Department of Chemistry, University of Toronto, Toronto, Ont.; Dr. H. C. Clark, Head, Department of Chemistry, University of Western Ontario, London, Ont.; Dr. R. J. Gillespie, Head, Department of Chemistry, McMaster University, Hamilton, Ont.

- No. 8 — *Chairman:* Dr. D. R. Muir, Director, Research & Development, Columbia Cellulose Ltd., New Westminster, B.C.  
*Members:* Dr. R. S. Evans, Columbia Cellulose Ltd., New Westminster, B.C.; Dr. D. A. I. Goring, Research Group Leader, Physical Chemistry Division, Pulp & Paper Research Institute of Canada, Pointe Claire, Que.; Dr. H. B. Marshall, Associate Research Director, Domtar, Senneville, Que.; Dr. H. Schwartz, Programme Co-ordinator, Forest Products, Department of Forestry and Rural Development, Ottawa, Ont.
- No. 9 — *Chairman:* Mr. M. L. Staples, Director, Textile Department, Ontario Research Foundation, Sheridan Park, Ont.  
*Members:* Mr. C. H. Bayley, 425 Hinton Avenue, Ottawa, Ont.; Mr. H. C. Mercereau, Assistant to Vice President & Technical Director, Canadian Celanese Company, Montreal, Que.
- No. 10 — *Chairman:* Dr. R. A. Back, Division of Pure Chemistry, National Research Council, Ottawa, Ont.  
*Members:* Dr. C. H. Amberg, Chemistry Department, Carleton University, Ottawa, Ont.; Dr. D. M. Wiles, Division of Applied Chemistry, National Research Council, Ottawa, Ont.
- No. 11 — *Chairman:* Dr. R. B. Anderson, Department of Chemical Engineering, McMaster University, Hamilton, Ont.  
*Members:* Mr. J. W. Anderson, J. W. Anderson Ltd., Dundas, Ont.; Dr. A. A. Robertson, Department of Chemistry, McGill University, Montreal, P.Q.
- No. 12 — *Chairman:* Dr. R. H. Betts, Head, Department of Chemistry, The University of Manitoba, Winnipeg, Man.  
*Members:* Dr. D. A. Armstrong, Acting Head, Department of Chemistry, University of Calgary, Calgary, Alta.; Dr. T. A. Eastwood, Head, Research Chemistry Branch, Atomic Energy of Canada Ltd., Chalk River, Ont.
- No. 13 — *Chairman:* Dr. E. J. Casey, Defence Research Board, Shirley's Bay, Ottawa, Ont.  
*Members:* Dr. P. L. Bourgault, Manager, Electronic Components Division, Johnson Matthey and Mallory Ltd., Toronto, Ont.; Professor B. E. Conway, University of Ottawa, Ont.; Dr. W. C. Cooper, Head, Research Division, Noranda Research Centre, Pointe Claire, Que.; Mr. R. Ellison, Senior Analyst, Market Research, Cominco, Montreal, P.Q.
- No. 14 — *Chairman:* Dr. G. R. Finlay, Assistant Director of Research, Norton Company, Chippawa, Ont.  
*Members:* Mr. I. R. Cameron, Director, Project Formulation, C.T.S. Branch, Department of National Defence, Ottawa, Ont.; Professor B. E. Conway, University of Ottawa, Ottawa, Ont.; Professor J. Plamback, University of Alberta, Edmonton, Alta.; Professor R. Stager, University of Windsor, Windsor, Ont.
- No. 15 — *Chairman:* Dr. R. F. W. Bader, Department of Chemistry, McMaster University, Hamilton, Ont.  
*Members:* Dr. C. C. Calvo, Department of Chemistry, McMaster University, Hamilton, Ont.; Dr. G. W. King, Department of Chemistry, McMaster University, Hamilton, Ont.
- No. 16 — *Chairman:* Dr. P. Sims, Food Research Institute, Central Experimental Farm, Ottawa, Ont.  
*Members:* Dr. H. Hurtig, Pesticide Specialist, Food Research Institute, Central Experimental Farm, Ottawa, Ont.; Dr. F. B. Johnston, Food Research Institute, Central Experimental Farm, Ottawa, Ont.; Dr. D. P. Ormrod, Associate Professor, Department of Food Science, University of British Columbia, Vancouver, B.C.; Dr. E. Y. Spencer, Director, Pesticide Research Institute, Canada Department of Agriculture, London, Ont.

- No. 17 — *Chairman:* Dr. L. Berlinguet, Université Laval, Faculté de Médecine, Cité Universitaire, Québec, P.Q.  
*Members:* Dr. K. K. Carroll, University of Western Ontario, London, Ont.; Dr. N. B. Madsen, Department of Biochemistry, University of Alberta, Edmonton, Alta.; Dr. L. Sehon, Department of Chemistry, McGill University, Montreal, P.Q.; Dr. L. C. Vining, Atlantic Regional Laboratory, National Research Council, Halifax, N.S.
- No. 18 — *Chairman:* Professor D. S. Scott, Department of Chemical Engineering, University of Waterloo, Waterloo, Ont.  
*Members:* Dr. J. Hay, Manager of Research & Development, Dow Chemical of Canada Ltd., Sarnia, Ont.; Dr. P. M. Reilly, Polymer Corporation Limited, Sarnia, Ont.
- No. 19 — *Chairman:* Dr. R. W. Boyle, Head, Geochemistry, Geological Survey of Canada, Ottawa, Ont.  
*Members:* Dr. I. C. Brown, Acting Chief, Hydrology Division, Water Research Branch, Department of Energy, Mines & Resources, Ottawa, Ont.; Dr. L. J. Cabri, Mineral Sciences Division, Mines Branch, Department of Energy, Mines & Resources, Ottawa, Ont.; Dr. J. S. Clark, Soil Research Institute, Department of Agriculture, Central Experimental Farm, Ottawa, Ont.; Dr. D. R. Clews, Vice President, Barringer Research Ltd., Rexdale, Ont.; Professor J. H. Crocket, Department of Geology, McMaster University, Hamilton, Ont.; Dr. J. A. Maxwell, Head, Analytical Section, Geological Survey of Canada, Ottawa, Ont.; Dr. J. L. Sullivan, Department of National Health & Welfare, Tunney's Pasture, Ottawa, Ont.; Dr. J. P. Tully, Fisheries Research Board, Sir Charles Tupper Building, Ottawa, Ont.; Dr. R. K. Wanless, Head, Isotope Geology Section, Geological Survey of Canada, Ottawa, Ont.
- No. 20 — *Chairman:* Dr. J. E. Brown, Chief Librarian, National Science Library, National Research Council, Ottawa, Ont.  
*Member:* Dr. J. Morrison, Editor, Canadian Journals of Research, National Research Council, Ottawa, Ont.

## Appendix V

### CLASSIFICATION BY MAJOR FIELD,<sup>8</sup> C.I.C. R. AND D. AREA AND M. AND I. SPECIALTY

#### 200 ANALYTICAL CHEMISTRY

##### *Committee 01 — Analytical Chemistry*

###### *Area 011 General Techniques*

- 0201 Biochemical analysis
- 0203 Chromatographic analysis
- 0204 Distillation analysis
- 0205 Electrochemical analysis
- 0208 Extraction analysis
- 0211 Gravimetry
- 0214 Microchemical analysis
- 0215 Nucleonics and radiochemistry
- 0216 Qualitative analysis
- 0217 Titrimetry
- 0219 Other general analytical techniques

###### *Area 012 Spectroscopy*

- 0200 Absorption spectroscopy
- 0202 Chemical microscopy
- 0206 Electron microscopy
- 0207 Emission spectroscopy
- 0209 Fluorimetry, phosphorimetry, and Raman spectroscopy
- 0210 Gas analysis
- 0212 Magnetic resonance spectroscopy
- 0213 Mass spectroscopy
- 0218 X-ray and electron diffraction
- 0219 Other spectroscopy

#### 210 INORGANIC CHEMISTRY

##### *Committee 02 General, etc.*

###### *Area 021 General Inorganic Chemistry*

- 0220 Atomic structure
- 0221 Boron and silicon compounds; asbestos, clay, glass, etc.
- 0222 Carbon, germanium, lead, tin; includes graphite, etc.
- 0223 Co-ordination compounds
- 0224 "Electron-deficient" compounds; boron hydrides, metal alkyls, etc.
- 0225 Electropositive elements and their compounds (alkalis and alkaline earths, building products, etc.)
- 0227 Hydrogen and the hydrides
- 0228 Inner transition elements
- 0229 Inorganic materials useful as solid state electronic devices, semi-conductors, etc.

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<sup>8</sup> Major field titles and code numbers, e.g. 200 ANALYTICAL CHEMISTRY, and committee titles are based largely on an N.R.C. classification. Specialty titles, e.g. Biochemical analysis are from the N.S.F. 1966 code and carry four-digit code numbers from the M. & I. coding manual, except, for metallurgy, where the numbers and titles originated with the C.I.C. survey.

- 0231 Nomenclature and symbolism
- 0232 Non-metals; halogen, oxygen, and nitrogen families, high energy oxidizers
- 0236 Synthesis of inorganic materials
- 0238 Transition elements
- 0239 Other general inorganic chemistry

*Area 022 Physical Inorganic Chemistry*

- 0226 Equilibrium and thermodynamic relationships in inorganic systems
- 0230 Mechanism of inorganic reactions; reaction kinetics
- 0234 Solutions and solvent theory
- 0235 Structure of inorganic compounds; crystallography, spectroscopy, etc.
- 0239 Other physical inorganic chemistry

*Area 023 Theoretical Inorganic Chemistry*

- 0237 Ionic models, ligand field theory, molecular orbital theory, theory of metals, etc.
- 0239 Other theoretical inorganic chemistry

## 0059 METALLURGY

*Committee 03 Metallurgy*

*Area 03I Metallurgy*

- 0301<sup>9</sup> Chemical metallurgy
- 0302<sup>9</sup> Physical metallurgy
- 0303<sup>9</sup> High purity metals
- 0304<sup>9</sup> Intermetallic compounds
- 0305<sup>9</sup> Composite materials of metals and non-metals

## 220 ORGANIC CHEMISTRY

*Committee 04 General Organic & Physical Organic Chemistry*

*Area 04I General Organic Chemistry*

- 0242 Aliphatic chemistry
- 0246 Aromatic hydrocarbons and derivatives
- 0254 Free radicals
- 0255 Heterocycles
- 0256 Hydrogenation
- 0264 Photoproducts
- 0272 Structure of organic molecules
- 0277 Other general organic chemistry

*Area 042 Physical Organic Chemistry*

- 0257 Isotopes, use of
- 0267 Reaction mechanisms
- 0270 Stereochemistry
- 0277 Other physical organic chemistry

*Committee 05 Fuels, etc.*

*Area 05I Fuels, etc.*

- 0248 Coal
- 0252 Explosives and rocket fuels
- 0258 Oils, fats, and waxes
- 0261 Petroleum, petrochemicals, etc.

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<sup>9</sup> C.I.C., not M. & I. code numbers.

*Area 052 Coatings and Detergents*

- 0251 Emulsions
- 0266 Protective coatings
- 0269 Soaps, detergents, surfactants

*Area 053 Dyestuffs*

- 0249 Dyestuffs

*Committee 06 Pharmaceuticals and Natural Products*

*Area 061 Pharmaceuticals and Natural Products*

- 0243 Alkaloids
- 0262 Pharmaceuticals
- 0274 Terpenes and other alicyclics
- 0244 Amino acids
- 0245 Antibiotics
- 0247 Carbohydrates (basic)
- 0271 Steroids

*Committee 07 Polymers, etc.*

*Area 071 Elastomers, Plastics, and Resins*

- 0250 Elastomers and related products
- 0265 Plastics and synthetic resins

*Area 072 Organometallics*

- 0259 Organometallics

*Area 073 Fluorine, Phosphorus, Silicon, and Sulphur Organic Chemistry*

- 0253 Fluorine compounds
- 0260 Organophosphorus compounds
- 0263 Phosphorus compounds
- 0268 Silicon compounds
- 0273 Sulphur compounds

*Committee 08 Pulp and Paper, etc.*

*Area 081 Pulp and Paper*

- 0240 Adhesives
- 0276 Wood, paper, cellulose

*Committee 09 Textiles*

*Area 091 Textiles*

- 0275 Textiles and related products (leather)
- 0277 Other organic materials

**230 PHYSICAL CHEMISTRY**

*Committee 10 Chemical Kinetics, etc.*

*Area 101 Chemical Kinetics*

- 2695 Chemical kinetics
- 2708 Molecular dynamics
- 2711 Photochemistry and energy transfer

*Area 102 Catalysis*

- 2694 Catalysis and surface chemistry
- 2712 Polymer chemistry

*Committee 11 Thermodynamics, etc.*

*Area 111 Thermodynamics and States of Matter*

- 2696 Colloid chemistry
- 2702 Gaseous state
- 2705 Ion exchange and applications
- 2716 Thermodynamics, thermochemistry, homogeneous chemical and phase equilibria

*Committee 12 Nuclear and Radiation Chemistry*

*Area 121 Radiation Chemistry*

- 2710 Nuclear chemistry
- 2714 Radiation chemistry

*Committee 13 Electrochemistry, etc.*

*Area 131 Electrochemistry*

- 2699 Electrochemistry
- 2715 Solid state chemistry
- 2706 Liquid state and solutions; electrolytes and non-electrolytes

*Committee 14 High Pressure and Temperature Chemistry, etc.*

*Area 141 High Pressure and High Temperature Chemistry*

- 2700 Flames and explosives
- 2701 Fused salt
- 2703 High pressure chemistry
- 2704 High temperature chemistry
- 2707 Low temperature studies

*Committee 15 Crystal Structure and Theoretical Chemistry*

*Area 151 Crystal Structure and Theoretical Chemistry*

- 2697 Crystal structure
- 2698 Determination of physical constants
- 2709 Molecular energy levels and geometry
- 2713 Quantum and valence theory
- 2717 Other Physical Chemistry

**096 AGRICULTURE AND FOOD CHEMISTRY**

*Committee 16*

*Area 161 Agriculture and Food Chemistry*

- 2600 Alcoholic beverages
- 2601 Animal and vegetable fats, oils
- 2602 Animal feeds
- 2603 Bakery and confectionery products
- 2604 Cereals, carbohydrates
- 2605 Fertilizer processing
- 2606 Flavours
- 2607 Food and feed additives
- 2608 Fruits, vegetables, juices
- 2609 Meat, fish, dairy, and poultry products
- 2610 Microorganisms; bacteria, yeasts, algae, molds
- 2611 Non-alcoholic beverages
- 2612 Pesticides; insecticides, herbicides, fungicides
- 2613 Plant growth regulators
- 2614 Other Agriculture and Food Chemistry

## 090 BIOCHEMISTRY

### *Committee 17*

#### *Area 171 Biochemistry*

- 2615 Amino acids, peptides, proteins
- 2616 Antimetabolites
- 2617 Biochemical mechanisms
- 2618 Carbohydrates
- 2619 Clinical chemistry
- 2620 Cyto-histochemistry
- 2621 Endocrines
- 2622 Enzymes, coenzymes
- 2623 Fermentation
- 2624 Intermediary metabolism, biosynthesis
- 2625 Lipids, (phospho-, glyco-): fats, oils
- 2626 Medicinal chemistry
- 2627 Microbial processes, syntheses
- 2628 Microbiological chemistry
- 2629 Nucleic acids (purines, pyrimidines)
- 2630 Oncology, carcinogenesis
- 2631 Photosyntheses
- 2632 Physical biochemistry
- 2633 Steroids
- 2634 Technology, methodology
- 2635 Vitamins
- 2636 Other Biochemistry

## 400 CHEMICAL ENGINEERING

### *Committee 18*

#### *Area 181 Chemical Engineering*

- 0278 Absorption and adsorption
- 0279 Chemical separation
- 0280 Corrosion and preservation
- 0281 Electrochemical operations
- 0282 Chemical economics
- 0283 Fuels and combustion
- 0284 Fluid flow
- 0285 Heat transfer
- 0286 Mass transfer
- 0287 Materials handling
- 0288 Measurement and control
- 0289 Mechanical separation
- 0290 Mixing
- 0291 Nuclear processes
- 0292 Operational analysis
- 0293 Pilot plant
- 0294 Plant and process design
- 0295 Quality control and standards
- 0296 Other Chemical Engineering
- 0297 Other Chemistry

## 003 EARTH SCIENCES AND RELATED FIELDS

### *Committee 19*

#### *Area 191 Chemical Oceanography*

- 0521 Chemical oceanography



*Area 192 Atmospheric Chemistry*

- 0401 Atmospheric chemistry
- 0432 Air pollution
- 0452 Cosmochemistry

*Area 193 Geochemistry*

- 0453 General inorganic geochemistry
- 0454 Isotopes and geochronology
- 0455 Mineral synthesis and stability relations of minerals
- 0456 Organic geochemistry
- 0457 Other geochemistry

*Area 194 Water Chemistry*

- 0510 Erosion and sedimentation
- 0511 Evaporation and transpiration
- 0512 Glaciology
- 0513 Ground waters
- 0514 Precipitation
- 0515 Quality of water
- 0516 Snow, ice, and permafrost
- 0517 Soil moisture
- 0518 Surface waters
- 0519 Other Earth Sciences Chemistry

## 12 LITERATURE AND INFORMATION

*Committee 20*

*Area 201 Literature and Information*

- 2801 Abstracting
- 2807 History
- 2809 Indexing
- 2810 Information retrieval
- 2811 Information system design
- 2814 Library and archival service
- 2816 Literature
- 2828 Translation

**Appendix VI**

**STATISTICAL SURVEY**

**DATA TABLES<sup>a</sup>**

TABLE No.

**GOVERNMENTS<sup>2</sup>**

1	Number of Completed R.U.Q.s <sup>4</sup> and P.Q.s <sup>5</sup> Received
2	Intramural R. and D. Expenditures
3	Sources and Amounts of Funds (1966 or '66-'67)
4	Number of Reporting Units Reporting Difficulties
5	Effort in Man-Years
6	Operating R. and D. Intramural Expenditures of Reporting Units Reporting Difficulties
7a	(Histogram) Number of Reporting Units at Given Levels of Intramural Operating R. and D. Expenditures (1966)
7b	(Histogram) Number of Reporting Units at Given Levels of Operating R. and D. Intramural Expenditures (1970)
8	Number of Projects Reported for Each Major Field, Committee and Specialty of C.I.C. Classification
9	Number of Projects Reported and Number Previously Reported
10	Number of Projects Reported for Each Category of C.I.C. Classification of Industry
11	Operating R. and D. Intramural Expenditures for Each Major Field, Committee and Specialty of C.I.C. Classification
11a	Character of Intramural R. and D. by Each Specialty of C.I.C. Classification
12	Operating R. and D. Intramural Expenditures for Each Category of C.I.C. Classification of Industry
13	Operating R. and D. Intramural Expenditures for Each C.I.C. R. and D. Area <sup>6</sup>
13a	Character of Intramural R. and D. by C.I.C. R. and D. Area
14	Total Scientist and Engineer Manpower Effort on Chemistry <sup>1</sup> Intramural R. and D.
15	Total Technician Effort on Chemistry <sup>1</sup> Intramural R. and D.
16	Manpower Effort on Intramural R. and D. for Each Major Field, Committee and Specialty of C.I.C. Classification
17	Number of P.Q.s <sup>5</sup> Reporting Difficulties
18	Operating R. and D. Intramural Expenditures of P.Q.s <sup>5</sup> Reporting Difficulties
19	Number of P.Q.s <sup>5</sup> and Level of Effort Reported
20	Intramural R. and D. Operating Expenditures of P.Q.s <sup>5</sup> Classified by Reported Level of Effort
21	Number of P.Q.s <sup>5</sup> Reporting Neglected C.I.C. Specialties
22	Manpower Effort on Intramural R. and D. for Each C.I.C. R. and D. Area <sup>6</sup>

### COMPANIES<sup>3</sup>

- 23 Company Questionnaires Classified by Starting Month of Reporting Period
- 24 Intramural R. and D. Expenditures
- 25 Sources and Amounts of Funds, 1966
- 26 Intramural R. and D. Operating Expenditures for Each C.I.C. Committee, Area<sup>6</sup> and Character of R. and D.
- 27 Total Scientist and Engineer Manpower Effort on Chemistry<sup>1</sup> Intramural R. and D.
- 27a Total Scientist, Engineer, Technician Effort on Chemistry<sup>1</sup> Intramural R. and D. for Each C.I.C. Committee and Area<sup>6</sup>
- 28 Total Technician Effort on Chemistry<sup>1</sup> Intramural R. and D.
- 29 Number of C.Q.s<sup>7</sup> Reporting Difficulties
- 30a Companies<sup>3</sup> Reporting Difficulties in Securing Personnel, Equipment or Computer Service for R. and D.
- 30b Distribution of Table 30a Response over Biochemistry, Chemical Engineering and "Other Chemistry"
- 31a Operating and Capital R. and D. Intramural 1966 Expenditures on Chemistry<sup>1</sup> for each D.B.S. Industry Group
- 31b Scientific and Engineering Manpower Effort on Chemistry<sup>1</sup> Intramural R. and D. by D.B.S. Industry Group
- 32 (Histogram) Number of Companies at Given Levels of 1966 Intramural Operating Expenditures on Chemistry<sup>1</sup> R. and D.
- 33 (Histogram) Number of Companies Forecasting Given Levels of 1970 Intramural Operating Expenditures on Chemistry<sup>1</sup> R. and D.

### PROVINCIAL RESEARCH COUNCILS AND FOUNDATIONS

- 24P Intramural R. and D. Expenditures
- 25P Sources and Amounts of Funds, 1966
- 26P Intramural R. and D. Operating Expenditures for Each C.I.C. Committee Area<sup>6</sup> and Character of R. and D.
- 27P Total Scientist and Engineer Manpower Effort on Chemistry<sup>1</sup> Intramural R. and D.
- 27Pa Total Scientist/Engineer and Technician Manpower Effort on Chemistry<sup>1</sup> Intramural R. and D. for Each C.I.C. Committee and Area<sup>6</sup>
- 28P Total Technician Effort on Chemistry<sup>1</sup> Intramural R. and D.
- 29P Number of C.Q.s<sup>7</sup> Reporting Difficulties
- 30P Intramural Operating R. and D. Expenditures of C.Q.s<sup>7</sup> Reporting Difficulties

### UNIVERSITIES AND INSTITUTES

- 34 Number of Completed U.D.Q.s<sup>8</sup> Received
- 35 University and Institute Funds Available and Their Allotment
- 36 Chemistry<sup>1</sup> R. and D. Funds by Source
- 37 Intramural Chemistry<sup>1</sup> R. and D. Expenditures by C.I.C. R. and D. Area<sup>6</sup>
- 38 Manpower Effort in Man-Years on Intramural R. and D. for Each C.I.C. R. and D. Area<sup>6</sup>
- 39 Intramural R. and D. Operating and Minor Equipment Expenditures for Each C.I.C. Committee, Area<sup>6</sup> and Character of R. and D.

- 40 Number of Academic Staff by Each C.I.C. Committee, Area<sup>6</sup> and Character of R. and D.
- 41 Number of Total Staff by Each C.I.C. Committee, Area<sup>6</sup> and Character of R. and D.
- 42 Number of U.D.Q.s<sup>8</sup> Received by Character of R. and D.
- 43 Forecasts of Chemistry<sup>1</sup> Intramural R. and D. Expenditures
- 44 Manpower Effort in Full-Time Equivalents on Intramural R. and D. for Each C.I.C. R. and D. Area<sup>6</sup> (1966-67)
- 45 Intramural Chemistry<sup>1</sup> R. and D. Operating Expenses for Each Category of C.I.C. Industry Classification

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<sup>a</sup> References:

<sup>1</sup> Chemistry: including chemical engineering and other related disciplines.

<sup>2</sup> Governments: excluding provincial research councils and foundations.

<sup>3</sup> Companies: companies, including provincial research councils and foundations.

<sup>4</sup> R.U.Q.: Government Reporting Unit Questionnaire.

<sup>5</sup> P.Q.: Government Project Questionnaire.

<sup>6</sup> Area: C.I.C. Committee and Area Classification.

<sup>7</sup> C.Q.: Company Questionnaire.

<sup>8</sup> U.D.Q.: University Department (or Institute) Questionnaire.

**Appendix VII**  
**SPECIMEN QUESTIONNAIRE**

Survey of  
**CHEMICAL AND CHEMICAL ENGINEERING  
RESEARCH AND DEVELOPMENT IN CANADA**  
  
for the  
**SCIENCE SECRETARIAT OF THE PRIVY COUNCIL OFFICE**  
  
by  
**The Chemical Institute of Canada.**

**COMPANY QUESTIONNAIRE**

**Instruction:** For definitions see page 2 of this questionnaire. Please report on all your chemical and chemical engineering R&D as defined for year 1966 or the most recently available twelve month period.

In entering numbers in the boxes, please do not leave spaces at the right hand end of the box.

SURVEY CODE	
Office Use Only	
Card No.	<input type="text" value="1"/>
Company	<input type="text"/>
2-	

Item (1) Company Name	
Company Address	
Name of person responsible for completing this return.	
Official Position	
Date	Telephone number

SURVEY CODE	
Office Use Only	
Card No.	1
Company	
2-	

- (2) Date ..... Reporting period .....to .....  
 Instruction: Use the 12 month period which is closest available equivalent to calendar year 1966.

- (3) Total intra-mural expenditures by the company on chemical and chemical engineering R&D for the reporting period, and forecasts of comparable totals for future periods. See definitions.

(in thousands of dollars)	
Operating	Capital
1966 .....	
6--	11--
1967 forecast .....	
16--	21--
1968 forecast .....	
26--	31--
1969 forecast .....	
36--	41--
1970 forecast .....	
46--	51--
Five Year Total .....	
56--	62--

Instructions: Do NOT include payments for R&D made to other organizations. Any such work done in Canada will be reported by the performing organization. Do NOT include any capital depreciation costs or capital consumption allowances in any answer. See "Definitions"

- (4) Sources and amounts of funds for total expenditures entered in (3) for the reporting period 1966.

(in thousands of dollars)	
Operating	Capital
Own Company .....	
68--	72--
Canadian federal government .....	
76--	206--
Canadian provincial governments .....	
10--	14--
Other .....	
18--	22--
Total (to agree with first row of (3)) .....	
26--	30--

- (5) Classification of total R&D expenditures reported for 1966 under (3) by R&D area and type.

(a) R&D Area Code Number (s) .....			
34--	37--	40--	43--
(b) % of Total R&D Expenditures ....			
46--	49--	52--	55--
(c) Basic Research .....			
58--	61--	64--	67--
(d) Applied Research .....			
70--	73--	76--	306--
(e) Development .....			
9--	12--	15--	18--

Instructions: See C.I.C. Committee Classification for R&D area code numbers. If areas reported exceed 4 in number, please use additional forms. All percentage entries in the above table should be percentages of the total R&D expenditure reported under (3), i.e. row (b) should total 100% and in each column (c), (d) and (e) should total to the percentage shown in row (b), see example below.

(a) R&D Area No. ....	071	072	102
(b) % Total R&D Expenditures .....	70	10	20
(c) % Basic Research .....	5	3	10
(d) % Applied Research.....	25	7	10
(e) % Development .....	40	0	0

(6) Scientific and engineering effort (scientists, engineers and managers/supervisors of R&D), engaged on chemical and chemical engineering R&D in man-years during the reporting period, employed as:

	Doctor	Master	Bachelor
Biochemists .....			
	21—	24—	27—
Chemical engineers .....			
	30—	33—	36—
Chemists .....			
	39—	42—	45—
Mathematicians .....			
	48—	51—	54—
Metallurgists .....			
	57—	60—	63—
Physicists .....			
	66—	69—	72—
Other engineers .....			
	75—	406—	09—
Other scientists .....			
	12—	15—	18—
Totals .....			
	21—	24—	27—

Instructions: Use highest degree. Associateships of professional organizations, (e.g. A.C.I.C., Professional Engineer), may be taken as equivalent to bachelor degree.

(7) Number of technicians engaged on chemical and chemical engineering R&D.

Biochemical technicians .....	
	30—
All other chemical and chemical engineering technicians .....	
	33—
Other .....	
	36—

(8) Was effort expended on chemical and chemical engineering R&D during the reporting period limited by difficulty in securing:

	Biochemical		All Other Chemical		Chemical Engineering	
	Yes	No	Yes	No	Yes	No
Qualified R&D directors? .....	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>
	39—		40—		41—	
Qualified R&D Professional Personnel? .....	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>
	42—		43—		44—	
Qualified R&D Technicians? .....	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>
	45—		46—		47—	
Access to more sophisticated equipment? .....	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>
	48—		49—		50—	
Access to computer services? .....	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>
	51—		52—		53—	

Please discuss under item (10) below any other factors which you believe to be unduly limiting R&D effort in Canada.

(9) Have any of the R&D expenditures reported in item (5) been included in replies to other Science Secretariat Surveys covering other disciplines? Check one.

	Yes	No
1	<input type="checkbox"/>	2 <input type="checkbox"/>
	54—	

If yes, please list the surveys:

.....  
 .....  
 .....

(10) Comment on chemical and chemical engineering R&D in Canada.

The survey will welcome any comments on the present Canadian situation with respect to chemical and chemical engineering R&D and suggestions of ways for securing adequate growth in the future. These may be attached hereto or submitted separately.

Please list specific areas of chemical and chemical engineering R&D which you feel should receive more attention in Canada by universities, government and/or industries. Comments may cover such factors as economic environment, size of company, tariffs, patents, etc.

Please indicate by checking the appropriate box to the right whether your company name may be quoted in connection with these comments.

	Yes	No
	<input type="checkbox"/>	2 <input type="checkbox"/>
	55—	