# Technological Innovation Studies Program

# Programme des études sur les innovations techniques

## Research Report

## Rapport de recherche

TECHNOLOGICAL INNOVATION IN THE
NONDESTRUCTIVE TESTING INDUSTRY

by

Dr. Dirk Leemans

Faculty of Environmental Studies
York University
Downsview, Ontario
February, 1985

#101

Government of Canada
Gouvernement du Canada

Regional Industrial Expansion
Expansion industrielle régionale

Office of Industrial Innovation
Bureau de l'innovation industrielle

ISSN 0226-3122

# TECHNOLOGICAL INNOVATION IN THE NONDESTRUCTIVE TESTING INDUSTRY

by

Dr. Dirk Leemans

Faculty of Environmental Studies
York University
Downsview, Ontario
February, 1985

#101

# TECHNOLOGICAL INNOVATION IN THE NONDESTRUCTIVE TESTING INDUSTRY

A Report to the Office of Industrial Innovation of the Department of Regional Industrial Expansion

February 1985

Dr. Dirk Leemans
Faculty of Environmental Studies
York University
Downsview, Ontario

**ACKNOWLEDGEMENTS**

The author wishes to thank Professor P. Homenuck for his continuous support and advice, the Canadian Society of Non-Destructive Testing for their collaboration and Mr. D. Abbott for his assistance with questionnaire development and analysis. Also, this study which uses surveys to a considerable degree could not be made without the graceful collaboration of the study subjects to whom the author extends a heartfelt expression of his gratitude. The author also wishes to thank the Department of Regional Industrial Expansion for the generous grant offered towards this study. Finally, the author is grateful for the cooperation and assistance provided by Dr. Chummer Farina and Mrs. Louise Williamson.

Table of Contents

Table of Contents

## EXECUTIVE SUMMARY


The nondestructive testing (NDT) field is an essential part of the industrial apparatus of this country. Its purpose is to inspect products without affecting the serviceability of the object tested. It plays a major role in securing the safety of structures and in improving productivity, mainly in the manufacturing industry. Questions of human safety and environmental pollution focus great attention on the integrity of plants and the safe operation of machinery and transportation systems. Nondestructive testing will remain a growth area for the next ten years.

In this study it is estimated that the nondestructive testing industry employs about four thousand people in Canada. The largest sector is the inspection industry which employs about three thousand workers spread over about two hundred companies. The manufacturing and sales of NDT equipment involves a few hundred people.

In the coming years substantive changes will take place in this industry. First the clientele will change. At the present time, the main user of NDT inspection is the oil & gas industry. This will remain the case over the next five years but its importance will decline. NDT has considerable growth potential in the manufacturing sector. Another area were NDT will be very active is in off-shore exploration.

There will be some changes in the NDT techniques used. Currently radiography is the most prominent NDT technique followed by ultrasonics. This will remain the case at least over the next five years. However radiography will see its share of NDT activity reduced while use of ultrasonics will be increasing. The biggest changes will take place in the nondestructive inspections which are not mandated by codes and regulations. It is unlikely that the codes will change dramatically over the next five years.

There will be also changes in the way that inspections are carried out. Four changes were identified in this study; computerization, the use of robotics and hybrid systems (the use of two complementary NDT techniqes simultaneously) and the production of images of the test object. In order to implement these advances a collaborative effort between industry, universities and governments must be established.

The technological changes in NDT will not be isolated events but will be integrated in the whole process of technological change mainly in the manufacturing industry. In this particular sector technological advances in nondestructive testing will give an impetus for change in automation and computerization.

The report points out several opportunities for fruitful governmental actions. The suggestions relate to the NDT equipment manufacturing sector, to the training both at the university and community college level and to transferability to the inspection industry of new NDT technologies. The main suggestion is the setting up of a Canadian Institute for Nondestructive Testing which would focus on the manufacturing sector and be a resource to the NDT inspection community.

Chapter 1

# NONDESTRUCTIVE TESTING: WHAT IS IT?

Man has always been concerned with the quality and reliability of the artifacts he manufactures. Continually he has sought to improve the means to assess the quality of his products. A famous example of this drive to evaluate quality is the story of Archimedes' testing for the silver content in Hiero's crown. Nondestructive testing (NDT) can be formally defined as those inspection techniques which check compliance of materials quality or structural integrity to agreed specifications without in any way affecting the serviceability of the objects tested. These techniques would include the shaking of cantaloupe and listening for the rattle of seeds to determine the ripeness of the fruit and the doctor's listening by stethoscope to the breathing of a patient. However, in our technological society NDT is mainly associated with the inspection of man's artifacts.

Although man has always been concerned with nondestructive evaluation, skills and tools for this task have generally lagged behind his capability to manufacture products. Most of the present techniques used in NDT are less than fifty years old; many are less than twenty years old. Until recently NDT was considered more a technical craft than a scientific pursuit. It was during World War II that the major NDT methods (liquid penetrant testing, magnetic particle testing, X-ray radiography, ultrasonic testing and eddy current testing) reached a high, though not definitive, state of development. The fast industrial change since World War II has furthered refinement of the big five NDT methods and a short description of each of these techniques (acoustic emission which might be develop into an important technique is also included) as well as their advantages and disadvantages are given in Appendix A. The post-war boom has spawned also the generation of a host of new techniques. A recent survey reproduced in Appendix B lists sixty nine techniques and undoubtedly many new ones will be discovered. These refinements and new developments are based on advanced physics, electronics and computers.

One of the main purposes of nondestructive testing is the prevention of engineering system failures that kill or injure people. Its methods are therefore analogous to preventive medicine; dangerous conditions are detected when remedies can still be applied. It has been estimated that NDT saves worldwide about 25000 lives per year and prevents about three million human injuries. A whole field in medicine is parallel to NDT now as well as in the past. In the early days of NDT there were often as many medical personnel as industrial contributors to nondestructive testing conferences and journals. Both fields have interacted vigorously in the past and continue to do so in the present. The fields of tomography and fluoroscopy are good examples of this crossfertilization. In this study however the non-medical aspects of nondestructive testing will be emphasized.

NDT techniques thus provide a means of assessing the integrity of structures and products without impairing their use. There are at the present time six main techniques used for this purpose. Their outputs are charts, images or just numbers. In the following chapter the impetus for growth in nondestructive testing will be analyzed by looking at the role of NDT in industrial society.

# Chapter 2

# IMPETUS FOR GROWTH OF THE NONDESTRUCTIVE TESTING INDUSTRY

## 2.1 Introduction

In the past NDT has grown in response to problems as they arose. Recently research programs are being carried in the NDT field in response to perceived future needs. The reasons for growth in this industry are mainly twofold:

1. Cost savings mainly related to productivity growth;

2. An increase in the concern for safety and health and therefore in regulatory activity.

These two main elements for NDT expansion will now be reviewed in more detail.

## 2.2 Cost Savings in Quality Control

Nondestructive testing is a powerful tool for reducing costs and improving and maintaining product quality. NDT does not destroy any production whereas destructive testing for quality assurance purposes must destroy a certain percentage of production. Furthermore destructive testing must be done by a batch method, so entire batches are rejected when the sample, destructively tested, does not meet specifications. Batch testing unlike NDT does not allow for examination of 100% of the production. NDT will allow the scrapping of only those items (and not batches) which do not pass the test.

The flexibility of NDT allows for testing at different stages of the manufacturing process. This can be highly advantageous by saving the cost of processing faulty stock. Control of the raw materials in coordination with design is the first stage where nondestructive testing can be used to reduce costs. Production monitoring is the next stage in the manufacturing process where nondestructive tests can yield substantive benefits. The best point at which to check for processing flaws is directly after the processing step in which they could originate. One major advantage is that immediate feedback of NDT information can lead to quick identification of the cause of the flaws. Another use of NDT in the manufacturing industry is in process control with the output of the NDT inspection an important parameter. This will become more important with the introduction of robotics in the workplace. NDT measurements will steer the robot to certain activities. Lastly NDT can be used to monitor the manufacturing equipment itself. Often it is possible to assess the state of equipment by measuring telltale properties. A well-known example is the development of loose parts monitoring systems.

The advantages of NDT tests can be summarized:

- Can be done on production items without regard to part cost or quantity available, and no scrap costs are incurred except for bad parts.

- Can be done on 100% of production or on representative samples.

- Can be used when variability is wide and unpredictable.

- Different tests can be applied to the same item simultaneously or sequentially. The same test can be repeated on the same item.

- May be performed on parts in service.

- Cumulative effect of service usage can be measured directly.

- May reveal failure mechanism.

- Little or no specimen preparation is required.

- Equipment is often portable for use in the field.

- Labor costs are usually low, especially for repetitive testing of similar parts.

It should however also be noted that NDT has certain limitations:

- Results often must be interpreted by a skilled, experienced technician.

- In absence of proven correlation, different observers may disagree on meaning and significance of the test results.

- Properties are measured indirectly and often only qualitative or comparative measurements can be made.

- Some nondestructive tests require large capital investments.

## 2.3 Cost Savings in Materials, Energy and Manpower

Non-destructive testing can be used to eliminate the need for some of the gross over-design incorporated into parts and structures because of the traditional need to account for unknown defects. The designer can use less material in each component because there is less need to allow for variations in characteristics of the raw material.

Clearly if less material is needed and less effort spent on material, which was faulty to begin with, there will be proportional savings in energy. NDT equipment has modest power requirements and can save tons of materials and megawatt-hours in energy.

The improvement in productivity owing to NDT is mainly related to the following:

1. No manpower is wasted on processing faulty material;

2. NDT of 100% of the manufactured goods can often be done with less personnel than batch testing.

3. Less material can be used as products can be designed closer to theoretical limits.

## 2.4 Cost Savings in the Area of Product Liability

It can safely be stated that a good NDT program instituted in a manufacturing plant will considerably cut down on repair and replacement costs of products sold under warranty. A good example is the savings of $ 16 M/year made in warranty expense by Matsushita Electrical Industrial Company in Franklin Park, Illinois due to a sophisticated quality control program which included nondestructive testing. Furthermore the improved quality will make the products more competitive in the market. Some authors have argued that the industrial resurgence of both Germany and Japan was due to the manufacturing of high quality products with well integrated quality control programs which included NDT. Lastly such programs could cut product liability costs as they would document the integrity of the product on leaving the plant. NDT does not only ensure that the products are manufactured correctly it also can after the fact indicate that they were safe. It can be important in liability court cases to ascertain the responsibility of different parties in an accident. For instance, in a bus crash it might be important to know if the steering gear cracked when the bus crashed or that the bus crashed because of a cracked steering gear.

## 2.5 NDT and Regulatory Activity

The government plays an important role in ensuring safety in a wide ranging area of human activities ranging from the work place to leisure. To accomplish this goal the government often introduces a series of regulations to which products and procedures must adhere. The responsibility for developing and enforcing regulations lies with different levels of governments. Transport Canada is responsible for flight standards, the Atomic Energy Control Board is the regulatory body for nuclear reactors (among others). Provincial ministries (Consumer & Commercial Relations) have other regulatory responsibilities (eg. pressure vessels). Many of the regulations require nondestructive testing as a means of ensuring the integrity of structural components and products. Some areas in which government regulations will undoubtedly continue to play a major role are the aircraft industry, mining, atomic power stations, oil & gas industry, off-shore explorations and road transport. NDT will be asked to contribute more not less to safety in the future. Storage of oil, liquified natural gas, poisonous gas and nuclear wastes all require a concerted NDT effort to ensure the safety of society.

## Chapter 3

## THE STRUCTURE OF THE NONDESTRUCTIVE TESTING INDUSTRY

The nondestructive testing community comprises many people with different skills and training. To give some structure to the NDT industry a categorization of the different activities has been developed which gives a good overall picture of this industry.

The following categorization is suggested as appropriate for this study. The nondestructive testing industry comprises of:

1. The manufacturers of NDT equipment;

2. The sales component of NDT equipment;

3. The inspection industry;

4. The in-house inspection community in large firms;

5. The academic community related to NDT.

Each of these groups will now be described in more detail. For simplicity, the equipment related sections will be treated jointly. Also the inspection industry and the in-house inspection community of large firms will be described in one chapter. The academic community described in this context will be the universities. The community colleges and the institutes of technology who are the main vehicles for NDT training will not be analyzed seperately since it is unlikely that they will be the primary engines of technological change in the field of NDT. Of course technological change will seriously impact on the NDT curriculum taught at these institutions. In the chapter on the inspection industry, NDT training will be reviewed.

# Chapter 4

# THE NDT EQUIPMENT SECTOR IN CANADA

## 4.1 A General Overview of NDT Testing Equipment in North America

In order to understand the Canadian situation an overview of the North American NDT equipment sector will be given. Many of the data presented are taken from a study by Frost & Sullivan called Industrial Nondestructive Testing Instrumentation Market in the U.S. and Canada done in 1980 with the dollars being 1980 US dollars.

It is estimated that the total market for NDT equipment in 1980 in North America amounted to about $ 143M. The accompanying table shows the break-down of the NDT equipment market among different techniques together with the projected growth rates of each NDT discipline between 1980 and 1985.

TABLE I. MARKET SHARES IN NDT EQUIPMENT

| Discipline | Market Estimate (in 1980 $ M) | % Market | % Yearly Growth (1980-1985) |
|---|---|---|---|
| Ultrasonics | 32.5 | 22.7 | 5.6 |
| Eddy current | 9.7 | 6.8 | 5.8 |
| X-ray | 69.25 | 48.4 | 4.0 (on supplies only) |
| Gamma ray | 2.5 | 1.8 | 0.0 |
| Penetrants | 13.0 | 9.1 | 4.0 |
| Acoust. emis. | 7.0 | 4.9 | 4.0 (dependent on codes) |
| Magnet. part. | 9.0 | 6.3 | 3.0 |

The projected growth rates for 1980-1985 are considerably smaller than the growth rates in the seventies when they were averaging about 9% a year.

There are about one hundred and fifty firms competing for this North American market. There is considerable concentration in this industry as the twenty eight largest firms (none Canadian) control over 90% of the market. It is therefore obvious that the competition for small firms trying to enter this market is extremely fierce.

## 4.2 The Manufacturers of NDT Equipment in Canada

First a clarification is in order. Many users of NDT adapt their equipment to their particular needs. These modifications range from the simple to the sophisticated. However in the manufacturing category only these firms will be categorized who produce equipment made for other firms. The number of firms who produce NDT equipment or supplies in Canada is small. It is estimated that not more than fifteen firms actually produce equipment. They can be categorized as being small business with most of them having less than twenty employees.

They often combine their manufacturing efforts with consulting, sales of imported equipment and inspection activity. Many of these companies are recipients of government funding programs like DIPP (Defence Industry Productivity Program), IRAP (Industrial Research Assistance Program) and PILP (Program for Industry/Laboratory Projects).

An estimate of the workforce is that about one hundred people are involved in the manufacturing of NDT equipment. The products manufactured vary widely and include transducers, multifrequency eddy current equipment and software.

## 4.3 Sales of NDT Equipment

As can be surmised from the previous section most of the NDT equipment is imported. This is consistent with the general trend in Canada on the importation of scientific and professional equipment. Data obtained from Statistics Canada publications indicate that the level of import penetration in scientific and professional equipment has ranged from a high of 90% in 1970 to a low of 76% in 1976 with the level for 1981 (the last year of the statistics surveyed) being 81% resulting in a trade deficit of about 2 billion dollars per annum. It is estimated that the level of imports of NDT equipment is even less flattering and hovers between 90% and 95% with a trade deficit estimated at about 25 million dollars.

An estimate of the number of firms who act as representatives of foreign equipment manufacturers is not easily obtained. A list produced by a reputable trade magazine (Metals Progress) lists seventeen firms in Canada. However this is an underestimate of the number of vendors of foreign equipment as there are few firms from Quebec or Western Canada mentioned in that list. A more reasonable estimate based upon advertising in trade magazines (like the CSNDT Journal) would be that around forty firms are involved in the sale of NDT equipment in Canada.

The expertise of the vendors is usually good as many have an excellent grasp of the technology they are selling. It should however be acknowledged that for very detailed discussions about the specifics of the instruments the original manufacturer outside the country has to be contacted.

### 4.4 Summary

The NDT equipment industry in Canada employs about two hundred people, evenly divided between manufacturing and sales. The NDT equipment manufacturing sector at this point in its development is heavily dependent on government support. The trade deficit in NDT equipment is estimated to be around 25 million dollars.

# Chapter 5

# The NDT INSPECTION INDUSTRY

## 5.1 The Structure of the NDT Inspection Industry

In the small survey carried out as part of this study one hundred and nineteen firms were contacted and thirty seven responded. A copy of the questionnaires is included in Appendix C. It is estimated that there are about two hundred inspection firms in Canada. Most of these firms are small with only a few employees the norm.

This is supported by the data collected. Estimates of the level of NDT activity in 1983, 1984 and 1985 were obtained for thirty five firms. The results can be summarized by the following table which gives the average man-years in the inspection industries.

TABLE II. EMPLOYMENT LEVELS IN NDT INSPECTION COMPANIES

| Man-years in | 1983 | 1984 | 1985 |
|---|---|---|---|
| MEAN | 11.8 | 12.9 | 14.1 |
| MEDIAN | 8.Ø | 8.Ø | 8.Ø |

These data imply that the total amount of people involved in the inspection industry is about 3ØØØ people. The growth rates are about 9 % per year. However the median stays stationary, indicating that most of the growth is taking place in the larger companies.

## 5.2 Training and Certification of NDT Inspectors

### 5.2.1 NDT Certification in Canada

Another good indication of the activity in the inspection industry can be found in the number of certifications issued by the Canadian General Standards Board. To comprehend the importance of these data a short explanation of the system of certification is in order.

The increasing need for properly qualified personnel to carry out NDT forced the introduction of a system of certification in 1960 in Canada. From 1960 till 1979 there were two levels of competence in radiography and ultrasonics (started in 1970) and one level in the magnetic particle and liquid penetrant methods (started in 1971). The junior level qualified an operator to carry out inspection work under supervision but did not allow him to establish inspection techniques or to assess radiographs, signals or other test results. The senior level qualified a person to assume full responsibility for any inspection tasks including the preparation of procedures and interpretation of the results. The assessment of the ability of the candidates was done with an examination system administered by a federal government department (Energy, Mines & Resources).

In 1979 the standards were revised to make the Canadian system of certification more similar to the American SNT-TC-1A recommended practice of certification. A third level was added in the areas of ultrasonics and radiography. There are now two levels for the magnetic particle, liquid penetrant and eddy current methods (started in 1982).

The following table gives a breakdown of the number of certifications. It should be noted here that all the people with a certificate in liquid penetrant or in magnetic particle inspection before 1979 were automatically categorized as Level II inspectors.

TABLE III. NUMBER OF CANADIAN CERTIFICATIONS

| | Period 1979-1984 | Total |
|---|---|---|
| Radiography | | |
| Level I | 776 | 2675 |
| Level II | 276 | 1082 |
| Level III | 90 | 90 |
| Ultrasonics | | |
| Level I | 521 | 1460 |
| Level II | 143 | 454 |
| Level III | 42 | 42 |
| Magnetic Particle | | |
| Level I | 23 | 23 |
| Level II | 492 | 1399 |
| Liquid Penetrant | | |
| Level I | 11 | 11 |
| Level II | 538 | 1518 |
| Eddy Current | | |
| Level I | 160 | 160 |
| Level II | 15 | 15 |

It is not straightforward to estimate non-destructive testing activity from these data. First, many people hold several certificates. Furthermore it is not obvious that people who obtained their certificate in 1963 are still active. The Department of Energy, Mines and Resources estimates that there are about three thousand active files. This must be the most accurate measurement of qualified inspectors in Canada. This estimate is in good agreement with our own estimates based on the survey data.

Not all people involved with inspections require certification. Some engineers working for the larger inspection companies are not certified inspectors. It is noteworthy that in the U.S. only about one third of the members of the American Society of Nondestructive Testing is certified.

### 5.2.2 NDT Training

The training required to obtain certification is carried out mainly by community colleges and the Canadian Society for Nondestructive Testing (CSNDT) Foundation. There are several community colleges and institutes of technologies with NDT programs in many parts of Canada. The CSNDT Foundation has since its inception in 1976 been involved with the training of 4000 students. It has developed intensive training courses which they give in different locations from Vancouver to Halifax and Trois Rivieres. They provide about sixty NDT courses and about thirty practical workshops a year. Training patterns are changing as more and more people get trained in different disciplines.

An estimate of the wage rates gives an idea of the economic consequences of nondestructive inspection. The wage rate changes from province to province and of course, as well with qualification. The top rate is $19.61 per hour for a Level II Technician in Ultrasonics or Radiography while a Trainee with no certificates in the Atlantic Provinces earns $9.36. Another benchmark is that the average 1982 salary for the members of ASNT (American Society of Nondestructive Testing) was $ US 36300.

## 5.3 Clients of the Inspection Industry

Many different industries require the services of the inspection industry. Two sources are available to estimate the importance of different clients to the nondestructive inspection industry. The first source is based on a survey done by ASNT in 1982. The respondents were asked which was their industry of primary involvement.

TABLE IV. PRIMARY USERS OF NDT PERSONNEL IN THE US

| Industry | % of Respondents |
|---|---|
| Utilities | 19 |
| Chemical/Petroleum | 14 |
| Aerospace | 13 |
| NDT lab | 10 |
| Ferrous Metals | 9 |
| NDT Equipment & Supplies | 5 |
| Materials Joining | 5 |
| Marine | 4 |
| Nonferrous Metals | 4 |
| Ordnance | 2 |
| Electronics | 2 |
| Automotive | 1 |
| Composites | 1 |
| Government | 1 |
| Nuclear (nonutilities) | 1 |
| Manufacturing/equipment | 1 |
| Other | 6 |

This list is not an exact reflection of the clients of the inspection industry; it is a useful benchmark as it reflects the NDT employment patterns in the US.

The second data source is the survey carried out for this study. Thirty five inspection firms gave their breakdown of their present clientele and what they expected it to be in five years. The data are summarized in the following table

TABLE V. CLIENTS OF CANADIAN INSPECTION COMPANIES

| Industry | present average % | average % in five years |
|---|---|---|
| Utilities | 11.6 | 12.1 |
| Oil & Gas | 41.4 | 37.8 |
| Pulp & Paper | 7.3 | 7.3 |
| Transportation | 8.5 | 9.3 |
| Steel & Nonferrous | 7.6 | 7.9 |
| Manufacturing | 13.2 | 16.1 |
| Other | 10.4 | 9.5 |

What is immediately noticeable is the importance of the oil & gas industry as a client. It is more than twice as important a client than any other industrial sector. Therefore the health of the NDT inspection industry in Canada will be tied to the performance of the petroleum sector.

Changes over five years are to be expected. The main change is the anticipated increase in the use of NDT in manufacturing. This has also been confirmed independently in several interviews. The decline in the importance of the petroleum industry as client has to be interpreted carefully. First it only represents a relative drop of 8.6% in five years. Second a distinction has to be made between off-shore activity, which will result in a substantial increase in NDT work, and the traditional oil & gas work which will likely see a small decline in its NDT activity. Specific programs should be developed to deal with the expected growth in NDT requirements in submarine environments. The small decline of NDT in the oil & gas has to be contrasted with the increase in NDT in manufacturing which is about 23% (relative) in five years.

A more detailed look at the statistics collected indicates that most inspection companies have only a few client industries which provide the bulk of their income. Their individual client profiles do not correspond to the average client profile given above.

The differences between the US data and the data obtained in our Canadian survey are not that surprising. They can be partially explained by pointing out that the US survey was not a survey of inspection companies but of members of the American Society of Nondestructive Testing. The preponderance in their statistics of utilities as industry of primary involvement is because in our survey the in-house inspection component in Canadian utilities was not included. The importance of the petroleum sector reflects the opportunities for this industry in the Western Provinces, the Canadian North and the off-shore.

To summarize, the oil & gas industry is the main customer of the NDT inspection industry. The health of the inspection industry is therefore intimately tied to the performance of the petroleum sector. There are distinct opportunities for expansion of NDT activity in the manufacturing sector. Another specific area of potential growth is off-shore exploration.

## 5.4 NDT in Large Corporations

A significant amount of inspection is carried out inside large corporations (utilities, steelmakers, etc). While it is difficult to judge the amount of NDT activity in large corporations, a reasonable estimate would be that about 150 people are engaged in this kind of activity. A small survey gives some indication of the trends in this sector of the inspection community.

The employment levels are quite low. At present they average about 1.8 man-years and will increase over five years up to 2.7 man-years. Our estimate of one hundred and fifty people involved is based on estimating that there are about sixty large companies involved in nondestructive testing.

In the few companies surveyed about 80% of all the NDT needs are taken care of in-house. This will actually slightly increase in the next five years to about 84%. This might have some small repercussions for the established inspection companies.

The survey indicates that about two thirds of their inspections are mandated. If one includes all inspections, the estimate of mandated inspections would be closer to 80% of all inspections. This points to the importance of codes and regulatory activity for this industry. Most of these mandated inspections are connected to welds in metal structures.

About half of the respondents claim that their needs for qualified Canadian NDT personnel are not met. They expect this situation not to improve. In a comment on the adequacy of NDT inspections they claim that on the average in 80% of the cases nondestructive testing provided them with the quality data on which informed business decisions could be made. This indicates satisfaction with the performance of NDT as well as the scope for improvement by technological innovations.

## 5.5 Summary

The NDT inspection industry employs between three and four thousand people in Canada. Employment is spread over about two hundred firms, with many firms having only a few employees.

The major client of the nondestructive inspection industry is and will be for the near future the petroleum industry. The most important growth area is the manufacturing sector because managers are becoming aware of the potentially substantive savings that can result from a good quality control program which includes NDT. The off-shore exploration business will require extensive submarine nondestructive inspections for which present Canadian expertise might be lacking.

Some concern has been expressed about the availability, now and in five years, of qualified Canadian NDT personnel. Suggestions have been made about the need for possible apprenticeship programs.

It is estimated that between 65% and 85% of all inspections are mandated. This indicates the large role played by the regulatory bodies in determining the level of inspection in this country.

# Chapter 6

# THE ROLE OF UNIVERSITIES IN TECHNOLOGICAL INNOVATION IN NONDESTRUCTIVE TESTING

## 6.1 Introduction

Universities can and should play a crucial role in the fostering of positive attitudes towards technological innovation. Their main contributions are in the following areas:

1. Education of engineers able to identify opportunities for NDT innovation;

2. Education of the engineers and scientists who will carry out specific R & D programs;

3. Development in the universities of research programs whose results can be transferred to industries.

To ascertain the role universities play in promoting technological innovation in the nondestructive testing a small survey was carried out. The two questionnaires are included in Appendix D. The first one deals with the amount of teaching spent on nondestructive testing. The second questionnaire deals specifically with NDT research activities in the different departments.

It should be pointed out that this survey was strictly speaking not scientific as the respondents are not a random sample. The education questionnaire was sent to all deans of faculties and chairmen of departments of engineering in Canada. The research questionnaire was sent to all the above as well as to the chairmen of the Canadian physics faculties. No efforts were made to secure responses of any of the participants in the study.

## 6.2 NDT in Engineering Education in Canada

A total of 111 questionnaires were sent out to chairmen of engineering faculties in Canadian universities. Forty three replies were received (38.7%). As suggested above this set of 43 replies does not constitute a random sample. It is likely that departments with little interest in NDT are less inclined to participate in the study. Given these reservations the data were carefully analyzed.

The first question deals essentially with the level of instruction devoted to NDT. The data at the undergraduate level give the following results:

1. The mean for the whole sample indicates that about 6.4 course hours are spent per academic year on teaching nondestructive testing.

2. It is however suggested that the information given by Deans of the Faculty of Engineering is less accurate than the information presented by chairmen of departments. If these less reliable data are excluded the estimate of course hours spent on nondestructive testing at the undergraduate level is reduced to 4.76 course hours per academic year.

3. This simple descriptor is inadequate to describe what is really happening in NDT education at the undergraduate level. First about half of the respondents indicate that no teaching is given in this field. This number is an underestimate and in reality closer to 70% of all engineering departments do not have any courses in NDT.

4. The frequency distribution shows that there are a few schools that have an extensive program in NDT while by far the majority have very little interest in this discipline.

5. The analysis of variance shows that the sample is not homogeneous. The sample is divided in five groups: chemical engineering, electrical engineering, mechanical engineering, metallurgical engineering, others. It indicates that mechanical engineering and metallurgical engineering departments show more interest in NDT than the other ones.

The data on graduate level courses follow a similar pattern.

1. If all the replies are included the mean for graduate courses is 3.8 hours per academic year devoted to NDT. If only the most reliable answers are included this mean is reduced to 2.5 hours per academic year.

2. About 78% of all replies indicate no activity at the graduate level. The frequency distribution shows that only a few departments are really active.

3. The analysis of variance points to the same conclusions as for the undergraduate level. Most activity takes place in the mechanical and metallurgical engineering departments.

On the question related to plans to increase coverage of nondestructive testing, two thirds of the respondents indicated that they have no plans to increase their level of NDT activity. Again the analysis of variance points out that mechanical and metallurgical engineering are more open to possible increases in NDT activities.

The correlation matrix substantiates what intuition would have guessed:

1. There is a positive correlation between activities at the undergraduate and the graduate level. It is indeed normal that interests at the undergraduate level also surface at the graduate level.

2. There is a weak correlation between the level of activity in the department and the desire to see activity increase.

To summarize NDT is not a major study area at Canadian engineering faculties. It is estimated that of the graduating engineers only a small percentage will be acquainted enough with this field to identify it as a possible method to solve professional engineering problems.

## 6.3 NDT Research in Physics Departments in Canada

The research questionnaire was sent to 46 physics departments in Canada and 21 replies (45.7%) were received. An identical questionnaire was sent to chairmen of engineering departments. Since the responses of physics departments were likely to be drastically different from the responses of engineering departments, the two sets of responses are analyzed separately. The physics departments would indicate the more fundamental research done in nondestructive testing, while engineering departments would be by nature more technologically oriented. The results of this survey indicates the following:

1. There are eight research programs related to NDT in place in five physics departments. They include three ultrasonic programs, two eddy current programs and one each in holography, acoustic emission and proton radiograhy.

2. All programs are supported by government funds. For two programs there is joint funding from government and the private sector.

3. Four programs had funding over $ 50K, while two programs each were in the less than $ 20K and between $ 20K and $ 50K categories.

The results indicate that there is a small NDT research activity taking place in the physics departments at Canadian universities. It should be noted that half of the research programs is carried out in departments of Military Colleges indicating a specific interest by the military in this area. Government is the main source of funding for these programs.

## 6.4 NDT Research in Engineering Departments in Canada

Forty nine replies were received from a total of 111 queries, yielding a response rate of about 44%. Analysis of the results indicate the following:

1. A total of forty two research programs were identified.

2. About a third of these programs is devoted to ultrasonic testing. The other nondestructive testing techniques as a percentage of all research programs fare less well. Acoustic emission has about 23%, radiography about 10%, holography and eddy currents each about 7%. The rest (about 20%) is devoted to NDT research which does not fall under the above categories.

3. About half of these programs are small in nature with a budget under $ 20K. A third can be classified as medium (budget between $ 20K and $ 50K) while the other programs are benefitting of funding levels in excess of $ 50K.

4. About one tenth of these programs is funded solely by the private sector while one fourth benefits of joint funding from the private and public sector. The other programs

(about 65%) are solely funded by the government.

5. The forty two research programs are spread over twenty seven departments.

The areas in which most plans for expansion of NDT research exist are equally shared by acoustic emission, ultrasonics and eddy current. Ultrasonics is singled out as the NDT discipline that deserves additional research efforts in view of the needs of Canadian industries.

In summary, the Canadian engineering faculties have a sizeable research effort under way in nondestructive testing. The two most researched techniques are ultrasonics and acoustic emission. Most research efforts have a small budget and the support by industry for NDT research is disappointing.

## Chapter 7

## TECHNOLOGICAL FORECAST IN THE FIELD OF NDT

### 7.1 Introduction

This forecast is based on several sources of information which include:

1. Survey of the inspection companies in Canada;
2. Survey of some key consumer industries;
3. Data from the literature;
4. Interviews with key informants.

First a description of the present state of NDT technology will be given. This will be followed by a forecast of the changes that can be anticipated for the next five years.

### 7.2 The Present Technology

I shall compare three basic sources of information on the breakdown by technology:

- The Frost & Sullivan study on NDT equipment;
- Our survey of inspection companies;
- Our small survey of some key industries (called consumers).

The use of different NDT technologies is summarized in the following table.

TABLE VI. USE OF DIFFERENT NDT TECHNOLOGIES

| DISCIPLINE | F & S | INSPECTION | CONSUMERS |
|---|---|---|---|
| Ultrasonics | 23 % | 23.2 % | 35.7 % |
| Eddy Currents | 7 % | 1.1 % | 18.5 % |
| Radiography | 50 % | 43.1 % | 21.4 % |
| Penetrants | 9 % | 5.6 % | 9.3 % |
| Magnetic Particle | 6 % | 10.8 % | 10.7 % |
| Acoustic Emission | 5 % | 0.5 % | 3.6 % |
| Other | | 15.7 % | 0.8 % |

The large variations between the different estimates are not surprising. The Frost & Sullivan study is U.S. based and deals only with equipment sales. Our survey of consumers had a small sample and is statistically not very significant. Furthermore it demonstrates the differences between the use of NDT in large corporations and in the inspection companies.

Notwithstanding these discrepancies, the following conclusions can be drawn:

1. Radiography is the dominant NDT technique used at the present. It is more the domain of the inspection companies than of the in-house NDT capabilities of large companies.

2. Ultrasonics is the second most important technique. Together with eddy current it is an important component of in-house inspection. The difference between the activity in eddy currents in inspection companies and in-house inspection is noteworthy. It is partially based on the often difficult interpretation of eddy current signals which requires back-up research often beyond the financial capabilities of the small inspection companies.

## 7.3 NDT Techniques Reported in the Literature

The papers presented in scholarly journals can give an indication of the NDT areas which are presently being researched. As indicators I have chosen the excellent NDT bibliography in NDT International and the important book series titled Research Techniques in Nondestructive Testing edited by R.S. Sharpe. From the first source I have averaged the NDT references over seven recent issues. The articles in the seven issues of "Research Techniques in Nondestructive Testing" were categorized and used as indicators.

TABLE VII. NDT REFERENCES IN THE LITERATURE

| | NDT International | Research in NDT |
|---|---|---|
| Ultrasonics | 53 % | 36 % |
| Radiography | 10 % | 20 % |
| Eddy Currents | 9 % | 8 % |
| Acoustic Emission | 15 % | 1.5 % |
| Optical Techniques | 5 % | 5 % |
| Thermal | 3.5 % | |
| Magnetic | 4.5 % | |
| Others | | 29.5 % |

These data can be compared with the projections made by industry in the next section or with the research carried out in Canadian universities. In the previous chapter it was noted that ultrasonics had 33% of all Canadian university NDT research programs, acoustic emission 23%, radiography 10% and eddy current 7%. The NDT research carried out at the Canadian universities does not reflect the present breakdown of the use of NDT technologies in industry but it is similar to the profile given in NDT International. While the lack of enthusiasm for research in liquid penetrants and magnetic particle can be understood--there is little scope for innovation in these areas--the discrepancies between NDT use and research effort in Canada are disturbing. With radiography as dominant as it is now in the inspection industry, a larger research effort in that area is warranted. These discrepancies demonstrate a large gap between the NDT practitioners in the field and the academic community. This is also manifested in the low level of private sector funding received by the universities for their NDT research programs.

## 7.4 The Future of NDT Technologies

In our questionnaire both the inspection companies and the NDT consumers were invited to speculate which techniques they were going to use in five years. The results are tabulated in the next table.

TABLE VIII. PROJECTED USE OF NDT TECHNOLOGIES IN 1990

| DISCIPLINE | INSPECTION | CONSUMERS |
|---|---|---|
| Ultrasonics | 31.3 % | 36.4 % |
| Eddy Currents | 2.5 % | 18.6 % |
| Radiography | 35.2 % | 18.6 % |
| Penetrants | 5.3 % | 5.0 % |
| Magnetic Particle | 11.2 % | 10.0 % |
| Acoustic Emission | 1.0 % | 7.8 % |
| Other | 13.5 % | 3.8 % |

Again there are notable discrepancies between the two sets of data. However it is possible to extract qualitative trends out of this set of data by comparing it to the one presented in the previous section. The following conclusions can be put forward:

1. Radiography is going to drop in importance in the near future. The drop will be about 15% (relative) in five years.

2. The great winner will be ultrasonics. It will benefit from its capabilities to detect and size flaws which are or undetectable or difficult to size by radiographic techniques. This will be particularly the case if the Fitness for Purpose philosophy gets accepted by the regulatory bodies. This view states that if fracture mechanics can prove that the flaws found in a structure will not propagate, the structure is to be considered sound. Fracture mechanics requires the accurate dimensions--often only available by ultrasonics--of the defects.

3. Penetrants and magnetic particle will keep their share of the market because of the ease of use of the techniques.

4. Eddy currents and acoustic emission are uncertain commodities. Key informants indicate that eddy current use should increase significantly but there is considerable reluctance in the inspection community to share this view. However in this instance the success of eddy currents as demonstrated by the large in-house activity will convince the inspection community that it is an important inspection tool.

5. The verdict on acoustic emission is still out. While it is an intellectual and engineering challenge to make it work, its success up to the present has been in relatively narrow

areas. Acoustic emission has become an accepted way of testing "bucket trucks" sanctioned by the American Society for Testing Materials. It very likely will become a code regulated procedure to test fiber reinforced plastic storage tanks with acoustic emission. But these codes apply to a rather small market. The American Society of Mechanical Engineers (ASME) will review the application of acoustic emission as a possible replacement for mandatory radiography in its pressure vessel codes (Section VIII) but it is not at all assured that this will be accepted. If no such breakthrough is achieved which will enshrine acoustic emission practices further in codes, standards and regulations (not only in recommended practice), then the growth of acoustic emission will remain small.

6. It is not likely that new techniques will capture a significant share of the market. Markets for such techniques as holography, liquid crystals, neutron radiography, microwaves have failed to materialize. This does not mean that some new techniques might not be the right approach for a specific problem (magnetic techniques for pipeline inspections?). In general however it is thought that these esoteric techniques will make only a small impact. In Appendix E new techniques with potential are described in some detail.

There are also changes to be expected which go well beyond changes in market shares. Some of the generic changes which will occur over the next five to ten years are mentioned in the following list.

1. One major challenge is to improve on the reliability and repeatability of NDT inspections. The lack of reliability and repeatability has especially plagued acoustic emission, ultrasonics and eddy currents. The trend now is to remove as many variables as possible by computer control and automation. This will mean that the inspector of the future will be an operator of computer controlled equipment with recording and interpretation done automatically.

2. Another trend which is becoming clear is the trend to imaging. Ultrasonics and eddy currents traditionally do not give a picture of the test piece. Computerized techniques will produce images which can be easily interpreted and therefore can be compared with radiography.

3. The third major trend is to develop hybrid inspection systems - a mixture of different inspection techniques which complement each other. Ultrasonics and eddy current as well as ultrasonics and acoustic emission are good complementary techniques. These hybrid systems will be

usually designed and built for specific purposes which will give opportunities to small companies to build one of a kind systems.

4. Lastly none of the trends mentioned will be achieved without the development of capabilities in robotics and automation. The four trends mentioned here will be highly interactive with hybrid systems requiring robotics and giving as end product images of the test piece.

## 7.5 Summary

Radiography and ultrasonics are the two dominant technologies at the present time. Radiography will decline in importance and ultrasonics and to a lesser extent eddy currents and maybe acoustic emission will become more important. Computerization will be used to improve reliability and repeatability of NDT tests. Its main impacts will be on ultrasonics, eddy currents and acoustic emission. Furthermore there will be an increased effort made to produce images of test objects and hybrid systems, combining several NDT techniques which complement each other, will become more important. All these new innovations will require extensive collaboration between the fields of advanced physics, signal processing, robotics, artificial intelligence and computers.

# Chapter 8

## LINKS BETWEEN NDT TECHNOLOGIES AND CLIENT INDUSTRIES

There are definite links between the type of client industry and the NDT techniques to be used. If these links can be established, it would be possible to predict which techniques will be growing from the economic projections for certain industrial sectors. Two sources are available to establish this linkage: the Frost & Sullivan study and our own survey.

Frost & Sullivan identify the major NDT techniques used in a series of industries. Their results are summarized in the following table. UT stands for ultrasonics, EC for eddy currents, XR for radiography, LP for liquid penetrants, MP for magnetic particle.

TABLE IX. MAIN NDT TECHNIQUES IN MAJOR US INDUSTRIES

| | UT | EC | XR | LP | MP |
|---|---|---|---|---|---|
| Aerospace | x | | x | | |
| Aircraft Maintenance | | | x | x | |
| Aircraft Manufacture | x | | | x | |
| Automobile Manufacture | | x | | | |
| Heavy Metals Fabrication | | x | | | |
| Primary Metals | x | x | | | |
| Heavy Forgings | | | x | | |
| Heavy Castings | | | x | | |
| Petroleum | | | x | | |
| Ordnance | x | | | | |
| Shipbuilding | | | | x | x |
| Utilities | x | | x | | |

In the survey of thirty five inspection companies questions were asked about the NDT techniques used and the client industries. It indicates that there are some clear correlations between technologies and clientele. The strongest is the correlation between radiography and the oil & gas industry (.54). Also in contrast with the U.S. data of Frost & Sullivan, there is a meaningful correlation between utilities and eddy currents. The canonical correlation between "clients" and "technologies" is Ø.71. The data also implies that the increases in NDT in the manufacturing area will go mainly to ultrasonics and acoustic emission. It should be noted that the correlations between present technologies and present clients are similar to the correlations between technologies used in five years and anticipated clientele in five years.

The information presented above allows economic forecasters to apply their data on the performance of specific sectors to the nondestructive testing industry. If a resurgence of the petroleum industry is anticipated then clearly radiography will be in high demand. Expansion of the manufacturing industry will likely have an impact on ultrasonics and to a smaller degree on acoustic emission. It is however felt that the production of such sectoral economic forecasts is beyond the scope of this study.

# Chapter 9

# ROLES FOR THE FEDERAL GOVERNMENT

## 9.1 Present Governmental Activity in the NDT Field

The federal government is at the present time involved in the field of nondestructive testing assuming different roles:

- Certification of NDT inspectors by the Department of Energy, Mines and Resources;

- Providing funding for NDT activities in the private sector under such programs as IRAP, DIPP, PILP and the contracting-out policy;

- Providing support for NDT research at universities through the Natural Sciences and Engineering Research Council;

- Establishing research laboratories. The NDT laboratories at the Industrial Materials Research Institute in Boucherville, at Atomic Energy Chalk River National Laboratories and at the Defense Research Establishment (Pacific) are among the most important ones in the country.

In our questionnaire sent to the inspection industry the following question was included:

> Do you favour an expanded role for the Federal Government in the areas of:
>
> - NDT related training;
> - Providing technological innovation support;
> - Other.
>
> Please provide comments as appropriate.

The answers indicate that there is no overwhelming desire on the inspection community's part to increase government's role in NDT training (8 yes, 8 no, 21 no opinion). Some correspondents expressed concern that the certification process would leave the Department of Energy, Mines and Resources and go to another body like the Canadian Welding Bureau. Several firms advocated the establishment of apprenticeships funded by the government. Their concern is based on the high cost of training followed by the movability of the then trained personnel.

The inspection community is much more supportive of a role for the federal government in providing technological innovation support (19 yes, 5 no, 13 no opinion). Several firms make the comment that they support this idea in principle but warn that such a program has to be managed well, indicating some disenchantment with certain branches of the federal bureaucracy.

## 9.2 Policy Options for The Federal Government in NDT

There are several opportunities for fruitful initiatives by the federal government in the area of nondestructive testing. The following are some suggestions which were made in interviews with key informants.

### I. Manufacturing of NDT Equipment

There is almost universal agreement that without government assistance this small segment of the industry would at the present time be unable to survive. The programs now in place (DIPP, IRAP, PILP, EDP) are necessary for survival of this industry. To develop it into a healthy self-sustaining industry the government can take some specific actions. The most efficient one might be the establishment of a joint marketing effort funded by the government. It should be noted that most of these small entrepreneurs (with at least on exception) are not in competition with each other. Their products are more complementary than competitive. Furthermore it should be clear that to survive, penetration in the international market will be essential. Few of these companies have the financial support and wherewithall that allows a serious marketing effort. The government could be a major help by developing a joint marketing effort for all the companies.

### II. Universities

I have demonstrated that the graduating engineers are not aware enough of the advantages that NDT techniques can bring to solving engineering problems. It is not clear that the universities at the present time are able and willing to change this situation. The following suggestion could be helpful in this context. A visiting chair in NDT could be established which would each year visit about fifteen universities for one week each. During this week this authority on nondestructive testing would lecture and advise students in the area of NDT. This would create an awareness of nondestructive testing in the universities and Canadian engineers would be better informed of the possibilities offered by nondestructive testing in their chosen field.

### III. Inspection Firms

While the majority of firms supports federal initiatives in technological innovation, it is not clear what the best method of implementing this expressed wish for more technologically innovative work in the inspection industry is. The following two suggestions are put forward. First the Patent Office could be used to inform NDT users regularly of new innovations for which patent applications have been filed. This would give the NDT users a good idea of what new techniques are being developed in Canada and the world. The second suggestion is to follow up on this information by providing grants to inspection companies who want to test out new Canadian or foreign technologies. Many technological innovations die an early death because of the lack of field trials. With enough incentive the larger inspection firms could be persuaded to carry out field trials of new inspection methods, especially those developed in Canada often with government money.

A possible area for governmental activity (possibly at different levels of government) could be in training. Technological change puts considerable pressure on the NDT training community. Curricula, equipment and workshops have to be continuously updated to keep abreast with recent developments in the nondestructive testing field. Regionally special NDT training centers with excellent facilities might be the way of the future. This is presently attempted at the Southern Alberta Institute of Technology in Calgary but other parts of the country will not be as well served.

At the present there is only one training school for submarine nondestructive testing in Canada (Seneca College in Toronto). The concern has been expressed that the Canadian expertise in this area will not be sufficient and that foreign inspectors could be required for carrying out inspections on submersibles and other off-shore structures. Well designed training programs could forestall the loss of these employment opportunities.

### IV. A Canadian Institute for Nondestructive Testing

Our study has indicated that the main growth area will be the use of NDT in the manufacturing sector. Therefore it would be possible to envisage a NDT research institute which would focus its efforts in promoting and developing NDT tools for the manufacturing sector. There are several institutional models possible:

1. Forming a new group at an established institution like the Canadian Welding Institute in Oakville, Ontario.

2. Strengthening the present group at the Industrial Materials Research Institute in Boucherville.

3. Setting up an independent NDT research institute.

Such an institute could also provide resources to the inspection community without providing the inspection service itself. As pointed out in a previous chapter there is a distinct gap between the academic community and the NDT inspection firms. With a good outreach program the institute could provide the means of communications between these two segments of the NDT community.

The Industrial Materials Research Institute in Boucherville, P.Q., has a small group (between 12 and 15 people) which does NDT research directed to the manufacturing industry. They are successful in attracting customers and have more projects than they can handle. After developing a technique to solve a specific problem for a manufacturer, it is passed on to third parties for implementation. It is this kind of collaboration between industry and government which can yield fruitful results. If these ideas could be implemented on a larger scale, it would be advantageous to the manufacturing sector and the NDT industry in Canada.

There is a model for an independent NDT institute in Saarbrücken, Germany. The Institut für zerstörungsfreie Prüfverfahren is a very succesful undertaking which employs about one hundred people to help German industry with its NDT related problems.

A Canadian Institute for Nondestructive Testing could provide the following functions:

1. Carry out research and development work mainly for the manufacturing sector;

2. Be a resource on all NDT matters mainly for the inspection community;

3. Be a provider of system designs for NDT equipment manufacturers;

4. Be a link between the different segments of the NDT community.

# Appendix A

## DESCRIPTION OF THE SIX MAIN NONDESTRUCTIVE TESTING TECHNIQUES

### A.1 Magnetic-Particle Inspection

Magnetic-particle inspection is a nondestructive method of detecting surface and near-surface flaws in ferromagnetic materials. It consists of three basic operations:

1. Establishing a suitable magnetic field in the material being inspected.

2. Applying magnetic particles to the surface of the material.

3. Examining the surface of the material for accumulations of the particles and evaluating the serviceability.

Advantages:

- Can locate small and shallow surface cracks.

- Discontinuities below the surface can also be detected.

- Magnetic particle indications appear as a picture of the flaw as the particles outline it.

- Simple to use.

- Portability makes it ideal for field work.

- No limitations as to the size or shape of the object to be tested.

Disadvantages:

- Only good for ferro-magnetic materials.

- Flaws parallel to the magnetic field will not show up.

- Care required due to the high current levels used.

- Experience required for interpreting flaw indications.

## A.2 Radiography

Radiography is a nondestructive testing method that uses a beam of penetrating radiation such as x-rays or gamma rays. When the beam passes through the test object some of the radiation is absorbed and the intensity of the beam is reduced. Variations in beam intensity are recorded on film, or on a screen when a fluoroscope or an image amplifier is used. The variations are seen as differences in shading that are typical of the types and sizes of any flaws present.

Advantages:

- Can detect internal flaws.
- Can detect variations in composition, porosity and inclusions.
- It gives a permanent record.
- It can be used with a wide variety of materials and sizes.

Disadvantages:

- The radiation is a potential hazard.
- It requires a large space to set up. Furthermore both sides of the test object have to be accessible (except for fluorescence).
- The operating costs are high.
- Cracks and laminations are not always easily detected.

## A.3 Ultrasonics

In ultrasonics a beam of ultrasonic energy is directed into the test object and either the energy transmitted through the specimen is measured or the energy reflected from interfaces is indicated.

Advantages:

- Can be used for thick parts.
- High sensitivity to flaws at varying depths.
- Can characterize a flaw as to size, shape and position.
- Requires only access to one side of the test object.
- Gives instant results.
- Portable equipment available for field work.

Disadvantages:

- Requires highly specialized personnel.
- Flaws close to the surface are sometimes hard to detect.
- Rough unfinished parts are hard to inspect.
- No permanent record is available in routine inspections.
- For contact testing a couplant is required.

## A.4 Eddy Current

Eddy currents are set up in an electrically conducting test object if it is subjected to a varying magnetic field generated by a coil carrying an alternating electric current. The magnetic reaction of these eddy currents on the field coil or on a second probe coil is analyzed for amplitude and phase information to obtain the electrical conductivity and the magnetic permeability of the specimen. The data can often be correlated to the microstructure and the heat treating or cold working history of the test object. Also surface and subsurface flaws will alter the electrical conductivity and permeability of the tested material.

Advantages:

- Does not require contact.
- Well suited to in-line testing of high speed production.
- Is very versatile as sorting can be done according to dimensions, composition and deformation among others.

Disadvantages:

- The penetration is limited.
- The sensitivity to many variables can make interpretation difficult.
- Only metals can be tested.

## A.5 Acoustic Emission

Audio-frequency and ultrasonic signals are produced if a material is mechanically stressed. These waves can be detected by suitable sensors. The amplitude and frequency spectrum of these acoustic emissions is sometimes a function of fatigue damage, cracks and other defects in the specimen. The analysis of acoustic emission signals can therefore serve for detection of such defects. By designing timing circuits the source of the stress wave can be located.

Advantages:

- Capable of finding flaws and monitoring propagation.
- Can locate a problem area quickly.
- It is a real time test and can be carried out under operating conditions.

Disadvantages:

- Can localize but not pinpoint the location of the defect.
- No information on the size and shape of the defect.
- Experienced personnel is required for setting up and interpreting results.
- Not all materials are good sound emitters.

## A.6 Liquid Penetrant

Liquid penetrant consists of cleaning the specimen surface, drying, applying the penetrant, removal of excess penetrant, and application of a developer. The time of penetrant dwell before the excess is removed and the time of developer dwell affect the test sensitivity and are normally determined by specimen temperature, air temperature, expected defect depth and defect width.

## Appendix B

## LIST OF NONDESTRUCTIVE TESTING TECHNIQUES

1. Methods involving motion of matter

    1.1. Static loading

        1.1.1. Gravitation (Weighing)
        1.1.2. Hydrostatic Testing
        1.1.3. Microstrain Measurement
        1.1.4. Surface Distortion

            1.1.4.1. Optical Holography, Moire
            1.1.4.2. Photoelastic Coating
            1.1.4.3. Brittle Coating

    1.2. Audio Frequency

        1.2.1. Natural Resonance
        1.2.2. Acoustic Emission, Stress Wave

    1.3. Ultrasonics

        1.3.1. Imaging/Holography

            1.3.1.1. Probe Scanning
            1.3.1.2. Liquid Levitation
            1.3.1.3. Electronic Scanning
            1.3.1.4. Acousto-Optical Imaging
            1.3.1.5. Chemical Detectors

                1.3.1.5.1. Small Particle Suspensions
                1.3.1.5.2. Liquid Crystals
                1.3.1.5.3. Thermochromic Substances

        1.3.2. Echo Ranging
        1.3.3. Ultrasonic Spectroscopy

            1.3.3.1. Resonance
            1.3.3.2. Attenuation
            1.3.3.3. Defect-Echo Analysis

2. Electromagnetic Tests

2.1. Electrostatics

2.1.1. Thermoelectric Potential
2.1.2. Electrochemical Potential
2.1.3. Triboelectric Potential
2.1.4. Corona

2.2. Electric Current
2.3. Magnetic

2.3.1. Barkhausen Effect
2.3.2. Eddy Current
2.3.3. Magnetic Perturbation

2.3.3.1. Static Magnetic Field
2.3.3.2. Electric Current

2.4. Radio Frequency

2.4.1. Dielectric Test
2.4.2. Magneto Absorption

2.4.2.1. Electron Paramagnetic Resonance
2.4.2.2. Nuclear Magnetic Resonance

2.5. Microwaves

2.5.1. Transmission
2.5.2. Reflection, Mode change
2.5.3. Microwave holography
2.5.4. Microwave spectroscopy

2.5.4.1. Absorption Spectra
2.5.4.2. Nuclear Quadrupole Resonance

2.6. Infrared

2.6.1. Heat Flow, Temperature
2.6.2. Infrared Spectroscopy

2.7. Optical Testing

2.7.1. Visual Inspection
2.7.2. Optical Spectroscopy, Colorimetry

2.8. X-Rays

2.8.1. X-Radiography
2.8.2. X-Radiometry
2.8.3. X-Ray Diffraction
2.8.4. X-Ray Spectroscopy

2.8.5. Back-Scatter

2.9. Gamma Rays

2.9.1. Gamma Radiography
2.9.2. Gamma Radiometry
2.9.3. Gamma Ray Diffraction
2.9.4. Mossbauer Spectroscopy

3. Methods Employing a Probing Medium

3.1. Liquid Penetrant

3.1.1. Visible Dye
3.1.2. Fluorescent Dye

3.2. Gaseous Penetrant

3.2.1. Krypton 85
3.2.2. Leak Testing

3.2.2.1. Bubble Method
3.2.2.2. Mass Spectroscopy
3.2.2.3. Positive-Ion Probe

3.3. Macroscopic Particles

3.3.1. Electrified Particles
3.3.2. Magnetic Particles
3.3.3. Filtered Particles

3.4. Atomic Particles

3.4.1. Ion, Alpha & Proton Radiation
3.4.2. Radio-Isotope Tracer

3.5. Sub-Atomic Particles

3.5.1. Electrons, Beta Radiation

3.5.1.1. Electron Microscopy
3.5.1.2. Electron Diffraction
3.5.1.3. Beta-particle Thickness Gaging
3.5.1.4. Exo-Electrons

3.5.2. Neutrons

3.5.2.1. Neutron Radiography
3.5.2.2. Neutron Diffraction
3.5.2.3. Neutron Activation Analysis

3.5.3. Positron Annihilation

'I'm afraid my views are those put out
by mass media, based on opinion polls.'

# Appendix C

## INDUSTRY SURVEY QUESTIONNAIRES

On the followin pages the questionnaire sent to the inspection firms and the questionnaire sent to some large NDT users is duplicated.

### NDT INSPECTION AND SERVICE INDUSTRY QUESTIONNAIRE

1. How many man-years are devoted to NDT inspection activities in your company?

| In 1983 | 1984 (estimated) | 1985 (estimated) |
|---|---|---|
| .....(man-years) | .....(man-years) | .....(man-years) |

2. What NDT technologies are in use in your company (as a % of business revenue)?

| | At present | In 5 years |
|---|---|---|
| Ultrasonics | ....................% | .............% |
| Radiography | ....................% | .............% |
| Eddy Current | ...................% | .............% |
| Acoustic Emission | ..............% | .............% |
| Magnetic Particle | ..............% | .............% |
| Liquid Penetrant | ...............% | .............% |
| Other | ..........................% | .............% |
| Total | 100.00% | 100.00% |

3. Who are your current and likely future customers (as a % of business revenue)?

| | At present | In 5 years |
|---|---|---|
| Electrical Utilities | ...........% | ............% |
| Oil & Gas | .....................% | ............% |
| Pulp & Paper | ..................% | ............% |
| Transportation | .................% | ............% |
| Steel & Non-Ferrous | ............% | ............% |
| Manufacturing | ..................% | ............% |
| Other | .........................% | ............% |
| Total | 100.00% | 100.00% |

4. Do you favour an expanded role for the Federal Government in the areas of:

- NDT related training;
- Providing technological innovation support;
- Other.

Please provide comments as appropriate

------------------------------------------------------------

Your name:

Company name:

Address:

------------------------------------------------------------

NON-DESTRUCTIVE TESTING (NDT) QUESTIONNAIRE FOR INDUSTRY

Clarification: By non-destructive testing is meant those inspection techniques which check compliance of materials quality, or structural integrity, to agreed specifications without in any way affecting the serviceability of the objects tested.

1. Are your needs for qualified Canadian NDT personel met? (Please circle appropriate response.)

| Present | | In 5 years | |
|---|---|---|---|
| Yes | No | Yes | No |

2. Do the present NDT technologies provide you with the quality data required to make informed business decisions?

Yes....................% of the time

No....................% of the time

3. Are the present NDT inspections mandated by regulatory requirements?

Yes.............% of the time

No.............% of the time

4. What % of your NDT work is done or do you expect will be done:

| | Present | In 5 years |
|---|---|---|
| In house | ...............% | ..........% |
| Contracted | .............% | ..........% |
| | 100.00% | 100.00% |

5. How many man-years do you devote or intend to devote to research in NDT?

| | Present | In 5 years |
|---|---|---|
| Professional | ...................(man-years) | ...........(man-years) |
| Technologist | ...................(man-years) | ...........(man-years) |

6. What NDT technologies do you use or expect to use in the future?

| | Present | In 5 years |
|---|---|---|
| Ultrasonics.................... | % | ........% |
| Eddy Currents.................. | % | ........% |
| Radiography.................... | % | ........% |
| Magnetic Particle.............. | % | ........% |
| Liquid Penetrant............... | % | ........% |
| Acoustic Emission.............. | % | ........% |
| Other.......................... | % | ........% |
| Total | 100.00% | 100.00% |

Thank you for your collaboration.

---

Your name:

Position:

Company name:

Address:

Please return this questionnaire to

Dr. Dirk Leemans, P. Eng.
Faculty of Environmental Studies,
York University,
4700 Keele Street,
Downsview, Ontario
M3J 2R2

## Appendix D

## SURVEY OF UNIVERSITIES

On the following pages the two survey questionnaires related to universities are duplicated.

### QUESTIONNNAIRE ON EDUCATION IN NON-DESTRUCTIVE TESTING (NDT)

Clarification: By non-destructive testing is meant those inspection techniques which check compliance of materials quality, or structural integrity, to agreed specifications without in any way affecting the serviceability of the objects tested.

1. How much time (in course hours per academic year) does your faculty devote to teaching non-destructive testing:

. undergraduate level ........course hours

. graduate level ........course hours

2. Do you plan to increase coverage of non-destructive testing in your department? (Circle appropriate response)

Yes No

3. Please elaborate: What were the factors in making this decision (noted in question 2)?

---

Name:

Faculty:

University:

QUESTIONNAIRE ON NON-DESTRUCTIVE TESTING (NDT) RESEARCH

Clarification: By non-destructive testing is meant those inspection techniques which check compliance of materials quality, or structural integrity, to agreed specifications without in any way affecting the serviceability of the objects tested.

1. Are there presently any NDT research programs in place in your department?

| | Yes | No | Funding Level | | | Funding Source | |
|---|---|---|---|---|---|---|---|
| | | | < 2ØK, | 2Ø-5ØK, | > 5ØK | Private | Government |
| Ultrasonics | O | O | O | O | O | O | O |
| Eddy Currents | O | O | O | O | O | O | O |
| Acoustic Emission | O | O | O | O | O | O | O |
| Radiography | O | O | O | O | O | O | O |
| Holography | O | O | O | O | O | O | O |
| Other | O | O | O | O | O | O | O |

2. In which NDT areas do you plan to expand research efforts? Please elaborate

3. Which NDT areas are especially deserving of research efforts in view of Canadian industries needs and expertise?

---

Name:

Faculty:

University:

## Appendix E

## DESCRIPTION OF ESOTERIC TECHNIQUES

### E.1 Sources

The descriptions below often follow (almost literally) outlines in the literature which among others includes these sources:

1. Metals Handbook, Volume 11, Nondestructive Inspection and Quality Control, (Metals Park,Ohio: American Society for Metals, 1976).
2. R.E. Beissner, Electromagnetic-Acoustic Transducers: A Survey of the State of the Art, NTIAC-76-1.
3. First Seminar on Advanced Ultrasonic Technology, (Montreal: National Research Council Canada, 1980).
4. R.E. Engelhardt (ed.), NTIAC Handbook, NTIAC-79-1.

### E.2 Optical Holography

Holography uses coherent, monochromatic illumination and produces a photographic record that depends on the phase as well as the amplitude of the light reflected. To obtain a comprehensible image, a special reconstruction process employing a coherent light source (laser) has to be used to illuminate the hologram. Since the hologram registers the phase of light, which depends on the exact distance from a reflective surface element to the photographic medium, the three-dimensional properties of the interrogated object are obtained. The ability of holography to register the distance dimension is, of course, subject to the limitations on resolution imposed by the wavelength of the light used.
As the unevenness of the surface of a specimen can be registered by a holographic process, a distortion of the specimen surface changes its hologram. A superposition and reconstruction of holograms obtained before and after a mechanical distortion of the surface produces an image with interference rings. Cracks and other flaws, even if located below the surface, that cause surface distortion can sometimes be identified by observing the fringe patterns they

produce.

## E.3 Acoustic Holography

Acoustic holography is the extension of holography into the ultrasonic domain. The principles of acoustic holography are the same as those of optical holography discussed in the previous section because the laws of interference and diffraction apply to all forms of radiation obeying the wave equation. Differences arise only because the methods for recording and reconstructing the hologram must accommodate the form of radiation used. This need to accommodate the form of radiation restricts the practical range of sound-wave frequency that can be used in acoustic holography. There are two basic systems for acoustic holography - the liquid surface type and the scanning type. Neither of these two types of systems relies on the interferometric techniques of optical holographic systems, where information on flaws at or near the surface of a test object is obtained from the pattern formed by interference between two nearly identical holographic images that are created when the object is differentially stressed. Instead, systems for acoustic holography obtain information on internal flaws directly from the image of the interior of the object. A main application of the technique has been the inspection of welds.

## E.4 Acoustic Microscopy

A microscope is an instrument for the study of the microscopic structure of an object by means of the creation of an image which has a one to one correspondence with that object. The most promising of the acoustic microscopes is the scanning acoustic microscope which can use very high frequency waves (in the hundreds of MHz) and therefore achieve high resolution.
A flux of acoustic plane waves is launched from a transducer on the lens which focuses the wave at the focal plane in a liquid which is used as a propagating medium between lens surface and the object (which is placed close to the focal plane). A transmitted or reflected acoustic beam is received and an electrical signal is produced by the inverse piezoelectric effect. This signal is then amplified and detected to form a video signal characteristic of the area scanned. If now the specimen is mechanically scanned across the lens an image of the total specimen may be constructed.
Some of the advantages are

- High resolution (sub micron)

- Almost aberration free
- Can be used to focus on subsurface structures
- Sensitive to the elastic properties.

Its main interests are in the area of biological and medical subjects and in material characterization.

## E.5 Electro-Magnetic Transducers

The interest in EMATs is that they offer a completely noncontacting technique for the generation and detection of ultrasonic waves. Ultrasonic wave generation is accomplished by placing a source of electromagnetic field near the surface of an electrical conductive material in the presence of a strong, static applied magnetic field. The induced electron eddy currents interact with the material in such a way to produce ultrasonic waves propagating into, or along the surface of, the material depending on the coil configuration. Detection of the ultrasonic waves is accomplished by the reverse process.
The noncontacting nature of EMATs leads to applications such as inspection of materials at high temperatures, rough surfaces and difficult access. However one problem with this technique remains the low electrical-to-acoustical power conversion efficiency (insertion losses of 100 db are typical).

## E.6 Nuclear Magnetic Resonance

When a substance containing nuclei with a net magnetic moment is placed in a strong magnetic field, transitions between the magnetic energy states can be induced by a superimposed radiofrequency field. Resonances representing the nuclear energy state transitions can be determined by noting the accompanying radio frequency power absorption. Nuclear magnetic resonances cover a wide range of frequencies (up to 100 MHz). They depend on the magnetic field strength and the type of elements or isotopes contained in the test specimen. In addition, nuclear magnetic spectra are influenced by the lattice structure of the test specimen. The method is used for chemical analysis including the determination of trace elements and impurities. In addition, defects such as dislocations and boundary discontinuities can be detected.

## E.7 Positron Annihilation

Positrons entering a material are first slowed down, i.e. are thermalized by collisions with electrons, and finally are paired with electrons which leads to their annihilation with a concomitant emission of gamma rays. Since the decay of the positron population follows an exponential law, a mean lifetime can be defined (about 0.2 nanoseconds) and measured by detecting the gamma radiation associated with the pair formation. Dislocations and vacancies produced by deforming a specimen cause an increase in positron lifetime.
In another approach the angular distribution of gamma ray photons emitted from pair formations has been examined and was affected by the composition of the specimen and the amount of strain present. Positrons do not penetrate deeply. Only a surface layer about 0.1 mm thick can be examined.

Veuillez faire parvenir votre demande à PEIT:
Please forward your request for TISP reports to:

Program Manager
Technological Innovation Studies Program
Office of Industrial Innovation
Department of Regional Industrial Expansion
235 Queen Street (EOII)
Ottawa, Ontario
K1A 0H5