THE IMPACT OF METROLOGY ON THE QUALITY OF LIFE IN THE UK

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ABSTRACT

Measurements of physical and chemical quantities pervade our everyday lives. It is well known that industry relies heavily on accurate measurements to allow innovation and efficient manufacturing to grow. What is less well known is the extent to which we as individuals benefit from a wide range of measurements which every day are carried out in our interest, many of which go unnoticed. Fair trade, consumer protection, health, safety, law and order, and the environment are just some of the areas of modern living which influence our well being.

NPL has been addressing quality of life activities for the last hundred years; examples include protection from ionising radiations, noise and microwaves, and the assurance of a healthy environment and safe levels of ultrasound. In all cases, the activities were stimulated by the contemporary needs of society. NPL and other National Metrology Institutes have applied and continue to apply world class science, often with a high level of ingenuity, to the solution of problems which, had they not been resolved, would have detrimentally affected the quality of the everyday lives of people throughout the world.

INTRODUCTION

One of the endlessly fascinating aspects of metrology is identifying the extent to which measurements of physical and chemical quantities pervade our everyday lives; it is difficult to find an area of activity where measurement does not find some application. This conference is very much concerned with the impact which metrology makes on industry and science. The various presentations will leave you in no doubt that the competitiveness of industry is strongly dependent on an ability to make measurements of an appropriate accuracy.

A vital determinant of competitiveness is efficient manufacturing. Components must be manufactured correctly first time; if their design specifications are not met, there will be a costly waste of material and the expense of re-machining. Industry must be able to make measurements to the accuracy they need, quickly, in situ, and at minimum cost.

Competitiveness also depends critically on the production of new products and services. Scientific research and the generation of new technology, on which so many innovative products and services are spawned, also depend on metrology.

Metrology in support of efficiency and innovation in industry is not, however, the subject of this paper. I want to speak about the impact which measurements make on all of us in our everyday lives. We benefit from a wide range of measurements which are routinely carried out in our interest, many of which go unnoticed.

When we buy things in shops, for example, we don't want to be cheated. We expect that shop-keepers' scales and rulers are calibrated. For this we depend upon weights and measures legislation and, in the UK, on the work of the National Weights and Measures Laboratory. Their activity, legal metrology, depends upon national measurement standards held at NPL.

We, as consumers, also want the confidence that the goods we buy are safe and fit for purchase. In other words, we demand that they will do what the manufacturers claim.

When ill, we as patients must have confidence in the equipment used in hospitals for diagnosis and treatment. We also have a right to expect that the air we breathe and the water we drink meet certain standards of safety.

Our well-being has led to governments around the world and other authorities introducing directives and regulations which aim to provide goods and services which won't harm us. This paper is essentially about the so-called quality of life issues which are precious to us as individuals. In most cases, our well-being is assured through tests carried out to demonstrate conformance with appropriate directives and regulations. Tests inevitably depend on measurement and it is important that test laboratories have ready access to measurement standards of an appropriate accuracy. Governments determine what is needed and National Metrology Institutes such as CENAM in Mexico and NPL in the UK, develop appropriate measurement facilities to underpin the testing.
In establishing NPL’s research programmes, the UK government considers in great detail the potential impact that the work will make on the economy. Increasingly, the government is also considering the impact which the work will have on the quality of life. They ensure that the needs of the following five sectors are met:

- trade and consumer protection;
- health and safety;
- environment;
- law and order; and
- defence.

It should be mentioned that in many cases the same metrology can provide essential support both to industry and the quality of life.

In this paper I propose to begin by giving a general overview of NPL’s activities throughout the last century. I shall then conclude by discussing in detail three different areas which impact on our health and safety.

**HISTORICAL EXAMPLES OF NPL SUPPORTING THE QUALITY OF LIFE**

When one looks at a history of NPL’s activities it is clear that quality of life issues have been addressed throughout NPL’s hundred years, although ‘quality of life’ would not, in the earlier years, have been coined as the expression to describe such activities! Here are some examples of activities carried out at different stages of NPL’s history. They all serve to demonstrate that NPL was quick to respond to the contemporary needs of society.

1913 – adoption of the UK’s first radium standard;
1921 – start of acoustics work;
1934 – introduction of an x-ray protection service;
1934 – lighting for the Tate gallery;
1935 – studies of vehicle noise;
1943 – studies of aircraft noise;
1944 – sound insulation of houses;
1952 – start of Radiological Protection Service;
1952 – study of the properties of the human ear;
1972 – measurement of atmospheric pollution;
1978 – development of standards for ultrasonics;
1980 – facility for microwave hazard monitors;
1991 – tapestry conservation at Hampton Court Palace.

All of these activities were stimulated by the needs of society. During the 1920s and 1930s the general public became increasingly noise conscious. This was, no doubt, driven by the growing popularity of broadcasting, the increased mechanisation of the work place, the intensification of road traffic and the poor sound insulation properties of some of the newer building materials. To this day, sources of noise continue to be high on the list of discomforts which consumers endure. This has led to a wide range of directives and regulations on noise and it is NPL’s acoustic facilities and measurement services which ensure that sound levels in the UK are correctly measured.

Less immediately obvious, but much more devastating in the longer term, are the effects of ionising radiations. It is important that people working in potentially hazardous areas where radioactive materials are present are properly protected. It is also vital that equipment in hospitals used for radiotherapy delivers the correct dose: too much will damage healthy tissue, too little will fail to kill cancerous growths. NPL maintains a wide range of facilities to ensure that it can provide appropriate measurement services for ionising radiations to afford the protection we need. In recent years, the use of ionising radiations in the sterilisation industry and the treatment of food have stimulated further work.

The list of historical examples given also includes metrological work in support of the fine arts.

**NPL TODAY**

NPL is currently working on more than 60 projects which will to a greater or lesser extent make an impact on the quality of life. In this paper, three examples will be discussed in some detail. These relate to the measurement of pollutants in support of a safe environment, and the role of ultrasonics and radiotherapy in support of health and safety.

**i) pollutants in the environment:** NPL has a long tradition in the development and utilisation of state-of-the-art techniques for a wide range of atmospheric measurements. Research began at NPL over 20 years ago when Concorde took to the skies. There was some international concern that it would pollute the
global stratosphere and cause irreparable ozone depletion. As a result, the UK’s Department of Trade and Industry funded NPL to use newly developed far-infrared spectrometry to make measurements in the stratosphere from the ‘prototype’ Concorde to determine the extent, if any, of the problem.

This issue of Concorde pollution, however, soon became marginalized by the much more serious issue of ozone depletion due to chlorofluorocarbons (CFCs) which were predicted to cause serious stratospheric ozone depletion. NPL developed sensitive cryogenically-cooled spectrometers for high altitude, balloon-borne measurements. A much better awareness of the chemical complexity of stratospheric ozone depletion then developed. The measurements obtained at this time were used to underpin complex global 3-D computer models being developed to enable future predictions. However, such models were flawed at that time; they did not contain all the key physico-chemical ingredients; and they failed to provide valid predictions. Instead, it was left to measurement science and NPL to put atmospheric science back on a sounder footing. International protocols emerged rapidly as the scientific research pointed at CFCs as the main cause of ozone depletion.

This led to the present day key issues of stratospheric ozone depletion caused by man-made pollution and the related concerns of global warming. Research groups around the world are carrying out continuous, long-term ground based atmospheric measurements to determine the extent of the problems. They need access to travelling standards which NPL was well placed to develop given our expertise in advanced spectroscopic instrumentation. This equipment uses a well characterized, high resolution spectrometer to measure the concentration profiles of a wide range of key atmospheric species involved in stratospheric and climatic change. It is clear that NPL’s research ensures that the measurements made around the world are accurate. Only then can long-term trends be detected.

NPL has also developed and employed other optical remote sensing technologies to provide the UK’s Department of Energy and Transport with a robust inventory of the emissions of greenhouse gases from all UK landfill sites. This information has been passed to the expert Working Groups of the Intergovernmental Panel on Climate Change, a body committed to reducing emissions.

Recently, the connection between stratospheric ozone depletion and climate change has been the focus of a number of large international scientific campaigns. In the most recent, new flexible and lightweight spectroscopic instrumentation, developed by NPL, was used for high spatial resolution measurements of stratospheric tracers and greenhouse gases. This yielded new insights into the chemistry of ozone depletion and into large scale atmospheric transport processes. It also provided data which are used to validate three-dimensional predictive computer models.

In conclusion, NPL has brought its measurement expertise to bear on a wide range of scientifically challenging problems and done a great deal to further our understanding of the environment. This work has led to governments having the essential advice they need to ensure that appropriate steps are taken to safeguard the environment.

ii) ultrasonics in diagnosis and treatment: NPL was the first laboratory in Europe, in the late 1970s and early 1980s, to measure reliably the acoustic output of the ultrasonic transducers used in diagnostic ultrasound imaging. At that time the only parallel work in the world was that of the US Food and Drug Administration. We were able to show for the first time that the acoustic pressures generated were very high (not an atmosphere or two but many atmospheres in fact), and that the waveforms were unexpectedly distorted (the expected sinusoids had a sawtooth profile!). We soon understood that this phenomenon was caused by nonlinear propagation effects.

The safety of diagnostic ultrasound has always been a crucial issue, particularly so as the majority of the clinical applications of ultrasound are in critical clinical sites. Ultrasonic beams of very high acoustic pressure (which can be in excess of 10 MPa) and relatively high power levels (which may be fractions of a watt) focused on to small volumes of tissue can be very hazardous. Work at NPL has shown that temperature rises in vitro can approach 10 degrees Celsius. This and related work has enabled NPL to make major contributions to all aspects of the necessary underpinning work to ensure the safe use of ultrasound.

Over the years, the technical measurement problems in ultrasound have grown and become quite substantial, requiring a high level of innovation at NPL. Modern scanners can, for example, be used both for imaging tissue and for measuring blood flow. The ultrasonic beams generated are amazingly complex and involve sequences with dynamic focusing, mixed pulse types, and virtually all in real-time (using phased and linear arrays). To keep up with the need to separate out these pulse sequences and to be able to characterise and measure the acoustic output of these complex systems (needed to meet regulatory requirements), NPL has developed an Ultrasound Beam Calibrator. This system has been extensively used for projects for the UK’s Department of Health,
which are aimed at ensuring the continued safe use of diagnostic ultrasound.

Ultrasound systems are also used in physiotherapy. Here, higher power ultrasonic levels are used for the treatment of soft tissue injuries. NPL has developed methods of measuring the acoustic output of these systems and characterising the quality of the acoustic beam. As in the case of diagnostic ultrasound, this work contributes to ensuring the quality of the clinical treatment.

iii) radiotherapy: 270,000 new cases of cancer are diagnosed in the UK each year. Of these, between 150,000 and 200,000 will be treated at one of the UKs 60 radiotherapy centers: about two-thirds with the intent to cure and the rest to relieve pain and suffering. In radiotherapy, the aim is to deliver a radiation dose to the patient with X-rays or high energy electrons that is sufficient to kill the tumour, but not so high as to produce serious side effects endangering the patient’s life. The dose window between tumour control and severe normal tissue damage varies but is generally quite small. For example in the graph below, taken from a recent study on head and neck tumours, the probabilities of tumour control and of severe normal tissue damage are shown as a function of dose delivered.

![Probability of cure graph](image)

From these probabilities it is possible to calculate the probability of tumour control without severe normal tissue damage, or in other words the probability of cure as a function of dose. The authors of this study concluded that if the dose could be delivered with an uncertainty of ±1.7% then only 5% of patients who could potentially be cured would be lost. Increasing the uncertainty to ±3.5 % would dramatically reduce survival rates. Then only 10% of those who might have been cured would be lost. The problem is that measuring dose is difficult. The primary standards for X-rays and high energy electrons themselves have uncertainties of around ±1% and, due to the technical difficulty of making such measurements, are not standards of radiation dose to water (which is the quantity that needs to be measured in radiotherapy).

NPL has led the world in overcoming these problems and calibrating the instruments used in UK hospitals to ensure dose delivery is as accurate as possible. NPL collaborates with the Institute of Physics in Medicine and Biology to audit UK radiotherapy treatment centres. Each UK radiotherapy centre has an ionisation chamber which is calibrated in terms of absorbed dose to water at NPL at least once every three years. Until 1990 this was always done by calibrating against a standard for a related quantity (called air kerma) and then carrying out a conversion to absorbed dose. This procedure unfortunately introduced significant uncertainty. In 1990, NPL launched the world’s first service directly calibrating such radiotherapy reference instruments in terms of dose to water for X-ray radiotherapy. This reduced the uncertainty on calibration by about a factor of two from 3% to 1.5%. This was followed in 1998 by the launch of the world’s first such service for high energy electron radiotherapy. In this case the uncertainty of calibration was reduced by a factor of 3 from 4.5% to 1.5%. Scientists at NPL are now working on a new primary standard actually based on water, which, it is hoped, will reduce these uncertainties even further. There are many factors which determine cancer survival rates, but NPL is working to ensure that UK cancer patient treatments are based on the most accurate dose measurements in the world.

CONCLUSION

I began this paper by highlighting the importance of metrology to industry and science. In the UK and elsewhere in the world, studies have been carried out on the impact which this metrology makes on the economy. Governments are then able to prioritise their programmes and ensure that their economic growth is maximised.

To assess the economic benefits of the metrology carried out in support of the quality of life is considerably more difficult. Yet no one would doubt the wisdom of governments supporting the metrology described in this paper. Indeed, it is often anecdotal information on the quality of life issues which can persuade governments, especially in developing economies, to focus on their responsibilities to support metrology.

In conclusion, there is no doubt that metrology is a vital component of economic growth. Now, I trust, that there can be no doubt that metrology has an equally important role to play supporting the quality of our everyday lives no matter where we live in the world.