

Regina vs Smith

Analysis of Exhibited Material from a Technical Standpoint

Is the exhibited information available
in the public/scientific domain?

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Summary

This report addresses the question as to whether the technical information contained in the exhibited material could be obtained by legitimate means from the published scientific literature, trade journals, product brochures, patents etc or indeed by access to acknowledged experts.

The breadth of technologies presented is very wide indeed, but the depth to which these diverse technologies is exposed varies enormously from sketchy handwritten notes to detailed procedures for making and qualifying devices for application in military equipment. All of the technologies have, or potentially have, dual military and commercial use.

The classification of the various documents, where shown, is never higher than "Restricted" and is much more frequently "Commercial in Confidence" or "Company Confidential". Often there is no classification indicated. (In fact, there is only one document marked "Restricted", although there are two copies.)

The nature of the defendant's role, within the Quality Assurance department, gave him legitimate access to see and consider an enormous quantity of documentation relating to device fabrication and testing, from incoming materials inspection to final performance assessment. As a site Quality Audit manager (a completely different role), the Defendant would have had access to even more documentation not directly related to his work in the Q.A. section, but in the wider context of ensuring that proper procedures, across a whole range of activities, were being carried out within the Hirst Research Centre.

There is, however, some material which the Defendant would not have required in either of these roles, namely his own handwritten notes on the various research projects, although many scientists/engineers would make such notes for personal use, whether they were engaged directly on the project or not.

In most cases, it has been relatively easy to show that such information is readily available in the scientific literature, and even, in some instances, in the wider press - eg "The Economist". Appropriate references are given, and supporting material attached where practicable. In the remaining cases, work is ongoing to establish, or otherwise, that such information is readily available to a suitably experienced scientist/engineer with access to a Database, such as Inspec, or a large library with a good technical reference section - eg a university library. Where a particular search is as yet incomplete, I give my considered opinion as to the likelihood of a "successful" outcome. Obviously, such additional material will be forwarded as soon as it is available.

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Overview

The breadth of technologies presented in the exhibited material is very large indeed, but is nevertheless not untypical of a leading modern electronics research laboratory involved in both commercial/industrial and defence applications of its output. Particularly in the UK, the defence and electronics industries are very closely intertwined. It is frequently observed that this has been on the whole good for our defence capability but very bad for our consumer electronics sector. The close relationship between our electronics and defence industries does complicate the present case considerably, with many technologies having dual use.

A further complication arises in that the depth of detail exposed for the various technologies varies enormously. The documents range from being fairly sketchy handwritten notes about ongoing long-range research projects to detailed procedures for making and qualifying devices for application in military equipment. The classification of these documents, where shown, is never higher than "Restricted" and is much more frequently "Commercial in Confidence" or "Company Confidential". Often there is no classification indicated.

The nature of the defendant's role, within the Quality Assurance department, gave him legitimate access to see and consider an enormous quantity of documentation relating to device fabrication and testing, from incoming materials inspection to final performance assessment. This documentation could be of use to someone trying to "reverse engineer" the devices being fabricated, although in many instances the processes and procedures are so specific to the particular range of equipment being used that this would be a massive undertaking. With respect to the performance figures disclosed in the context of the Q.A. related documents, these would invariably form part of a product specification in any case, and as such would be circulated to current and potential customers for the technology in the normal course of marketing/sales.

As a site Quality Audit manager (a completely different role), the Defendant would have had access to even more documentation not directly related to his work in the Q.A. section, but in the wider context of ensuring that proper procedures, across a whole range of activities, were being carried out across the site.

In relation to the Defendant's own notes on the various research projects, many an inquisitive or frustrated scientist/engineer would have drawn up such notes on topics outside his/her normal remit. Indeed, often this type of activity would be encouraged for fostering better on-site communications and collaboration between departments, and may even form part of company policy on training,

brainstorming sessions, preparation for site tours etc etc. It is clear, for example, that the HRC Research Report itself was circulated within the GEC group as a whole, and even had a note on the front page encouraging wide circulation within HRC at departmental level ie. directed to all scientists/engineers.

The defence industry is highly competitive, perhaps even more so now that the cold war has come to an end, and there is no doubt that companies are continually trying to learn of each others' developments in terms of technology lead, production capability, nearness to market etc. In the winning of substantial orders from either the UK Armed Forces or that of countries overseas, the stakes are high indeed. There are well-attended exhibitions/conferences - some exclusively dealing with defence technology, all around the world every year - eg the Farnborough and Paris Airshows are well-known examples.

Undoubtedly much of the documentation contained in the exhibit bundles should not have been removed from the site without prior permission from senior management. The question is whether this activity was damaging to the interests of the national security, or was the defendant indulging in industrial espionage? This question seems to revolve largely around whether such information is well known to experts in the field and/or could be gathered via other, perfectly legitimate, routes, eg scientific conferences, defence equipment exhibitions, product literature etc etc. It is this latter question I have been asked to address in my report.

Research scientists, whether engaged on defence related activities or not, travel the world giving papers and seminars on their findings, frequently publishing in the specialist scientific journals. There are also many articles in such publications as the Jane's Defence Review, The Economist, New Scientist, Scientific American and even the Innovation section of the Sunday Times. The number of sources for scientific information is legion, and the main purpose of this report is to establish, where practicable, which parts of the exhibited material are readily available in the public/scientific domain and which are not. It should also be remembered that a vast section of scientific literature is not so readily accessible because of language difficulties, or because modern Western-style database facilities are not commonplace in some countries where the quality of scientific expertise is nevertheless excellent eg the former Soviet block.

In many instances, it has been relatively easy to establish that the information presented in the exhibits is readily available to anyone with expertise in electronics technology and some experience of how to go about finding published papers on specific topics. Professional research scientists would perform such searches in one form or another many times during their careers. For example, anyone submitting a thesis for a a Master's degree or a PhD would have to undertake a Literature Search to see what work had been done across a range of

topics before they pursued their own line of research. Similarly, a company engaging on a new product development would necessarily have to know what patents, copyrighted designs etc already existed in their chosen line of R&D. Such searches would not normally be as wide ranging as the present one, because of the diversity of topics covered, but in principle there is no difference.

In some cases, reference to a review paper or even a newspaper article is all that is required to establish that the material is readily available. Where the material is both broad ranging and has considerable depth, the information is much more likely to be scattered amongst various papers published over many years in various scientific journals. Nevertheless, the information is still in the public/scientific domain, although it requires a higher degree of expertise to uncover it, since the technologies involved in fabricating a given electronic device, for example, frequently range right across the physical sciences.

This report gives references, and includes citations from those references, as to where the main body of exhibited material can be found in the public/scientific domain. Some searches are still ongoing. Incomplete searches are acknowledged as such, but in these cases the basis for further, more detailed (or more wide ranging), searches is clearly given with an indication of the likelihood of success. However, it is my considered opinion that there is very little information, commercially or defence related, in the exhibited material which could not be obtained by perfectly legitimate means, from the recognised sources, given reasonable time and resources. It then becomes difficult to decide whether or not this small fraction of the exhibits is sensitive from a national security perspective, or whether it is sensitive in the context of the "normal" commercial operations of the defence industry, legitimate or otherwise.

Introduction

Before considering the detail of the exhibited material, it may be useful to give some background as to the nature of scientific research and development, how a modern research laboratory functions, how it is organised, and how its output is disseminated and utilised. Only then will the very wide range of information generated by a research establishment become apparent, and this in turn may help to clarify the question as to which categories of information contained in the exhibited material are readily available through perfectly legitimate sources and which are not.

Obviously, it is beyond the scope of this report to give more than a basic insight into the, often long drawn-out, process of R&D. Nevertheless, some basic understanding of the functions and organisation of a research laboratory servicing a high-tech company is required in order to set the information contained in the exhibited material in the context of communications around the site (and, more generally, within a large group occupying many sites, such as GEC) and selected communications to the public/scientific domain. In particular, the role of the Q.A. department, of which the Defendant was a member of staff, will be explained and its relationship with the research groups engaged on new product development.

i) The nature of research and development

Research and Development (R&D) is carried out by a company such as GEC Marconi primarily in order to introduce new products to the marketplace and to maintain a position of competitive advantage for existing ones. In the context of the electronics industry, new products may be new materials, new devices, new ways of fabricating devices, or complete systems ranging from controls for electric locomotives to radar equipment for airports and aircraft, civilian or military.

Research is the long-term life-blood of a high-tech company, but development is required to turn new ideas and concepts into new products. Research in itself is very expensive, but the development process, including technology transfer from research laboratory to production facility is even more so. Consequently, new products are often launched from within the research laboratory until there is sufficient demand to justify a separate production facility to cope with larger numbers and less reliance on "green-fingered" expertise. A Q.A. (Quality Assurance) department will always be present whenever production runs, however small, are carried out.

A point to be stressed is that there is considerable financial risk in R&D, many projects never seeing the light of day in any commercial sense. Often the

technical objectives are met, but the risk involved in commercialising the research may be too great. For example, a competing technology may have a shorter pay-back period. It is also important to note that the results of scientific research are often published irrespective of whether or not they are exploited commercially, in a military context or otherwise.

It is also necessary to distinguish between fundamental and applied research, before considering aspects of secrecy which may or may not pertain to them both. Fundamental research, as distinct from applied research, is even more difficult to finance because the pay-off may not occur for many years, sometimes decades. Nevertheless, even in the context of new product development, at least some fundamental research must be going on in the background in order to maintain a competitive position. Today's electronic devices rely so heavily on the fundamental nature of surfaces and interactions on a very small scale that a well equipped analytical laboratory incorporating such techniques as x-ray microprobe analysis and scanning electron microscopy are the bare minimum. Such laboratories may cost many millions of pounds.

It is quite fallacious to suppose that the more fundamental the research the more secret the work, whether for military or commercial purposes. The reputation, not to say quality, of a company's products do, to a significant extent, depend on the quality of the corporate research laboratory. Consequently, the giving of papers by scientists and engineers working on quite fundamental topics is normally actively encouraged by the company, although a close watch is kept on the "Intellectual Property" position - ie. whether patents could or could not, and should or should not be taken out relating to the work in progress.

There is often a "pre-competitive" phase for research during which companies quite openly communicate their results to one another. Indeed they often collaborate with each other in pursuit of some common goal. Although collaboration is often the subject of agreements between the companies, involving IPR (Intellectual Property Rights) and other aspects such as which company will supply which component, facility or whatever, the joint research is frequently communicated in scientific conferences, journals and the like. In other words, for all sorts of reasons, companies are rarely shy about their research capability, and often publicise it in order to enhance the company's image in some sense. Indeed, during the late eighties, it was common practise to give site tours to bankers, investors etc from the City in order to inflate share prices on the basis of research work being carried out. For example, a press release about a potential cure for AIDS can significantly affect the share prices of a drugs company.

The field of High Temperature Superconductivity (HTSC) was a prime example of this type of practice, perhaps unkindly referred to by some as "hype", with

very few players wishing to be left out of the game. Within a couple of years of its discovery in 1987, some 10,000 research papers had been published on this topic alone, including many on potential military applications. Indeed, it is often the case that military applications mark the first use of a new technology. Radar is an excellent example. Although some basic research was conducted many years before the Second World War, and was disclosed in the public/scientific domain, the war greatly accelerated its development. Now no civil airline worthy of the name flies without radar equipment on board the aircraft.

Perhaps because of Radar, a special relationship has grown up between the UK Ministry of Defence and the indigenous electronics industries. The result is that much fundamental work into electronic materials, devices and systems has been sponsored by MOD, both in government research laboratories, such as RSRE Malvern (now DRA Malvern) and companies such as GEC Marconi, Plessey (now part of GEC), Ferranti (parts taken over by GEC), Mullard (now part of Phillips), Racal etc. Again, MOD has largely encouraged these laboratories to publish their findings and share results for the common good of the advancement of defense-related electronics.

Not only has this arrangement helped these and other companies maintain good research laboratories, but the programmes have often had direct spin-off into more commercially oriented applications. (For example, SAW (Surface Acoustic Wave) devices are now used in virtually every television set and video recorder.) Unfortunately for the UK, these commercial spin-offs have often been taken up by other countries at the UK's expense, and to that extent the arrangement between MOD and the UK electronics industry has perhaps been somewhat counter-productive.

In general, any technology being developed primarily for military purposes, but with the potential for a wider commercial exploitation, has great value in the eyes of any companies sufficiently well-equipped and skilled to duplicate the technology and add enhancements. Hence the value of patents, which are published, to protect the interests of companies who have spent many millions developing a new product. Other companies may only manufacture the product under license for a period of 15 or 20 years after a patent is granted.

Even a cursory analysis of the scientific literature shows that, even for fundamental research, MOD funded research establishments publish as much, if not more, of their findings than their commercial counterparts. The point I am trying to make is that research for defence applications is rarely carried out in secret, and that publication of results is often actively encouraged. In fact, publications are necessary for research scientists to enhance their credibility, and that of their company, so as to ensure continued funding for further work, from, for example, the MOD or EC.

Occasionally, a finding or invention has such military or commercial significance that it is not disclosed for, say, a year or more so that the originator can maintain a leading position. These days, this is unusual. A potential cure for AIDS, for example, is headline news within days, as is a new electronic device. Normally patents will be taken out to protect the interests of the company during the development phase. Patents are published, but a company has to pay royalties to other companies if they use their inventions, as I have said before. Patents, in principle, have to be written in such a way that a person "skilled in the art" must be able to reproduce the results of the originator.

Disclosure of research work via press releases as well as publication in the reputable scientific journals is almost an everyday event for a research laboratory, and is part of the reason for its existence. Of course, details are rarely published in full (with the possible exception of filing a patent application) so that a competitive edge is maintained, at least for a while. Patent applications are declared invalid if preceded by "prior disclosure" - for example, at a scientific conference.

ii) The organisation of an R&D establishment

Industrial research laboratories in the electronics industry tend to be organised on broadly similar lines, generally headed by a Research Director with a number of Research Managers, Division Managers or Department Managers reporting to him. Each such manager will be responsible for an area of R&D, such as optoelectronics, microwave devices, sensors etc.

However the laboratory is divided up, there will inevitably be a great deal of overlap between the different departments, divisions or whatever because of the very nature of research. If there are no new advances, the structure of the laboratory will change or evolve very slowly. Innovation, which is after all what the business of the R&D should be, tends to proceed via inter-departmental interaction, scientists from two or more departments exchanging information and often in the process coming up with something new. This "rubbing together" of clever people frequently produces the sparks of innovation.

Thus it is the "synergy" between the different departments, or research groups within a department, which is often the source of new concepts and indeed new products. Senior management may actively seek to exploit this synergy, by ensuring that there is good communication between departments via, for example, a site monthly report given wide circulation. Even if this is not the policy, for reasons of confidentiality of the nature of the work etc, communication between scientists around the site will go on regardless, albeit it at a reduced level. Forces working against information flow around the site include over-tight budgetting constraints, whereby there is no "free time" for such

dialogue, and where every hour of every day has to be booked to a current project number. Nevertheless, research scientists and engineers are usually innately enthusiastic about their work and will frequently discuss it with colleagues from another part of the site, unless the work is so sensitive that all such discussion is barred.

The essential point is that, for the most part, good communications are encouraged and that consequently, it would be relatively easy for someone to acquire an excellent knowledge of ongoing projects on site over a period of time if they had a mind to do so. Nearly all research scientists have an inquisitive nature, almost by definition. The more senior scientists, and higher management, would, of course, have greater access across the site in the normal course of their everyday business.

So much for the research groups on site. There are other groups or departments whose job it is to support the research and development activities. For example, there will invariably be an "Admin" department for obvious reasons - personnel, secretarial support, accounts etc etc. There will also be an Engineering or Site Services department, dealing with aspects of refurbishing laboratories, installing and commissioning large apparatus etc etc. In a large R&D laboratory, there will also be a Q.A. department, although not necessarily bearing that name.

The function of the Q.A. department is wide-ranging indeed, giving its staff legitimate access to a colossal amount of nitty-gritty information. In the context of the development of a new electronic device, for example, as research projects progress from concept verification to a demonstration phase and then on to, perhaps, pre-production prototyping, more and more engineering support is brought to bear. If the device is to be successfully commercialised, there are many stages of fabrication which have to be reduced to routine operations rather than the more "green-fingered" approach of the originator. This is partly because the level of expertise at shop-floor level in a typical production environment is not of the same order as the level of expertise of the research scientist who has perhaps spent many years gaining the necessary experience and is using small-scale equipment of the highest quality. It is also because the techniques and processes developed by the research scientist may not be capable of scale-up for mass production. Additionally, research scientists are sometimes ignorant of production techniques and lack the necessary experience.

It is the role of the Q.A. engineer, in the context of R&D, to be intimately involved in the technology transfer process from research laboratory to production unit so that the key processes and their measurement are reliable and result in high yields. It is also his role to be very well versed in the performance characterisation of a device, and its routine assessment, to ensure that the quality and reliability are adequate for the customer. In a sense, the Q.A. engineer can

be regarded as the customer's representative and is consequently sometimes unpopular with the production engineers. The Q.A. engineer will also frequently liaise with the customer's Q.A. engineers. If the device is intended for military use, the specifications demanded by the customer are usually tougher, but many devices are in fact manufactured for both military and general use with those destined for the military market being given more detailed testing before acceptance, particularly with regard to reliability under adverse conditions of temperature, vibration etc.

It can be seen from the foregoing that the typical Q.A. engineer, far from being a jack-of-all-trades, master-of-none, needs to be very well versed in device fabrication and operation, and will develop meticulous procedures in his role, necessitating equally meticulous record-keeping. On the other hand, his knowledge would extend to many different devices/activities across the site. For example, he would normally be responsible for ensuring that instrumentation throughout the site was adequately calibrated at routine intervals. He would certainly be responsible for ensuring that all the information pertaining to the proper assessment of a device at various stages of its fabrication, was collated and documented. He may also be responsible for ensuring the incoming materials met their specification, and he may be involved in selecting appropriate suppliers.

This does not mean, however, that the Q.A. engineer would have access to every process/procedure in detail, although this may be the case for a relatively simple device. The Q.A. engineer is responsible for *verifying* all the steps necessary for satisfactory device fabrication and assessment, not for carrying out these steps in detail. Consequently, he may have in his possession a flow diagram for the overall process, and indeed the targets for each process, but the fabrication steps themselves may be missing, as indeed is the case for many of the exhibits.

The dissemination of scientific information.

i) information in the public/scientific domain

Science advances more and more rapidly every decade, and the quantity of scientific information published as scientific papers in the recognised journals (such as Journal of Applied Physics, Electronics Letters, IEEE Transactions on Solid State Devices etc etc) is truly massive. These journals form the main body of scientific knowledge in the world today, and every scientist knows how to search for specific information using the traditional route of Abstract Journals or the more modern electronic databases. The large public libraries (eg The National Lending Library, at Boston Spa), and nearly all university libraries, will keep copies of the Abstract Journals, which are essentially indexes to, and summaries of, the papers published in the many journals in different languages around the world.

The more modern approach to information retrieval is via the many electronic databases, most of which are accessible to anyone having a telephone line and a computer with a modem. The most relevant database for the current case is Inspec, which is described more fully in iii) below.

It should not be forgotten that much scientific information is available in a much broader, but much shallower, sense via the media. Certain newspapers and magazines, for example the Financial Times, The Sunday Times (which has an Innovation section every week) and The Economist, have regular columns or occasional articles on recent developments in science and technology. TV programmes, such as Tomorrow's World, Horizon and QED, often deal with innovations and scientific discoveries. "Popular" scientific literature, such as New Scientist, Scientific American and Nature, is widely read. These may not contain the detailed know-how revealed in the recognised scientific journals, but they nevertheless give quite a lot of information about the goals of such research programmes as "Star Wars" and the various EC and US initiatives covering different areas of technology. The well-known defence equipment journal, James Defence Review, also has a wide readership, and the information is not classified in any way.

Then there are the various institutes, such as the IEE (Institute of Electrical and Electronic Engineers), IOP (Institute of Physics), RSC (Royal Society of Chemistry" and so on. Many conferences are organised by such institutes, and very many scientific papers are delivered at these conferences before being published either in conference proceedings or in the journals. There are trade journals, often sponsored by the Institutes, such as IEE News, Physics Bulletin etc, and these give details of forthcoming events such as seminars, one-day

meetings and longer conferences. These events are often open to all-comers, although members of the appropriate institutes get hefty discounts.

In addition to textbooks for undergraduate teaching purposes, "monographs" or collections of key scientific papers all loosely on the same topic, are sometimes produced as are review papers - ie papers describing the advance of a specific scientific or technological area over a period of time and with reference to the key published developments over that period of time. When a scientist starts work in a new area of research (for him or her, that is) these review papers are often referred to, and their reference sections are so complete that further detail from published, more detailed, scientific papers is easily accessed.

Patents form another very important component of information within the public/scientific domain, not least because they represent the IPR (Intellectual Property Rights) of both companies and individuals. They are the means by which these rights are protected in law prior to, and during, the commercialisation phase which follows the R&D process. Patents form a key output of a research organisation, and are perhaps the most accountable "product", taken over a period of many years, of course.

In this country, six months after filing a patent application the application is published in the public/scientific domain. A patent is granted (or refused, normally on the grounds of lack of novelty) a year after a more substantive filing, which itself normally takes place a year after the initial filing. The onus is on the company or individual filing for a patent to prove that the device, process or whatever is truly novel and is not merely a variant on an existing device, process or whatever. The patent must also be written in such a way that "a person skilled in the art" is able to reproduce the device etc (although, of course, not for commercial gain without a license from the holder of the patent).

Before granting a patent, the patent examiner performs searches for "prior art" in both the patent literature and also in the public/scientific domain more generally to ensure that there really is an "inventive step". A substantial part of such searches is normally carried out in the UK by using the Derwent database, which is another electronic database similar to the Inspec database described more fully below, but restricted to patents rather than published papers. Nevertheless, patents (and indeed patent applications after six months has elapsed) are in the public domain and can be accessed by anyone, via Derwent or in person by visiting the Patent Office in London, where there is a nominal fee for conducting a search for prior art.

Companies keep a very close watch on each others' patent activities, since these provide an insight into the commercial direction a company is taking. After the first couple of years, maintaining patents (especially on a worldwide basis)

becomes a very expensive business and the whole process is not embarked upon lightly. Legal wrangles between companies have been known to run into many millions of pounds. After 15-20 years (depending on the country of origin etc) patents expire and the product/process can be exploited by anyone.

ii) information within a research centre

Within a research centre itself, there are also many ways in which scientific information is disseminated. There will normally be a site library, containing the relevant journals both current and dating back over many years. There will inevitably be a significant number of textbooks covering the topics studied at the research centre, both current topics and almost certainly topics which may have been investigated many years previously. Obviously this information is a microcosm of what can be found in the public/scientific domain as explained in *i)* above.

There will, however, be a great deal of information which is specific to the research centre, and which in some cases will not exist anywhere else in the world. For example, all practising scientists keep their own notes, often in the form of "Lab Notebooks", which give detailed notes on the results of experiments, formation of hypotheses etc. Much of this sort of information is now to be found on personal computers also. There will be internal project reports, project proposals, detailed instructions for operating equipment and conducting measurements, Q.A. procedures, minutes of internal meetings, brainstorming sessions, and Sponsor's Meetings.

Meetings, of course, act as paths for information transfer irrespective of whether minutes are taken. There may be progress reviews for project staff, briefing meetings about administrative matters for all staff, and training sessions for staff at all levels. There will be Site Tours, for visitors from inside the Company and from Universities, other companies, potential investors, collaborators etc etc, and even (on "Open Days") for members of the public.

Much research is still carried out in universities and there are many liaison activities. Students, both undergraduate and postgraduate, may spend part of their training courses at the research centre, and this requires coordination meetings and correspondence including the nature of the work to be carried out.

It is commonplace for the larger companies with significant research capability to produce a "House Journal" of R&D on an annual basis. In the present case, this would be the GEC Journal of Research which covers the R&D activities of the whole company. The GEC Journal contains R&D papers very similar to those published in the major specialist scientific journals, and also "Techbriefs" from the various GEC-research centres on a number of topics. Such journals are

in the public domain. It is also normal to have an annual research report for the R&D establishment which is given wide circulation within the company, and distributed to selected customers. In this case, the appropriate report is the GEC HRC Research Report, which is not in the public domain as such, although widely distributed. It contains an index of "Techbriefs" issued by HRC, and these are distributed freely by the Information Centre at HRC.

In addition, for most research establishments, there are site brochures and graduate recruitment pamphlets - examples are shown in Appendix . In short, there is a tremendous amount of information continually circulating the site in one form or another, including informal discussions amongst the scientists themselves, which are often where the real leading-edge innovations take place. Clearly, much of the information is not controlled, and neither should it be if the research is to be innovative and result in patents and eventual commercial exploitation of the work carried out. Some information, particularly relating to sensitive projects, whether defence-related or commercially driven, clearly has to be controlled, and hardcopy should then be marked "Company Confidential", "Commercial in Confidence", "Restricted" or whatever.

Finally, most research centres engage in activities such as pilot scale production, fabrication of pre-production prototypes etc. It is then very common for appropriate marketing information to be generated, such as "Advance Product Information", draft specification sheets and so on. At this stage - often referred to as the "technology transfer" stage where there will be close involvement with operating division and business units external to the research centre but still within the same company - there is very significant involvement by the Q.A. department. Documentation of procedures becomes more and more important as the new product or process begins to pass from the research laboratory to the production units.

iii) information retrieval using the Inspec Database

In the field of electronics alone, there are tens of thousands of papers published annually, covering electronic materials, devices and systems. By far the vast majority of these papers are catalogued by the Inspec Database, which allows rapid electronic retrieval of information classified by, for example, Title, Author, Author Affiliation, Journal, Publication Date, Language etc etc. There are many examples of the results of searches relevant to the present case in the Appendices, and it can be seen that there are papers from the former Eastern Block countries in addition to Western countries. Again, all this information may be classed as "Public Domain" , although one would need to have some training in information retrieval, and, to make sense of the results, one would need to have at least some scientific background. Detailed reading, interpretation and assessment of most papers would require a combination of appropriate

background and general research experience. Subscriptions to these databases vary, but most are now within the means of the private individual let alone companies.

An Inspec Abstract contains the above basic information followed by an abstract (summary) of the published paper together with a list of essentially key words and classification codes in the areas of technology with which the paper is concerned. Searches can be conducted by "keying-in" any snippets of information which are thought relevant in the context of finding papers dealing with particular topics in the shortest possible time. The more information that can be entered at the outset, the narrower the search and the shorter the "on-line" time (and hence the lower the cost of the search). *Efficient* searching is in itself a skilled business, but detailed interpretation requires a high level of expertise and experience.

iii) "Common knowledge"

There is also a body of knowledge, which scientists may refer to as "common knowledge", but which the layman would perhaps find outside his own sphere of common knowledge. For example, every scientist knows what the mathematical terms "exponential growth" and "sinusoidal motion" means, but I doubt if many laymen could give a proper explanation. Unfortunately, the concept of exponential growth (or decay) and sinusoidal motion are of importance in just about every branch of science. Consequently, in explaining a new invention or discovery to a non-scientist, it is often necessary to start with some basic, but perhaps quite difficult, concepts, perhaps requiring at least some mathematical background. It then becomes difficult for the non-scientist to separate out what is really significant and novel from what has to be known in the first place in order to appreciate the significant step.

Materials

Electronic devices are made up of materials which are carefully selected for their properties, at the very least their mechanical and electrical properties. Optical properties are very often important too, such as in display devices (eg liquid crystal) and optoelectronic devices generally for telecommunications and a host of other applications. Conductors, insulators and semiconductors are the principal classes of materials used in electronic devices.

Single crystal material is the norm rather than the exception for the working parts of device itself, and the purity and quality generally of this single crystal material far exceeds that of naturally occurring crystals, such as diamond or salt. The principal single crystal materials relevant to the electronic devices contained in the exhibited material are silicon, gallium arsenide, cadmium mercury telluride, quartz, spinel and sapphire.

All electronic devices have electrical contacts, and these are usually thin metallic films of precise geometry deposited onto the surface of the single crystal material. Not all devices have this "planar" structure, but it is the most common nowadays.

Every device has to be mounted in a package of some sort, and connections have to be made to the outside world. Materials typically used for packaging include alumina ceramic, brass, Kovar, gold plating and various plastics. A gold-silicon eutectic alloy or silver-loaded glass is frequently used for sticking the device to the package in high reliability (including military) applications. Bond wires are normally gold, and they are attached at one end to "pads" on the device itself and at the other end to pads within the package which in turn connect to the leads of the package.

Device Fabrication

A recurring theme in the context of the exhibited material is that of device fabrication, which includes all the processing steps necessary to "build" a device. Rather than give an exhaustive list for each type of device, very common processing steps are :

crystal growth
cleaving, sawing
polishing, lapping

substrate preparation

photolithography

cleaning
metallisation
spin on photoresist
bake
UV exposure
development
etching
photoresist removal
cleaning

packaging

mounting
wire bonding
encapsulation

Very often there will be thin film deposition/fabrication techniques such as doping by diffusion from gases, ion implantation, epitaxial growth (by chemical vapour deposition, for example), annealing, and a host of other well-known techniques.

See the HRC Techbriefs appended to this Report for further background to device processing.

Device Performance

Obviously every type of device has its own performance characteristics which are developed by R&D scientists and engineers, over a period of time, usually with a specific application in mind. For example, a device intended for use in a burglar alarm may respond to movement or heat. A quartz crystal oscillator device will control the timing of a watch. A microprocessor chip will control your central heating controller etc.

Every device from a batch of devices will not be identical - there will be a spread in the performance characteristics, and there will be rejects. The higher the yield, the more commercially viable the process.

Very often, sophisticated electronic measuring equipment is used during the assessment of devices prior to their release for sale. A number of different parameters will be measured depending on the type of device. A transistor for use as an amplifier may be assessed for its noise performance, for example, and a solar cell will be assessed for the amount of electrical energy it delivers under known light intensity.

Q.A. documentation

Most of the the exhibited material is in the form of Q.A.- related documents. To demonstrate this, one needs to consider the role of the Q.A. department and its "inputs" and "outputs". The role has been discussed in the Introduction section, under "The organisation of an R&D establishment". The type of documents associated with the inputs and outputs are broad-ranging, and in some cases detailed. The following lists illustrate this, but may not be exhaustive.

Inputs

AOIs (Assembly Operator Instructions) and equipment operating instructions
Goods Inwards (including Materials Inspection and Certificates of Conformance)
Purchase Specifications
Meeting Reports, letters
Organisational Charts
Process Specifications
Procedures
Change Notes
Performance Specifications
Vendor Audits and selection

Outputs

manufacturing flow charts, including process flow charts
documents relating to standards eg AQAP and BS9540
Concessions
Approvals
Quality Manuals
Equipment Calibrations
Certificates of Conformance
Liaison with vendors' and customers' Q.A. departments

Comments on military applications of devices

i) military specifications

The military environment makes higher demands on device performance, particularly with regard to reliability, compared with commercial applications. Thus devices specified for military use have to satisfy more stringent testing programmes. Key parameters are :

temperature range - to cover temperatures encountered in service

shock, bump, vibration - ground-based military vehicles and aircraft

humidity - to simulate military operations in diverse geographical areas

acceleration - eg devices used in airborne systems

packaging - special requirements regarding materials and construction

reliability - MTBF (Mean Time Between Failure) statistics used on production batches to estimate in-service lifetime and give confidence factors

There are well-defined standards for testing and specifying device performance and reliability. For example, AQAP-1 is the standard defining the NATO requirements for an Industrial Quality Control System for a manufacturer/supplier of military equipment. That is to say, a would-be manufacturer/supplier would have to implement a rigorous site-wide quality policy before receiving AQAP-1 approval. DEF STAN 05-21 is the equivalent standard required by the MOD in the UK.

In addition, certain British Standards apply to manufacturing and quality control. In particular, the BS 9000 (General requirements for Electronic Components of Assessed Quality) series of standards are relevant to the exhibited material. Frequently mentioned is the BS9450 standard, which refers to integrated circuits incorporating methods of test. BS9450 generally applies to devices for commercial applications eg telecommunications, domestic appliances etc. Usage of this standard, rather than the military standards mentioned above, throughout the exhibits implies that the devices are commercially available.

In order to maintain BS9000 certification the manufacturer is obliged to perform batch sampling at regular intervals according to BS9450. "Batch sampling" refers to the procedure by which samples are taken at random from a production batch and tested (by the Q.A. department) against specified criteria. Statistical

analysis is used to infer the characteristics of the batch as a whole, in order to give an overall confidence in the manufacturing process.

ii) radiation hardness

Electronic devices used for military purposes can be subjected to conditions not normally encountered by their commercial counterparts. High acceleration ("g forces") have already been mentioned above. An overriding requirement for NATO equipment over many years has been the need to remain operative after a nuclear event. The extent to which devices can tolerate bursts of radiation which emanate from a nuclear explosion is called the "radiation hardness". Devices used in satellites, whether military or commercial, also have to withstand correspondingly large, but cumulative, doses of radiation which are encountered in normal orbit around the earth.

A great deal of research effort has been expended in developing radiation hard devices, often using standard technologies as the starting point. Some specific technologies have been developed with radiation hardness being the principal driving force. Among these are CMOS on SOS (Complimentary Metal Oxide Semiconductor on Silicon on Sapphire), and CDI (Collector Diffusion Isolation) - a bipolar technology now implemented by Ferranti. The driving force for further developments, now that the Cold War has ended is increased lifetime of electronic systems in communication satellites.

GEC is one of the principal suppliers of SOS technology in the world today, and many papers have been published on this topic. Generally, given a particular technology, the more complex the device the lower its radiation hardness. Strangely, many compound semiconductor devices are more tolerant of radiation effects than their silicon counterparts.

The Exhibit Bundles

The "Main" Bundle

There are three principal components of the main exhibit bundle. The largest section of the documentation is concerned with Q.A. related aspects of SAW devices. Included in this section are several documents which are AOIs (Assembly Operator's Instructions) and even equipment operating instructions for standard mask aligners, wire bonders etc. The latter are of course completely innocuous documents as far as the national security is concerned, and a higher level of detail would be found in the manufacturers' manuals/handbooks.

Next there are the handwritten notes on various leading edge research projects, which were all current at HRC at the time they were written. This forms a relatively short section, but the material is diverse and not Q.A. related. It does, however, require considerable attention, especially since some of the programmes are amongst the front-runners of their kind. Finally, there is documentation relating to the manufacture and testing of a particular bulk delay line, much of which is Q.A. related, but the level of production detail is considerable. The technology itself is thought to be obsolete.

The "SR4" Bundle

The SR4 bundle is a much more motley selection of documents than the main bundle in that a large part of it relates to "Advance Product Information", "Preliminary Information", and "Advance Information". This is marketing material often released prior to gearing up in earnest for a production run - perhaps to be carried out by one of the operating companies (eg MEDL or MSDS) should the number of enquiries merit it. As such, advance product information has to be regarded as in the public domain, even when, as is often the case, the marketing activity is principally directed to companies involved in defence electronics. Research papers will normally pre-date such advance information during the R&D phase.

The documents in SR4 which fall into this "Advance Product Information" category are considered in separate sections below. They are concerned with a video delay line buffer and an arithmetic logic unit (ALU) both implemented in CMOS on SOS technology, and various GaAs MMIC devices for high frequency applications. Other parts of SR4 relate to thermal imagers, critical dimensions assessment (including linewidth measurements) and procurement specifications relating to silicon-on-sapphire and ordinary epitaxial silicon wafers. In terms of possible breaches to the national security, the thermal imaging and silicon-on-sapphire sections require special attention.

EXHIBIT ANALYSIS - MAIN BUNDLE

EXHIBIT NUMBER 2 - ALH/1 - PHOTOGRAPH SHOWING COMPONENTS - JS/14

Some of the exhibited devices are packaged in chip carriers and dual-in-line packages used the world over.

Without examining these devices under a scanning electron microscope and with other analytical facilities in combination with relevant data sheets and/or performance characteristics, it is difficult to draw any conclusions as to whether these devices are in the public domain.

It is certainly not beyond the realms of possibility for these devices to have been collected by anyone working in a research establishment for personal interest. Many scientists/engineers who have worked on particular devices over a period of time would have a few samples to show visiting scientists etc.

In principle, one could reverse engineer some of the devices that appear here although this would be a more difficult process than starting to build them from scratch using public domain information. Some of the unpackaged "loose" chips may well be test devices for quality control purposes, whilst it is probable that some of the packaged devices are available commercially.

I would need associated specification sheets and performance characteristics to establish the exact position with these devices.

Pages 7 to 17a of the Research Bundle gives some insight into different device packages, device types and failure mechanisms.

EXHIBIT NUMBER 3 - JS/15 - BLUE FOLDER CONTAINING 174 SIDES OF
TYPEWRITTEN DOCUMENTS AND PLANS - PAGES 2 TO 175 (INCLUSIVE)

These pages relate to surface acoustic wave devices (SAWs).

General:

A surface acoustic wave device consists of a substrate of piezo-electric material on which are deposited inter-digitated electrodes ("fingers"). When an electric field is applied to piezo-electric material it mechanically deforms and similarly when it mechanically deforms it generates an electric field. The purpose of the inter-digitated electrodes which are comb like structures made of a thin film of metal is to convert an electric signal into an acoustic signal (a sound wave) and vice versa.

The inter-digitated pattern of the launch transducer generates a wave motion on the surface of the piezo-electric substrate when it is excited by a radio frequency field corresponding to an input signal. Similarly the receiving electrode converts the surface acoustic wave back into a radio frequency output signal. These aspects are all well known and considered in detail in many published papers and books, e.g. pages 18 to 117 of the Research Bundle. Also page 138 from a SAW Catalogue will serve as an introduction.

Uses:

Simple SAW devices can be used as delay lines in that the surface acoustic wave takes a finite time to travel from the input to output transducer delaying a signal, for example by "x" microseconds.

SAW devices can also be used as filters in that they can only pass those electrical frequencies which correspond to the wavelength of the surface

acoustic wave which is in turn determined by the spacing between the inter-digitated electrodes.

When used in the feedback loops of amplifiers, they are also used to make radio frequency oscillators.

SAW filters are widely used in video signal processing, (for example T.V.'s and video recorders). - More recent applications of SAW devices have been in communication equipment such as portable 'phones and I believe, some types of coded ignition keys for cars.

Hence, although surface acoustic wave devices were originally applied in the military communication sphere and electronic warfare applications, for example for identification of friend or foe, the usage of such devices in the commercial field is now very well established. Indeed a catalogue from Kyocera at pages 128 to 137 of the Research Bundle demonstrates that SAWs are commercially available for many applications, civil and military. Similarly, one of GEC's own catalogues clearly shows that GPS in Lincoln (previously MEDL) supply SAW devices commercially.

Analysis of the documentation:

A detailed explanation/breakdown of the exhibited material relating to SAW devices has been prepared by Mr R Senior (see Appendix 1).

From this report it can be seen that the majority of the paperwork relates to two specific SAW filters:-

- (i) a 200 Megahertz (MHz) Device - MEDL Number in 1982 DA9200; and
- (ii) a 120 Megahertz (MHz) Device - MEDL Number not revealed in the exhibit but probably DW9210).

The Quality Assurance Documentation relating to these devices is again more fully dealt with by Mr Senior and I agree with his conclusions that the exhibited material suggests that the two devices were commercially available - see GPS (previously MEDL) literature, at pages 119A to 119E of the Research Bundle..

Indeed in the case of the 200 MHz device, within the Research Bundle at pages 118 to 119 is a product specification sheet dating from August 1992 clearly indicating the usage of the device, its features, and performance characteristics. Essentially therefore the DA9200 200 MHz bandpass SAW filter is commercially available since a product specification sheet is an extract from a catalogue showing what is available.

Manufacturing Details:

All the manufacturing documentation which appears within pages 2 to 175 of the Research Bundle relates to the two SAW devices previously referred to.

Where the documentation relates to the usage of certain equipment used in the fabrication processes, for example the electron beam coater, quartz crystal orientator and Precima TCB 21 wire bonder, the procedures for using such equipment would be readily available from the manufacturer.

Where details of the fabrication processes appear, such details of device fabrication can be obtained in the open literature - see for example chapter 8 of "Surface Acoustic Waves for Signal Processing" by Michel Feldmann and Jeanine Henaff which gives details at page 260 (see pages 49 to 85 of the Research Bundle), for example, of a program for fabricating transducer masks, and a computer program itself appears in an appendix to the book.

Indeed in Volume 10 of the "Proceedings of the I.E.E." Volume 77 Number 10 published in October of 1989 a paper prepared by Colin K. Campbell on the applications of surface acoustic and shallow bulk acoustic wave devices also gives details of device fabrication, and design know-how, pages 86 to 117 of the Research Bundle.

Conclusion:

The precise method used by HRC to manufacture the two devices previously referred to would not be in the public domain. However, I would agree with Mr Senior's conclusions that the manufacturing and piece part information is a haphazard collection of unrelated documents. Although the narrow band thick film substrate could be manufactured by another party, other more important parts of the process, for example the design of the filter configuration, are not revealed in detail.

The documentation appearing in the bundles could enable commercial competitors to short circuit development programmes and improve or set up their own SAW capability. On the other hand, someone wishing to do this would be well advised to obtain a great wealth of information relating to SAW devices, and their manufacture, which is already in the public domain.

The information that is not in the public domain and may be of military significance is in relation to the 120 MHz SAW device being used in an airborne guided weapon (page 53 of the exhibit bundle). This is not of use without details of the weapon system itself and as Mr Senior states it would appear that both the 120 MHz device and the 200 MHz device are, or were, commercially available in any event. Furthermore there is frequent reference to the supply of devices into specific military systems in the HRC Research Report. This Report is commercial in confidence, but not "restricted" in the proper sense.

In the case of the SAW devices, a specific reference to their use in military systems is filed in the Research Bundle at pages 137b.

HRC's "low loss" filter designs are patented (see pages 138 to 144 of the Research Bundle) and the improvements in lithography patented also (see pages 145 to 151 of the Research Bundle). Pages 151a and 151b are extracts from the HRC Research Report, January to June 1986, and clearly

sets out that the DA 9200 device is being used as a CQC for BS9450 capability approval as part of the ESA Programme referred to in the exhibit bundle at pages 2 to 50.

EXHIBIT NUMBER 4 - JS/16 - THREE HANDWRITTEN PAGES RE "RUGATE FILTERS FOR SDI" DATED JUNE 1992 - PAGES 176 TO 178 (INCLUSIVE) OF THE BUNDLE

General:

The basic concept of an optical filter is that it allows the passage of light through it either equally at all wavelengths, when it is classed as a neutral density filter, or at some wavelengths more than others when it is classed as a selective filter. Selective filters may be "bandpass filters", i.e. allowing light in a particular wavelength band to pass through, or alternatively notch filters, which exclude all wavelengths of light within a particular band of the spectrum.

Optical filters are frequently fabricated (i.e. built) by depositing thin films on mechanically stable substrates (supporting materials) much as a mirror is fabricated by depositing a layer of silver on the back of a sheet of glass - the glass being the substrate. Some types of sunglasses have a reflective film on them which eliminates harmful ultra violet radiation. For some purposes, such as when these filters are subjected to very high input powers, for example from a laser as might be the case in a "Starwars" scenario, such filters may become unstable if the thermo-mechanical properties of film and substrate do not exactly match. Put simply, the film may peel off if it experiences an increase in temperature and has a different thermal expansion co-efficient to that of the substrate.

Instead of there being a sudden change in refractive index between dissimilar materials to produce an optical filter, it is possible to have a more gradual change in the same material thus eliminating the sharp boundaries between dissimilar materials which can lead to failure. A rugate filter is constructed by modifying the refractive index of a material in such a way that the desired optical properties are attained whilst

preserving mechanical integrity even at high powers (pages 152 and 154 of the Research Bundle). The filter does not consist of layers of dissimilar materials but rather one material (although sometimes on a substrate for support) modified so that its refractive index changes (usually in a sinusoidal manner) without any abrupt discontinuities (sinusoidal is simply the mathematical description of a wave motion).

By carefully controlling the depth profile of the variation in the refractive index, for example by changing the period, amplitude and number of the sinusoidal oscillations, a rugate filter can be made to reflect or partially transmit wavelengths of interests (pages 152 to 153 of the Research Bundle). Any one of a number of thin film processing techniques (see Pages 152 to 154 of the Research Bundle and also section on Device Fabrication earlier in this Report) may be used to produce the required profile, and hence the required spectral response.

Analysis of the Document:

Page 176 The background information given in the opening four paragraphs of Smith's notes is all HRC information. For example, the funding arrangements for the project appear at page 157a of the July 1989-June 1990 HRC Research Report which also makes specific reference to the Wright Patterson Airbase sponsoring the project through RSRE.

This Report also confirms the two year extension to the project.

The reference as to the uncertainties over the project's future merely echoes concerns worldwide leading up to 1992 over the SDI Programme, after the end of the Cold War.

The roughly sketched graph shows the variation in refractive index with stoichiometry (the ratio of the individual chemical

elements of the compound being deposited, in this case silicon oxy-nitride) and a refractive index of 1.9 is revealed for silicon nitride.

The interest in rugate filters composed of silicon nitrides is clearly established in the open literature (see page 152 of the Research Bundle) including variation of refractive index with stoichiometry for silicon oxy-nitride (again see page 152 of the Research Bundle).

Page 177

The information that silicon nitride is useful for infra-red applications because of its spectral characteristics is well known, and is also highlighted in the HRC July 1990 to June 1991 Research Report (page 157B of the Research Bundle).

The statement of the current work of the team is insufficiently detailed to be of any importance.

Details of the gases used in the process are given. All the gases are strong oxidising agents. They would be used to purge the apparatus of oxygen prior to film deposition in a nitrogen atmosphere and this type of pre-conditioning is routine in critical deposition processes.

Some diagrams are given as to the design of a notch filter.

At page 39 of the HRC Research Report July 1988 to June 1989 (page 157c of the Research Bundle) there is some more detail than that contained in Smith's notes with regard to the fabrication processes and background generally. Specifically the micro-plasma deposition process is revealed as a microwave plasma chemical vapour deposition process. Further, the reference to Fourier analysis in this report would indicate to any person familiar in the area that the design of the notch

filter is as set out in the diagram at page 177 of the notes. The Fourier transform technique would allow calculation of the number of notches physically realisable and give certain information about the precision to which the refractive index could be modulated. Thus the possibility of fabricating a 10 notch filter, for example, is determined not by any special or additional knowledge on the part of the HRC workers which in any case is not revealed, but by mathematical calculation/modelling from equipment limitations. Hence the diagrams at page 177 and 178 are applications of a generally known scientific principle.

The statement that a 10 notch filter design is possible stems from the context of the Fourier analysis and is not a statement about an actual filter.

The reference to the use of the application of the rugate filter in goggles is an obvious reference to potential applications.

Conclusion:

The information revealed is almost all available from the scientific literature and the HRC Reports. The remaining detail would be either superfluous, obvious to workers in the field or of indirect significance only. The applications revealed for such filters are well known and span both civil and military spheres.

EXHIBIT NUMBER 5 - JS/17 - THREE HANDWRITTEN PAGES RE
"MICRO-MACHINING PROJECT", "PRESSURE TRANSDUCER", "CRYOGENIC
REFRIGERATION" DATED JUNE 1992 - PAGES 179 TO 181 (INCL) OF THE BUNDLE

General:

Micro-machining refers to the various techniques for producing structures with dimensions of the order of a micron (one millionth of a metre). The concept arises from the various techniques that have been developed for making silicon integrated circuits and indeed to date most of the literature on micro-machining is concerned with the fabrication of minute structures in silicon. See, for example a paper published by an HRC author (pages 169 to 173 of the Research Bundle). There is some commercial activity e.g. see pages 174 of the Research Bundle.

Uses:

The importance of micro-machining is that theoretically its uses are infinite in the manufacture of any device requiring tiny components, for example microvalves. As the name microvalves suggests, they are tiny valves with applications in pressure and flow regulators, pneumatic and hydraulic controls for controlling gas and fluid flow, for example in medical, industrial and analytical instruments and automotive systems. Micro-machining is of interest in the military field as the devices are intrinsically radiation hard and on a more general level the military would be interested in tiny devices such as sensors, valves etc. An overview of the potential uses of micro-machining devices appear in numerous Inspec References referred to in the Research Bundle at pages 210 to 255, specific examples of which are embodied in this report. There is also a very readable paper on the techniques and applications of micromachining (pages 158 to 168 of the Research Bundle). Another paper entitled "Micron Machinations" is included in the Research Bundle at pages 175 to 183 of the Research Bundle.

Analysis of the Document:

Page 179 This page reveals the aims of the technique of micro-machining and the advantages of micro-machined devices together with some applications particularly relating to fluidic control. These comments are well known in the scientific literature (see generally pages 245 to 255, 210 to 231, 232, 239 to 244 of the Research Bundle) and all appear in the HRC Research Reports issued between July 1988 to June 1992, (pages 183A, 183B, 183C and 183D of the Research Bundle.

Page 180 The diagram of a pressure transducer is not of a usual silicon diaphragm pressure transducer but no information is given on how the device works. Detailed information is given as to an ink jet printhead nozzle which is of commercial significance only. The precise details given in Smith's notes on page 180 are not in the public domain, although such details are not meaningful, without further elaborations.

Page 181 A reference to cryogenic refrigeration with some performance figures appears together with the design for a printhead. The cryogenic refrigeration application of these devices was referred to in the HRC Report July 1991 to June 1992 at page 58 and therefore the application per se has been exposed. Details of the current achievements of the project have not been published but again without further information they are of little value. The design used for printheads is a design one would expect could be deduced simply from knowledge as to the aims of the project and the open literature.

Conclusion:

Although some of the detail given by Smith is not generally available, on its own it would not give a commercial competitor any salient information which would assist in developing a micro-machining capability, when compared with the mass of information in the open literature. HRC have also filed two Patents in this area, particularly relating to fluidic devices (see pages 184 to 209 of the Research Bundle).

EXHIBIT NUMBER 6 - JS/18 - FOUR HANDWRITTEN PAGES RE "QUASI OPTICAL CAR RADAR" DATED MAY 1992 - PAGES 182 TO 185 (INCL) OF THE BUNDLE

Everyone is familiar with the broad concept of radar which is the process whereby a radar wave is bounced off a given target and the reflection is translated into a blip on the radar screen giving the target's position.

Normal radar uses a revolving aerial which sends its pulses in all directions during a sweep of the radar. What is received on a screen is echoes from targets within the complete 360° rotation.

The difference between radar as it is usually understood and quasi optical radar is that the geometry of the transmitted and reflected beam and the methods for producing and detecting them are much more akin to optical systems design (for example, in laser experiments). In quasi optical radar the radar signal is produced from a carefully designed antenna and transmitted through a lens much as a beam of light in an optical instrument. In essence, quasi optical radar relates to optical design principles at radar frequencies. (Uses - this directional system is being developed for a close range car radar, as the name of the project suggests, for collision avoidance.)

Analysis of the Document:

Page 182 The general introductory paragraph refers to the Omega-prometheus project, an EC funded project.

The references to Briggenshaw, the project co-ordinators and client companies are of commercial significance only and this information would probably not be in the public domain.

The reference to a quasi optical antenna system appears in the patent application filed by Peter Briggenshaw on the 8th of

January 1992 (pages 256 to 266 of the Research Bundle). A computer designed lens is involved although no details are given of the computer design and the lens drawn by Smith is not the lens that appears at page 1 of the Patent, although the difference is not significant.

The response pattern is clearly referred to in the HRC Research Report July 1990 to June 1991 (at page 266A of the Research Bundle) which states "the antenna sub-system-transmits in the direction of motion a relatively broad beam width of 10° and receives selectively over a narrow beam width of 3°". The same information is highlighted in the above patent.

The decibels (dB) shown on the diagram refer to the intensity across the beam's profile as determined by computer or as measured experimentally. Again these details are not generally known but could be calculated. Smith does not show if these decibel patterns have been calculated or experimentally determined.

The information that the main lobe can be switched between three or more positions to cover a wider angle can be inferred from the Patent. However, Smith does not make it clear how the main lobe is switched between the three or more positions or indeed whether this switching function is really a feature of the receiving detector patches rather than that of the transmitter section.

Page 183 The information that one can make the side lobes larger is not of significance because it is a case of merely redesigning the lens using known optical principles. The fact that this could possibly eliminate the switching beam swinging system is significant but only when combined with more detail about the

alternative arrangement (which is not discussed) and in any event qualified by Smith's comment that Briggenshaw does not believe it will work anyway.

The remaining notes on page 183 could be categorised as commercial in confidence information although a reference to a 77 gigahertz (GHz) system appears in the Patent application previously referred to (page 259 of the Research Bundle), filed on the 8th of January 1992.

Page 184 The diagram produced by Smith is referred to in the patent previously referred to at page 1/1 of the Patent although the mixing circuit does not appear. However the mixing circuit is explained in the text of the Patent application at page 3 and a reference to the gunn diode transmitter also appears at page 2.

A reference to the switching circuit also appears in the Patent at page 260 of the Research Bundle. Indeed the refinements referred to by Smith are clearly to be found again in the same Patent at page 261 of the Research Bundle.

The detail concerning the modification of the patches by cutting off the corners is not mentioned in the Patent. From reading Smith's notes a circular beam is produced when the modified patch is used as a transmitter as Smith states. This however is not information in the public domain, but seems intuitively correct.

Page 185 The concept that patches can be used as both transmitters and receivers is covered in the Patent (page 261 of the Research Bundle) but not experimentally confirmed in the Patent. Whilst the concept may be in the public domain the detail given by Smith at page 185 is not. This information may be helpful to a commercial competitor.

The concept that a beam swing scanning system has potential for missiles is referred to at page 266A of the Research Bundle, from the July 1990 to June 1991 HRC Report. No further details are given in the exhibited material, but it is possible this scanning system is based on another invention patented by Peter Briggenshaw described in UK Patent Application 2-253-947A - this Patent was filed on the 22nd of March 1991 - see pages 267 to 276 of the Research Bundle. Further references are to be found in pages 277 to 280 of the Research Bundle.

Reference is made in the HRC Research Report of January to June 1985 to the application of a similar system for guided weapons (see page 280a of the Research Bundle)

The final paragraph refers to the attempted use of satellite mounted synthetic aperture radars to infer the chemical constitution of the upper atmosphere. This concept is in the public domain.

Conclusion:

Although radar systems are frequently developed for military purposes it is clear that the quasi optical car radar system is of primarily commercial significance. The Patents referred to give very much more information about the design of the overall system than Smith's notes provide.

EXHIBIT NUMBER 7 - JS/19 - ONE HANDWRITTEN PAGE RE "MICRON VALVE PROJECT" DATED MAY 1992 - PAGE 186 OF THE BUNDLE

General:

Valves can still be found in some electronic equipment today but they have largely been superceded by solid state devices such as the transistor. In a fundamental sense any ordinary T.V. screen or oscilloscope screen is part of a large valve. Some military equipment still employs valves particularly in the field of radar for high power signal generation. More generally, the military equipment of (former) Eastern Block countries is still largely dependent on valve technology partly because it is inherently radiation hard compared with the more modern solid state devices. Equipment using this technology tends to be very bulky for its performance when compared with its solid-state-based counterparts however, and considerable work has been carried out in various research laboratories around the world on miniaturised valves borrowing many of the fabrication techniques developed for integrated circuit production. Very readable articles on this topic are to be found in pages 281 to 286 of the Research Bundle.

Uses:

Military equipment generally, and particularly equipment likely to be used in a radiation environment. Some spin-off for satellites is probable.

Analysis of the Documentation:

The first two paragraphs contain general information which is discussed in infinitely more detail in, for example four U.K. Patent Applications filed by GEC (see pages 287 to 334 of the Research Bundle). Also an article entitled "Vacuum Micro Electronics" published by N A Cade and R A Lee in the GEC Journal of Research Volume 3 Number 3 of 1990 (see pages 336 to 345 of the Research Bundle) gives specific details of the manufacture.

The details of what makes a good tip are unknown but geometry/contamination are key factors. The problems are discussed by Cade and Lee in the paper referred to on page 338 of the Research Bundle.

The mounting of the devices in a dual-in-line package is well known and again appears at page 123 of the same paper.

The chip bonding materials cited are commonly used for bonding the world over. Gold Silicon eutectic is more common than the Gold Silver alloy mentioned, but in any case gold silver is referred to in the review paper. The silver glass bonding material is also well known - see page 362g of the Research Bundle. The special bond wire containing gold and titanium is mentioned in a U.K. Patent Application filed by David Jacobson and Giles Humptson on the 27th of February 1991 (see pages 346 to 362 of the Research Bundle).

The reference at the bottom of the page to "so far a maximum of 50 micro amps has been achieved from a single tip" is referred to it the July 1991 to June 1992 HRC Research Report at page 56 which states "a simple cathode conditioning method in which cathodes are ion beam cleaned prior to characterisation in vacuum has allowed 50 micro amp currents to be routinely achieved from single silicon emitter tips".

Conclusion:

There are no concepts in this note that are not in the public domain and discussed in infinitely more detail in the Patents and review paper herein referred to. Furthermore, extracts from the HRC Research Reports shown in the Research Bundle (pages 362a to 362f of the Research Bundle) show considerable detail.

EXHIBIT NUMBER 8 - JS/20 - ONE HANDWRITTEN PAGE RE "OLFACTORY RESEARCH PROJECT" DATED MAY 1992 - PAGE 187 OF THE BUNDLE

General:

Essentially this project is concerned with the concept of an electronic nose device which would discriminate between various gases in much the same way as the sense of smell which is of course a naturally occurring facility possessed by many of nature's creatures. Current gas sensing devices are not good at discriminating between gases and are easily upset and contaminated. Research work in this area usually focuses on mechanisms for achieving selectivity and pattern recognition techniques are often invoked. The HRC research is no exception, and there are a number of HRC Patents in this area (pages 375 to 405 of the Research Bundle).

Uses:

Potential applications in both the civil and military fields in gas sensing.

Analysis of the Documentation:

The potential use of SAW detectors in this field as indicated by Smith in the opening paragraph of his report is well known and indeed has been proposed and researched for over a decade. The earliest reference to it appears in a paper written by Yu. G. Orlov, a Russian scientist working at the Engineering and Physics Institute in Moscow entitled "Application of Surface Acoustic Waves (SAW) in Sorption Gas Analyzers" published in the USSR in the Journal "Zavodskaya Laboratoriya" Volume 47 Number 3 Pages 38 to 40, March 1981 (Inspec Reference 01897998 - Page 432 of the Research Bundle).

Smith appears confused by the concept since having mentioned SAW detectors in his opening paragraph the diagram he then draws is that of a bulk acoustic device.

A reference that appears in this document to polysiloxine is an incorrect spelling of polysiloxane and in any event the use of polysiloxane in this particular field has been discussed in a paper relating to a conference held on the 30th of September to 2nd of October 1991 published in March of 1992 - see page 434 of the Research Bundle. See also another Inspec Abstract, on page 433 of the Research Bundle.

In relation to the third paragraph, although no specific reference can be found to a frequency of 261 MHz for a SAW resonator, the precise frequency of this device is not significant; it is the principle of gas sensing that is important.

The reference to spin coating is simply to a method of putting polysiloxane film onto the device and merely indicates the method that HRC have found most convenient.

The fourth paragraph is an extremely poor and misleading statement of the concepts behind device response. This is clearly written by a non-expert in this field.

The remaining three paragraphs are all extremely general principles.

If one were interested in principles, applications and indeed manufacture of these devices, Patents have been published by HRC as indicated above and there are numerous references in the Research Bundle generally under the topic heading "Olfactory Research" indicating the position - see pages 406 to 432 of the Research Bundle. The relevant extracts from HRC Research Reports on this topic are given pages 434A, 434B and 434C of the Research Bundle.

Conclusion:

There are no concepts in these notes that are not in the public domain.

EXHIBIT NUMBERS 9 TO 25 (INCLUSIVE) - COPY DOCUMENTS RELATING TO
COSSOR ELECTRONICS, DRAWINGS OF F BAND DELAYLINES ETC - PAGES 188 TO
269 (INCLUSIVE) OF THE BUNDLE, EXHIBIT NUMBER 26 - PHOTOGRAPHS OF
JS/38 - BLUE PRINTS AND TECHNICAL DRAWING

General:

The original application of piezoelectric material was in bulk quartz crystal oscillators. A bulk quartz crystal oscillator is a plate of piezoelectric material of precise dimensions with evaporated planar electrodes on either side. When bulk crystals are excited by the planar electrodes the crystal resonates at a frequency corresponding to the standing wave pattern in the bulk crystal. By using a crystal cut to specific dimensions a particular frequency can be achieved. In short, as with surface acoustic wave devices, bulk acoustic crystals are frequency selective.

Just as surface acoustic wave devices can be used as delay lines, bulk acoustic wave devices can also be used as delay lines. The reason for this is that it takes a finite time for a signal to cross from one side of the crystal to another. However, the acoustic wave does not have to propagate within piezoelectric material, although it is initiated by the piezo-electric effect.

Bulk acoustic delay line devices are not as difficult conceptually as their SAW device counterparts since they do not have an interdigitated transducer. Furthermore, in many ways they are not as difficult to fabricate as SAW devices since there are no stringent requirements placed on the photo-lithographic process whereas in a SAW device the interdigitated pattern requires even electron-beam lithography on occasion.

Bulk acoustic delay line devices are thus suitable as broadband devices and able to function at higher frequencies precisely because of this lack of stringencies. This makes them suitable for radar applications at high

frequencies. With chirp radar systems (where the frequency varies during a radar pulse) a relatively high bandwidth is desirable.

Uses:

Bulk acoustic delay lines to delay a signal can be used in both military and civil radar products. They can be used for calibration and testing the system, as in this case.

Analysis of Documentation:

Reference is made within the bundle of exhibit papers to two separate delay lines:-

- (i) a 29 micro second delay line; and
- (ii) a 26.4 micro second delay line.

There is reference to the 29 micro second delay line being used for the Operator's Confidence Facility (OCF) in the Rapier missile system and an explicit set of instructions for the manufacture, testing and delivery of the 29 micro second delay line appears (see pages 435 to 448 of the Research Bundle for public domain literature on the Rapier Missile System).

In relation to the 26.4 micro second device, there is a complete drawing package and testing and dimensional specifications can be seen on the drawings.

The information on the 29 micro second device would enable anyone with access to similar equipment to reproduce both the 29 micro second and 26.4 micro second device given that the test procedures combined with information on how to re-work a device to achieve the required specification enables a good working model to be set up.

In the HRC Research Reports, the link between bulk acoustic delay lines and Rapier is clearly made. For example in the July 1985 to June 1986 Report (pages 448a of the Research Bundle) it is stated "during the period under review we have undertaken routine modifications and supplied delay lines to Cossor Electronics for use in the Rapier Operator's Confidence Facility" and in the HRC Report January 1986 to June 1986 (page 448b of the Research Bundle) "a range of bulk acoustic delay lines operating at micro wave frequency is being supplied for use in Rapier with delays ranging from 10 micro seconds to 30 micro seconds some temperature compensated are currently available operating at 1-3 GHz". Further, 3 GHz - the operating centre frequency of Rapier is referred to in connection with the Mark 3 delay line.

In addition it would appear that both the devices are commercially available since a product sheet entitled "Microwave Delay Lines and Modules" from HRC gives a range of delays between 1-4 GHz up to 30 micro seconds (pages 449 to 450 of the Research Bundle).

In relation to the device concepts and fabrication, Merion Lewis in a paper published in Electronic Letters in March 1972 (pages 451 to 452 of the Research Bundle) gives details as to the important fabrication details, for example the use of a zinc oxide transducer and the use of spinel. Although he refers to an "S" band delay line there are overlapping frequencies with the two devices referred to and the delays are of the same order as the delays referred to in the Prosecution papers.

From this paper, one can infer how to make the delay line. It is in effect a model for the devices under consideration and to make the 29 micro second or 26.4 micro second device only the dimensions of the device are changed.

Indeed a sub-system containing the delay line appears in a paper produced by Tia Mason (pages 453 to 457 of the Research Bundle). Further it is

clear that Russian scientists were aware of the principles of manufacturing bulk acoustic delay lines prior to 1976 as an Inspec paper number 0900195 entitled "Optimisation of Delay Lines" demonstrates - page 459 of the Research Bundle.

The value of the information contained in the exhibits is that some details of device fabrication may allow competitors to short circuit developmental programmes and improve their own bulk acoustic delay line capability. Such technology has now been rendered obsolete, however, with the advent of GaAs integrated circuits operating at high frequencies and advances in optoelectronics generally.

Conclusion:

As indicated the fabrication techniques are in the public domain. The link between the delay lines and their application in Rapier is firmly established in the HRC Research Reports.

ANALYSIS OF THE SR/4 BUNDLE

Introduction:

It would appear from the Prosecution papers that there are two areas of major concern within this bundle:-

1. Process Flow Chart (Pages 1-2 of the bundle); and
2. The Procurement Specifications from 100 millimetre diameter silicon on sapphire wafers (pages 32-36 of the bundle).

PROCESS FLOW CHART

General:

Flow charts are used in many industries and are a convenient reference guide to the steps in a process. Typically, a flow chart acts as a master or key to other literature which gives detail as to the steps referred to in the flow chart itself.

Analysis of the documentation:

As the document states on page 2 of SR/4, the flow chart is an "infra-red detector configuration flow chart". No details are given as to the application of this infra-red detector and one cannot conclude necessarily that this document refers to a military device. However, on page 1 in the centre of the page appear the words "CMT TED Test 0 4". This refers to the "Tom Elliott Detector" which is supplied to the military as part of the U.K. Thermal Imager Module and is also known as the "Sprite" detector. This detector has also found application in commercially available thermal imaging systems for industrial purposes, e.g. for examining the head losses

from buildings, detecting faults in high voltage power transmission lines etc. Examples of such commercial application appears at pages 507 to 508 of the Research Bundle in a booklet entitled "Thermal Imaging - A Transfer Of Technology" by David A Smith of RSRE. Further background information is to be found in the HRC Research Reports, extracts of which appear in the Research Bundle (pages 602a to 602d of the Research Bundle).

The document appears to be a QA document for the assembly of a CMT Detector array on a sapphire substrate for incorporation in a dewar (a double walled vessel designed so that the inner compartment is thermally isolated from the outer compartment) and cooled by a Joule Thompson Mini-Cooler. (A related design appears at page 560 of the Research Report). There are over 150 flow chart symbols representing various parts/materials procurement, test, assembly, operating, inspection, stock or shipment.

Critical steps and propriety steps are indicated but no details of these steps are given. In particular, critical details relating to the preparation of the CMT and its mounting onto the sapphire substrate are omitted and this is by far the most sensitive information. Without such detail, the chart simply represents an overview of the configuration of an infra-red detector array inside a dewar with an integral mini-cooler.

A similar flow diagram would be drawn for other types of infra-red detector assemblies with the exception of the information about the CMT wafer mounted on the sapphire substrate.

CMT is a fragile material and it is well known that it has to be supported by a substrate of some sort with sapphire being an obvious choice for the following reasons:-

- (i) it has a reasonably good match of expansion coefficient to that of CMT; and
- (ii) if the detector is destined for use in the 3-5 micron atmospheric window where sapphire is transparent, the possibility of back side illumination is introduced.

The idea that CMT can be mounted onto sapphire substrate is well known and published, for example in a U.K. Patent Application made by HRC published on the 7th of December 1988 with U.K. Patent Application Reference Number GB2-205-442-A (see page 575 to 584 of the Research Bundle). At page 577 of the Research Bundle reference is made to a "European Patent Number 7668" and describes a method in which "the CMT wafer is attached to a sapphire substrate and coated with a layer of photoresist which extends over the wafer and to the substrate".

This Patent is an example of the fabrication of an I.R. Detector array using the principle of CMT mounted on sapphire and gives details of the fabrication process in detail. Such detail is entirely omitted from the process flow chart.

Conclusion:

In my view there are far too many critical details omitted from this process flow chart for it to be of any real use to an enemy or even a competitor. There are many published papers on CMT technology, examples of which are shown in pages 462 to 491 of the Research Bundle, both written and published in the GEC Journal of Research. It is also interesting to note that much publicity has been given to the CMT thermal imaging capability at RSRE (now DRA) Malvern, an MOD Establishment (pages 492 to 544 of the Research Bundle). Indeed the Sprite (or Ted) detector is now used in commercially available equipment (see page 574 of the Research Bundle). The level of detail exposed in the HRC Patents (pages 575 to 602 of the Research Bundle) far exceeds the level of information given in the flow chart of the exhibited material.

CMOS ON SOS

General:

CMOS (Complimentary Metal Oxide Semi Conductor) on SOS (Silicon on Sapphire) is one of the most commonly used radiation hard technologies today for relatively complex integrated circuits which are likely to be exposed to doses of radiation. Such circuitry may be incorporated in military equipment or may increasingly be for use in satellites which act as a platform for a variety of purposes such as communications, broadcasting and surveillance (other than military surveillance). Ordinary CMOS and indeed metal oxide semi conductor technology in general is very susceptible to ionising radiation as a result of charge build-up in various parts of the circuitry, particularly in the oxide layer. Further background information is given in pages 641A to 641D of the Research Bundle extracted from a book on Radiation Effects by Andy Holmes-Siedle and Len Adams.

The Research Bundle at page 642 contains a list of known suppliers of SOS technology, most of them being US Companies. There are in fact several variants of SOS but CMOS on SOS is now the most popular, not least because CMOS has become the preferred silicon technology. Circuit designs actually become more simple when implemented in SOS because of the isolation of the substrate which effectively eliminates the requirement to protect against "latch up" (see pages 641B of the Research Bundle). This is the phenomenon which makes a conventional CMOS Silicon Circuit very susceptible to radiation as a result of charge build up (caused by ionization in the substrate) disturbing the normal conditions of some critical semi-conductor junctions throughout the circuit. The thickness and quality of the oxide layer is another critical factor and this usually determines the total dose the circuitry can withstand (see page 641C of the Research Bundle).

Analysis of the Documentation:

This is commercially sensitive information relating, it is believed to, a military product or to space applications i.e. in satellites.

The document indicates that HRC require their silicon on sapphire wafers to certain specifications (page 33 of the SR/4 Bundle). These parameters will affect circuit yield although in very general terms the importance of a customer company indicating its requirements to a supply company in considerable detail is a matter of common sense.

Several articles on details of SOS technology have been published by HRC (pages 605 to 625 of the Research Bundle). HRC Research Reports invariably contain a progress status report on SOS often including the radiation hardness figures achieved and the critical dimensions of the devices being produced, for example a 2 micron process has been demonstrated etc (pages 625A to 625F of the Research Bundle). The signal stream product family is clearly in the public domain. The SOS wafer specification of SR/4 is commercially sensitive in relation to both military products and satellite systems.

The specification is not a restricted document.

Furthermore, the standard specifications for SOS wafers as supplied by Kyocera are similar in many respects (see pages 626 to 641 of the Research Bundle).

CONCLUSIONS:

The exhibited material contains a large body of scientific information and manufacturing know-how. Virtually all of this information is in the public domain and cannot be said to endanger the national security, in that an enemy is, or may well be, already privy to this information and certainly has unrestricted access to it.

Of the remaining information, some is clearly of commercial significance only. The residue, some of which according to certain Prosecution witnesses is allegedly of potential use to an enemy, is exposed, often quite explicitly, in the HRC Research Reports for the period 1985 to 1992. These are widely circulated and, whilst being Commercial in Confidence, are not given any military classifications such as "restricted".

Indeed, the combination of these Reports and the public domain information is of far more significance than the exhibited material in combination with the public domain information.

I must therefore conclude that if the exhibited material is regarded as being a matter of national security, then so too are the majority of unrestricted Research Reports issued by the U.K. Electronics Defence Research Establishments both privately and publicly administered.

QUALIFICATIONS :

University of Bath: BSc (Hons) Physics with Physical Electronics 1970/74.

University of Bristol: MSc Physics of Materials 1974/75.

Thesis title: *"Investigation into the Aging of Quartz Surface Wave Devices"*
in collaboration with RSRE Malvern.

University of Birmingham: PhD Metallurgy and Materials 1975/78.

SERC Case Award with the Royal Signals and Radar Establishment, Malvern,
Title of Doctoral Thesis: *"The Physics of Counterdoped Materials for Extrinsic Silicon Infrared Detectors"*. PhD awarded 1985.

RESEARCH EXPERIENCE :

Summary:

Dr. Maher has worked in industrial research and in connection with MOD projects since 1978 in the area of electronic materials, devices and systems, with extensive computer controlled measurement/characterisation and modelling experience, resulting in many published papers and patents, particularly relating to optical devices and systems. This followed several years of research in universities, in collaboration with RSRE Malvern, where he gained experience in a wide variety of characterisation techniques and R&D methodology. He has extensive project management and man management experience, obtained in highly competitive commercial environments, to add to this broad technical background.

Background:

Dr. Maher's MSc thesis was concerned with degradation effects causing drift in frequency response and premature aging effects in surface acoustic wave (SAW) devices. This work was done in collaboration with RSRE, Malvern, under the supervision of Prof. A.R. Lang, FRS, at the University of Bristol. The objective was to correlate X-ray diffraction topographs of the single crystal quartz substrate, and its preparation, with device performance.

Dr. Maher's PhD thesis, on the subject of specially prepared silicon for infrared photodetector arrays for thermal imaging applications, was the result of a case

studentship at Birmingham University, with RSRE as the industrial sponsor, and subsequent work at Plessey Research (Caswell Ltd). At Birmingham, under the supervision of Dr. P.S. Dobson, electron microscopy observations of silicon surfaces doped by ion implantation were correlated with sheet resistivity measurements. The evolution of the damage structure was followed as a function of annealing temperatures and preliminary IR characterisation of the material was carried out by Dr Maher at RSRE.

In 1978 Dr. Maher joined Plessey Research (Caswell) Ltd as Senior Scientist to continue to assess silicon doped with transition metal impurities as a potential infrared detector material for thermal imaging applications. Sophisticated transient photoconductivity measurements coupled with resistivity measurements as a function of temperature were developed to obtain information on the photon and charge carrier capture cross-sections of the deep levels, and their densities. This work led to the fabrication of infrared detectors using high-voltage electron irradiation to introduce divacancies which act as deep level centres, which was the subject of a patent filed by Plessey in 1981. Promotion to Principal Scientist followed.

Research into counterdoped silicon detectors was funded by MOD, and Dr. Maher is the co-author of many papers in this field, both published and presented at conferences. Subsequently, he undertook extensive computer modelling exercises on the device's operation in order to elucidate anomalous device behaviour. This work is included in his PhD thesis.

After joining ERA Technology Ltd. in 1982 as Principal Scientist, Dr. Maher invented an attachment to the scanning electron microscope, which allows scanning optical microscopy to be performed in the SEM. The new device was featured in the Innovation Section of the Sunday Times, in The Economist and in an interview for BBC World Service. This development shows considerable promise for research into radiation sensitive devices, optically active materials and optoelectronic devices. Among these are CMOS devices, and the 'SOMSEM' system has been applied to the problems of defect location in integrated circuits using 'OBIC' (optically induced beam current) and 'Marginal Voltage' techniques. This work was funded by British Telecom and the United States Air Force (Rome Air Development Centre, USAF).

The 'SOMSEM' is now being manufactured under licence by Oxford Instruments, and instruments have been supplied to the European Space Agency, British

Telecom, Cambridge University and MIT (Boston, USA). The addition of a special laser heterostructure screen, fabricated by MOVPE (metal organic vapour phase epitaxy) using II/V compound semiconductor materials, should result in many more instruments being in use worldwide.

At ERA, Dr. Maher also worked on radiation effects on devices for MOD (in particular the radiation hardness of the Ferranti F100 microprocessor) and reliability physics generally (including ESD - electrostatic damage) generating successful proposals to MOD, British Telecom and USAF, and leading several projects. He filed a patent on a novel combination of optoelectronics technology and SAW devices in 1984. These projects involved computer controlled instrumentation, device physics and modelling. The possibilities of optically programmable devices are of particular interest to him.

Dr. Maher joined Johnson Matthey Technology Centre in 1985 as Group Leader, Sensors and Devices, in the Electronics Technology Department. He was responsible for progressing and patenting the TTI (Time Temperature Indicator) device, which was publicised in the national press during the various "food scares" of the 80's. The TTI awaits legislation on food safety before being commercialised.

At JMTC he initiated projects on temperature sensors, semiconducting oxide gas sensors, fibre optic sensors, high-temperature superconductors and II/VI infrared detector materials. After gaining promotion to Project Manager in 1988, his group was called 'Physical Electronics' and included a section devoted to producing high purity organometallic precursor materials, such as TMG and TMI, for optoelectronic and high-speed switching applications in compound semiconductor devices. Several products were launched from his group, including a fibre optic pyrometer system for profiling high temperature furnaces used for semiconductor device manufacture, and the new precursor materials. The TTI device alone is expected to have a market of many billions of units per annum worldwide. It is a thick film temperature sensor with integrated electrochromic display readout, capable of being integrated with bar code readers for stock control systems.

Since the closure of the Electronics Technology department at JMTC in 1991, Dr. Maher has operated as an independent consultant, specialising in technology- and marketing-oriented presentations and advising on information technology and computer equipment for small businesses, often in an R&D context.