Communications Research Centre Canada
An Agency of Industry Canada
Centre de recherches sur les communications Canada
Un organisme d'Industrie Canada

Photonics Research Program Review

External Review Panel Assessment

Prepared by:

Paul Jay,
with inputs from:
Robert Blake, Robert Corriveau, Frank Levinson and Prof David Plant.

Delivered to:
Communications Research Centre

Date: May 31st 2010

Canada

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CRC Photonics Activity Review 2010

Executive Summary

A panel of experts with international backgrounds in photonics technology was convened to review the ensemble of photonics activities across five groups at CRC. The Panel was provided with background notes prepared by CRC management and was also given presentations and laboratory tours on-site at CRC by the staff on these projects. Following on-site discussion of the data collected, this report was compiled and reviewed by all the Panel members, taking into account surveys completed by clients of each of the groups being reviewed.

The Review Panel was impressed by the calibre of the work presented, and especially by the objectivity of the managers in their presentations and self-assessments. In particular, the Panel would like to commend Dr Bérubé for his openness in arranging and coordinating the review process. The insistence on a forward-looking focus made this a healthy and valuable exercise and enabled the Panel to project more decisive conclusions regarding the potential value of the various activities.

The Panel evaluated the projects for their anticipated impact and excellence on the basis of a forward-planning 5-year window. The projects were assessed on their potential for excellence, based on the Panel's understanding of the competitive climate within which this work is occurring. Based on the information collected, the Panel offers recommendations, details of which are explained in the report:

- Across all the photonics activities, appoint a resource to pro-actively pursue a sales/marketing approach in relation to the photonics expertise and innovations at CRC, aimed at both generating revenues and collecting data. This resource should be closely linked to Canadian industry and other worldwide experts. In addition to actively looking for revenue opportunities this resource could provide an ongoing check of how relevant the research is in comparison to commercial activity;
- For the five groups reviewed, the Panel has prepared recommendations specific to each group and its activity, and these are detailed in the body of the report, where sections 2.1.7, 2.2.7, 2.3.7, 2.4.7 and 2.5.7 refer respectively to the recommendations for the RBON, ROCE, ROME, RPCT and RSS groups;
- The recommendations vary from sustaining, to revectoring and where necessary closure of parts of the activities reviewed.

The Panel believes that by taking note of these recommendations, the activities would be better focussed and matched to the resources, skillsets and funding available within CRC, while simultaneously being coherent with the overall CRC-SITT mandate.

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Table 1: List of Acronyms

Acronym	Description (or refers to)
AIRON	Autonomous Intelligent Reconfigurable Optical Network
APT	Advanced Plasma Technology
CAGR	Compounded Annual Growth Rate
CANARIE	Canada's Advanced Research and Innovation Network
CMC	Canadian Microelectronics Corporation
CRC	Communications Research Centre
CSA	Canadian Space Agency
CTO	Chief Technology Officer
DRDC	Defence Research and Development Canada
EDFA	Erbium-Doped Fibre Amplifier
FBG	Fibre Bragg Grating
GMPLS	Generalized Multiprotocol Label Switching
GSN	GreenStar Network
HSVO	Health Services Virtual Organization
IEEE	Institute of Electrical and Electronic Engineers (USA)
IMS-CPFC	Institute of Microstructural Sciences – Canadian Photonics Fabrication Facility
IP	Internet Protocol
IPR	Intellectual Property Rights
LEOS	Laser and Electro Optics Society (a part of IEEE)
MEF	Micro Electronics Facility (=ROME)
NINT	National Institute for Nanotechnology (part of NRC, located in Edmonton)
NRC	National Research Council
NSA	National Security Administration (USA)
NSERC	Natural Sciences and Engineering Research Council
OSA	Optical Society of America
PLC	Planar Lightwave Circuit
RBON	Broadband Applications and Optical Networks
ROADM	Reconfigurable Optical Add-Drop Multiplexer (optical switch)
ROCE	Optical Communications and Electrophotonics
ROME	Microelectronics facility and Optoelectronics Materials and Components
RPCT	Photonic Component Technology
RSS	Optical part of Satellite System Research
SITT	Spectrum, Information Technologies and Telecommunications Sector
SOA	Semiconductor Optical Amplifier
UCLP	User Controlled Light Paths
WDM-PON	Wavelength Division Multiplexing – Passive Optical Network

1 Overall mandate of the review exercise

1.1 The review process

This document outlines the conclusions of a review of the Photonics Research programs and CRC Microelectronics facility. This review is in response to the commitments made by SITT management following the 2009 CRC review.

The proposed review steps were:
- Establish details within the review scope;
- Research managers' assessment of programs;
- Management team assessment of programs;
- External third party committee review and recommendations;
- Presentation of report from External committee; and
- Analysis of responses and recommendations.

The external committee was constructed to include broad multi-disciplinary knowledge and was composed of 5 members representing international expertise, as well as experience of Canadian research and Canadian industry.

The focus of this review was on excellence, relevance and impact. Organizational assets and external factors were also taken into account.

1.1.1 Strategic Priorities

Within SITT (Spectrum, Information Technologies and Telecommunications Sector), CRC co-exists along with five branches focused on other activities. The function of CRC is to conduct world-class research that provides insight into future advanced information and communication technologies to help Industry Canada develop telecommunications policies and regulations. CRC's mandate also includes supporting other government operations such as national defence and public safety, and supporting Canada's communication sectors by engaging in industry partnerships and working with other research organizations.

Within the SITT context, CRC is also expected to adapt to changes at a global and national level, and these changes are influencing several fronts, such as:
- Global changes in demographics;
- Responses to economic crises in North America and the rest of the world;
- Drives towards a more 'green' economy;
- Better positioning to resist attacks on security of the internet and our communications infrastructure.

Only a few years ago Canada was a world leader in telecommunications technology, and especially in the photonics parts of that technology. Now the industrial presence in that market is dominated by other countries, but the vast and experienced Canadian photonics workforce still exists, albeit now distributed across many organizations and university laboratories. The potential for Canada to create new employment, innovations and exports out of that resource base is substantial, and the

CRC photonics activity is valuable in helping to preserve some concentrations of that expertise.

Within the scope of this review the Panel has endeavoured to take into account the fact that, while some of the technologies being studied have immediate potential in the telecommunications field, many also have potential for benefits to other industry sectors, for example past and new-generation fibre-Bragg grating technologies.

The challenge for CRC's photonics activity within this context is to maintain an awareness and a respected presence in the relevant communities, so that the government can be kept informed and up-to-date with needs, developments and technical advances. Ideally this is done with the most economical resource base possible, and by complementing rather than duplicating activities at other locations in Canada. Within the core activities some new technologies will emerge, and these may offer substantial benefits beyond telecommunications, even beyond the extended envelope of SITT responsibility. While these developments should not be curtailed if they are found to be innovative and fruitful, it may eventually be more logical to move some of them to a context of technology transfer or licensing, in order to ensure that:

a) returns on those investments are developed in a responsible manner on behalf of the Canadian taxpayer, and

b) the focus of the CRC activity remains centred on technologies relating to the SITT mandate.

1.2 The review panel

In assembling a panel of experts to assist in this review, the intent was to bring together individuals from different sectors who would comprise an awareness of the global context of photonics in relation to these activities. Members were asked to participate on the basis of their involvement in:

- Canadian photonics/telecom industry sectors;
- Canadian photonics academic sector;
- Canadian national laboratories and institutes involved in photonics research;
- SME technology company sector;
- Technology investment sector (Canada and global);
- Other technologies that relate closely to photonics deployment for example electronics.

The following is a list of the review panel committee members:

- Robert Blake, CEO, Octasic Inc, Montréal. Mr. Blake has extensive knowledge of the telecom industry. He has been developing ASICs and programmable logic for high-performance communication applications for more than 20 years. At Altera, Mr. Blake was responsible for defining the programmable logic product portfolio, ensuring that Altera's products leveraged the most advanced technology and precisely met customers' requirements. Prior to Altera, he developed ASIC technology at LSI Logic and Fairchild, where he worked in both engineering and strategic marketing.

- Robert Corriveau, President and CEO, Canadian Institute for Photonic Innovation (CIPI), Université Laval, Québec. Before joining CIPI, he was Vice-President, Marketing and Business Development at PhasOptx, a new company specializing in fibre-optic connectivity. Between 1995 and 2004, in his capacity as Senior Vice-President, he oversaw technology and business development at INO, a leading Canadian centre of expertise in applied optics and photonics, which provides contract R&D to industry and conducts a significant internal research program.
- Dr Paul R. Jay, Technology Consulting Services, Ottawa. Dr. Jay is the former CTO of Intelligent Photonics Control Corporation and has held various Director positions with the Canadian Photonics Consortium and Nortel Networks. He was also an Executive-in-Residence and Adjunct Professor at the University of Ottawa School of Information Technology and Engineering. For this Panel he took the role of Secretary in terms of compiling drafts of the written summary of the report.
- Dr Frank Levinson, Silicon Valley. Ex-CTO and Chairman at Finisar, Founder Small World Group, Partner at Cleantech Circle. Small World is a mixture of philanthropy, engineering and building profitable companies. The Cleantech Circle is a group of serial entrepreneurs and investors based in Silicon Valley who are committed to the growth and adoption of renewable energy generation and resource/energy efficiency technologies. Dr Levinson's specialties include: fibre optics, high speed networking, biological sensing, and clean technology.
- Dr David Plant, Chairman, Department Electrical and Computer Engineering McGill University. Dr. Plant heads the Photonics Systems Group which is doing research in packet-switched optical networks and agile all-photonic networks. Professor Plant is a Fellow of the IEEE and the OSA, having received these awards for his work in optoelectronics. He is also a Fellow of the Engineering Institute of Canada. He is quite active in the OSA and IEEE professional societies being an elected member of IEEE-LEOS Board of Governors. He has been a member of the CMC technical advisory committee for a number of years and also was chairman of the NSERC Strategic Grants committee for ICT in 2004 and 2005. He is also a VP of a start-up AKDP Photonics.

1.3 Purpose and focus of the review

This review was conducted following the commitments made by Spectrum, Information Technologies and Telecommunications (SITT) management to review the Communication Research Centre (CRC) major research programs following the recommendations of the CRC 2009 review. Its goal is to review all the Photonics research programs and the Microelectronics facility. In this document the Microelectronics facility is included when discussing research programs.

The focus of the review is to assess the current abilities and their potential for future impact in the domains of activity of CRC, and for the larger context of Industry Canada.

1.4 Brief historical context

A search for similar processes used by CRC in the past was done and various review questions and formats were provided to the panel. For the context of research organizations, the CRC Advisory Council meeting of October 16 2009 also noted the criteria that such reviews should focus on, namely:

- excellence,
- relevance, and
- impact.

CRC has demonstrated and continues to demonstrate excellence in its research by all standard measurable methods such as publications, collaborations, technology transfers, IP generation, patents, licenses, etc. Excellence will be assessed in this review. Also assessed will be the relevance and impact anticipated from these particular research programs in 5 years and beyond with respect to SITT and other clients' objectives and strategic priorities.

1.4.1 Previous reviews and outcomes

An earlier review in 1998 assessed the relevance and effectiveness of the Broadcast Technologies Research Branch. It also considered whether the Branch was being managed effectively, and examined the extent to which the quality of research and services provided met the needs of the Branch's clients and collaborators. The 1998 review was not limited to the Photonics activities. Data collection for the 1998 review was based on the following methods and tools:

- Analysis of recent publications;
- Interviews with managers and staff;
- Survey of 30 partners, collaborators and clients;
- Interviews with subject matter experts;
- Comparison with similar organizations in other countries; and
- In-depth studies of five major projects.

Another review in mid-2008 analysed the photonics projects underway at that time, and compared the capabilities and outcomes to similar activities elsewhere, as well as determining some success criteria and performance indicators to monitor and evaluate the program. It also considered any options for cost reductions, and possible consequences of stopping research in photonics at CRC.

In March 2009 a CRC Review addressed the following questions:

1. What does CRC do for its annual spending of $48 million?
2. How does the work benefit Industry Canada and other clients?
3. Do CRC clients pay their fair share of the work being done for them?
4. How does CRC determine its research priorities and make decisions on budget spending?

A further assessment in October 2009 set out terms against which to measure the Vision, Mission, Values and Goals of the various CRC R&D programs and Corporate functions. These included assessment benchmarks covering:

- Needs of the clients;

- Achievements of the program (value);
- Effectiveness of the program (cost); and
- Evolution of the program over the next 3-5 years.

The analysis phase would then ascertain whether less relevant programs should be:

- modified to better align with the CRC Vision, Mission Values and Goals;
- considered for transfer to another Government Department, or university/ private sector group;
- or considered for termination in the context of existing investments.

Accordingly, the CRC Managers and the 2010 Review Panel were asked to consider the following questions (section 1.4.2) in their assessment of the CRC Photonics activities.

1.4.2 Questions presented to the managers and the review panel

Why?

- Why is this research program selected?
- Why is it relevant to SITT and other clients' strategic priorities?
- Why should this research be conducted at CRC versus another government lab, university or by industry at large?

Who?

- Who are the clients?
- Who are the collaborators?
- Who is the competition?

What?

- What is the anticipated impact to the strategic priorities?
- What are the milestones along the way?
- What organizational assets (staff, infrastructure, equipment and funding) do you currently have and what will be required in order for this research program to be successful in the next 3 to 5 years?
- What are the consequences of stopping this research at CRC (answers also to be gathered from clients)?

When?

- When are the milestones anticipated?
- When is the impact anticipated?

How?

- How is this research excellent?
- How are external factors monitored to determine their effects on the relevance and impact of the research programs?

2 Summary of present capabilities

The following programs are within the scope of this review:

- The optical part of Broadband Applications and Optical Networks (RBON) headed by Michel Savoie;
- Optical Communications and Electrophotonics (ROCE) headed by Dr. Stephen Mihailov;
- Microelectronics facility (ROME) and Optoelectronics Materials and Components (ROMC) headed by Robert James;
- Photonic Component Technology (RPCT) headed by Dr. Claire Callender; and
- The optical part of Satellite System Research (RSS) headed by Mario Caron.

2.1 Capabilities of RBON group (Advanced Optical Network Technologies and Control & Management of Next Generation Optical Networks)

This activity is of strategic significance to the security of communications within Canada, especially in a context of increasing threats of cybercrime against a network infrastructure that is ubiquitously dependent on optical technologies. A substantial segment of the Canadian technology economy is also rooted in this type of application, and a well-focussed effort at CRC has the potential to provide globally-significant valuable support to small and large industries in the Canadian communications sector. The increasing pervasiveness of our dependence on secure communications underscores the need for Canada to be knowledgeable and authoritative in this arena.

The topic is also under-served in the world, highlighting an opportunity for Canada to take a leadership role in developing international cooperation towards new solutions and standards for increased network robustness and security against localised failure or deliberate intrusion.

2.1.1 Summary of current capabilities

The RBON team consists of about 8 individuals with considerable and relevant experience in the domain. The capital investment in this activity is not large, given that much of the activity can depend more on software and simulated approaches than on the expensive state-of-the-art hardware needed for increasingly-high data rates of the network core.

The review panel was impressed by the calibre and energy of the research team involved in this group, and also noted that the core assets of this activity are primarily intellectual assets, somewhat independent of high capital or operating costs related to equipment, and so represent an excellent investment with a potential for high return.

2.1.2 Risks and potentials evaluation

A detailed risk analysis questionnaire specific to the RBON activity was completed by internal CRC staff as well as by members of the external review panel. The questions presented are reproduced in Appendix 2 of this report, and the summarised results integrating both the internal and external inputs are reproduced in Appendix 3 of this report. Because of the nature and groupings of the questions, the small sample sizes surveyed (12 on average), and the large deviations in the responses, we will limit the analysis here to consideration of those responses that averaged in at least one of the extreme high categories, i.e: involving either Significant Impact, or High Likelihood, or both together.

For RBON only one response averaged a high category. Question F12 was felt to have a high likelihood of occurring, with potential for moderate impact. Question F12 addressed the concern that the costs to run various programs and facilities may continue to increase, and could result in a scaling-down of activities so as to remain within budget.

2.1.3 Client base and evaluation

At this time the primary clients for this activity appear to be limited to university and academic groups. Given the potential significance for this work to influence matters relating to global standards and commercial deployment scenarios, the Panel felt that it would be very valuable for the RBON group to engage relationships with some of the major private sector players that are represented locally and across Canada. In particular, the studies and outcomes of this work should be of interest to service providers such as Telus, Bell Canada, Rogers etc., and would also be of significance to companies in Canada and elsewhere whose activities are tributaries of the previous photonics activity concentrations at Nortel, JDS-U, Newbridge etc.

RBON lists as clients a large number of entities, including groups involved in university collaborations as well as private sector players. Of the 3 RBON clients contacted for evaluation inputs, all of which were academic groups, only 1 responded, and with a supportive, if not enthusiastic, evaluation. The Panel would recommend RBON to cultivate more tangible forms of support of these joint activities, manifesting in either contract revenues or visible achievements in terms of contributions to national or international standards definitions.

2.1.4 Evaluation of competitive position

Activities in the RBON research program are essentially 5 projects grouped into two themes:

1. Advanced optical Networking Technologies:
    a. Autonomous Intelligent Reconfigurable Optical Networks (AIRON);
    b. WDM Passive Optical Networks (WDM-PON);
2. Control & Management of Next Generation Optical Networks:
    a. User Controlled LightPaths (UCLP) within a virtual environment;
    b. Network Planning and Optimization; and
    c. GMPLS control plane survivability.

The Panel felt that 1a (AIRON) and 2a (UCLP) are areas of competitive strength for CRC and warrant further encouragement to develop their impact to a higher level. As a combination, the two approaches can take advantage of functionality that is increasingly built-into optical network elements such as optical amplifiers (EDFAs, SOAs), optical switches (ROADMs) and optical performance monitors. By enabling these elements with IP addresses, their remote activity can be monitored and modified according to traffic demands or threats facing the network. By making each of these elements addressable and configurable as objects in a virtual environment it is possible to simulate and also manage network parameters across a range of scenarios from normal optimised operation to survivability in a damaged or compromised situation.

The notion of addressability and reconfiguration of individual optical functions has been a possibility for several years, but as more and more of the deployed modules include this capability, the need for an over-arching software approach to handle the coordination is timely, and this group has the knowledge base and awareness to contribute significantly in that domain.

Although an understanding of the line rate traffic characteristics (for example at 2.4Gb/s, 10Gb/s, 40-100Gb/s) is necessary for the team, the management and hierarchical control of these elements generally takes place well below the high capacity transport speeds, and so the most expensive equipment is less necessary. The management and control layer is largely data-rate agnostic, and the required functionality can be embedded in the increasingly powerful signal processing electronics that typically accompanies these functions in their field-deployed context.

2.1.5 Potential of this activity for future impact and relevance

This activity has the potential for major relevance in a world where network intrusion is becoming an increasingly frequent threat to business, institutional and domestic users of the network.

Some parts of the activity (UCLP for example) have involved prior collaborations with CANARIE as a test-bed, and the history of tool development from that relationship is strong and widely-recognised. It would be good to develop that partnership further and to see if CANARIE and CRC could jointly offer an environment for evaluating/calibrating network management capabilities across elements made (possibly loaned/donated?) by various commercial suppliers. Such a collaboration would offer the benefit of being commercially independent ,and so enabling an objective comparison of capabilities, as well as serving to keep Canada informed on the evolving state of network control capability from a strategic control point of view. An increased proactive role in standards organisations would be a valuable element of this activity that would both serve to gather strategic understanding of network evolution, and also provide a platform for third party equipment evaluation of value to other global players.

By contrast, the Panel felt that the WDM-PON (1b) and WDM Network Planning (2b) contributions were more difficult to justify, in a context where the pure optical part of the network is a very competitive and economically challenging activity in which to keep up to date. This type of work now centres on 40-100Gb/s, and also is becoming increasingly dominated by electronic as opposed to optical approaches to impairment compensation and correction. Effort from these projects would be more fruitfully re-focussed on enhancing the control and reconfigurability aspects. Some parts of 2c (GMPLS survivability) would combine well with the UCLP work. Approaches to WDM configuration challenges would be better handled at a software level, and this would help to minimise the otherwise considerable financial obligations of staying current with WDM hardware technology in the high data rate transport plane.

2.1.6 Major challenges facing this activity at this time

This type of activity must be concentrated where it is most effective, and in the domain of long-haul high bit-rate transmission technology (10-100Gb/s), equipment and modules are expensive and evolving rapidly in a very competitive commercial environment, making it very difficult for a non-commercial participant to maintain competitivity. The notion of 'all-optical networks' is evolving into one of optical networks with control and compensation managed through powerful high speed silicon electronics. It is probably therefore not cost-effective for the group to expand its investments in all-optical network technology.

Given that the lifetime of planning decisions made now would offer a potential 5-year window of activity, it is a unique opportunity to apply the substantial CRC expertise in this area towards enhancing the controllability and manageability of the network using software approaches that could potentially result in tools and IP of a marketable nature.

In order for any usable intellectual property to be recognised for its potential value, it is important for the team to have presence and visibility in the relevant user communities, and this could be achieved through:

a) more proactive business development activities building on this capability; and

b) participation in joint exercise bodies such as standards committees etc.

2.1.7 Recommendations regarding this activity

Based on the information presented and received at the review, the Panel proposes the following recommendations regarding the RBON activity at CRC:

1. discontinue the WDM-PON activity and refocus resources towards the UCLP and AIRON projects;
2. minimise or discontinue the Network Planning and Optimization activity, since the notion of all-optical networks is become progressively less likely as silicon DSP control becomes more effective;
3. Focus on development and growth of the AIRON and UCLP activities, bringing in survivability features of the GMPLS work, with the intent of developing Canada's role as a major player in the much-needed global effort for more secure and robust networks standards, conditioned to resist and recover from cyber-security threats.
4. Aim to get actively involved in standards bodies representing Canadian national and industry interests;
5. By virtue of pursuing (3) Canada and CRC will be well-informed on strategic aspects of communications infrastructure, as well as providing capability and study results that will be of value to SMEs and major players in the communications industry.
6. Work hard to get more paying clients in the commercial user space, particularly Canadian service providers, and also to develop more joint projects taking advantage of the CANARIE infrastructure. Establish a close dialogue with Rogers, Bell etc which will provide valuable feedback on new aspects of network usage, such as 'how data centres are operating' (eg Facebook, Google – new players at the Optical Fiber Communications conference).

2.2 Capabilities of ROCE group (Optical Communications and Electrophotonics Research Program)

The activity in this group is born of the discovery over thirty years ago that structural changes in optical materials could be created by illumination with ultra-violet light. This subsequently led to the invention of a process for mass-producing optical grating structures in fibre, and that technology has been successfully licensed to a number of commercial users, creating a substantial income for CRC based on the revenues from the intellectual property agreements.

A fortunate coincidence was that many of the applications of the Fibre Bragg Grating (FBG) technology were optical functions that solved pressing problems in the newly-developing domain of optical communications, resulting in extensive deployment of FBG devices in the burgeoning fibre network. Many other FBG applications exist and in some cases are still emerging, for example as sensors or as key elements in fibre lasers or fibre optic gyroscopes, however these new applications do not yet approach the volumes enjoyed within the telecom market. Indeed, for sensor applications, the traditional FBG technology has a fundamental drawback in terms of high temperature stability, which mitigates against its deployment in some aggressive environments such as oil-well drilling etc.

Within the telecom context, the usage of FBGs may well have passed its peak as more and more optical impairments can be corrected by using increasingly sophisticated electronic signal processing techniques, and this is also occurring at a time when the period of patent protection for the original FBG process is coming to a close.

Nevertheless, building on this powerful heritage of expertise in FBG technology, the ROCE team has applied its expertise and understanding of light sensitivity in fibre to develop a potent new technique using ultra-fast infra-red pulses to induce localized stable index changes in fibres, offering a new lease of life to the notion of FBG technology and opening the door to a host of potential new applications. This is a brilliantly insightful advance and represents a jewel of Canadian technology, for which the most powerful applications may not even yet be apparent, and may well exist outside the domain of fibre communications.

2.2.1 Summary of current capabilities

This 8-person team maintains a laboratory base of approx $3M worth of capital equipment including high power lasers and other diagnostic/characterization equipment. Other than some repair costs involved in re-commissioning some of the excimer lasers for operation in the newly-occupied Photonics building, most of the projected future costs for this activity are dominated by salaries and other operating costs, many of which are offset for a few more years by revenues from the existing FBG licensing agreements. The grouping of skills in this team appears well-suited to the task of supporting existing licensee interests at the same time as developing new approaches, in particular as emergent from the femto-second grating-induced technology with its rich spread of potential applications.

2.2.2 *Risks and potentials evaluation*

A detailed risk analysis questionnaire specific to the ROCE activity was completed by internal CRC staff as well as by members of the external review panel. The questions presented are reproduced in Appendix 2 of this report, and the summarised results integrating both the internal and external inputs are reproduced in Appendix 3 of this report. Because of the nature and groupings of the questions, the small sample sizes surveyed (12 on average), and the large deviations in the responses, we will limit the analysis here to consideration of those responses that averaged in at least one of the extreme high categories, i.e: involving either Significant Impact, or High Likelihood, or both together.

For the case of ROCE, 1 question (R10) was deemed to be significant and with a high likelihood of occurring, and this addressed the potential for cost recovery from IP generation, especially in the context of the femtosecond FBG creation technology.

A further two questions (P3 and R11) were judged to be of high significance with a medium occurrence likelihood. P3 outlined the risk of loss of production capability in the event of equipment breakdown, especially in respect of the high cost laser systems involved in the FBG fabrication process. R11 considered the potential to produce high quality research in any given direction, based on the current knowledge and expertise within the group. Notwithstanding that innate strength in the group, it would be inappropriate to distract the axis of research too far from the main theme of the current expertise.

Question F11 was assessed to have moderate potential for impact and be highly likely to occur, and considered the risk of increasing costs to run various programs and facilities, especially in relation to high costs of consumables and maintenance for the high power laser systems used.

2.2.3 *Client base and evaluation*

This group has developed a solid base of external clients and users, many of whom are emerging Canadian suppliers with a strong reputation. The clientele for these technologies are international in terms of demographics, and are not limited to telecom users.

Users from the US Defense industry speak of benefitting in a strategic way from access to this group and the related technology, and acknowledge value in terms of services, samples software and technical guidance. They predict that future involvement with this team has potential to continue or even increase, representing a capability that is unique in the world. Evaluations of the team's contributions are ranked high to maximum in both excellence and impact, and testify to an enthusiasm for ongoing collaboration. International users also indicate value for Canada in terms of sales of Canadian products to US entities, and increased visibility of Canadian technology with US defence and industry users.

While the number of external collaborators includes significant players in Government as well as academic labs (both in Canada and internationally), the client base also shows some rising stars in the Canadian SME sector as well as several major international names such as Schlumberger, Siemens, Exxon, GE and Sumitomo Electric.

2.2.4 Evaluation of competitive position

The four main project areas of this activity are:

- Photosensitivity in optical materials;
- Bragg grating technology and applications;
- Fibre-based component development; and
- Exploitation of fibre component technology.

This world-class capability arises from the historical capability in FBG technology, but has successfully built on that foundation to generate a powerful new approach to gratings, taking advantage of ultra-fast pulse technology in which Canada has a major base of expertise, such as Paul Corkum's lab at NRC. Extension of this type of materials modification to two- and three-dimensional periodic optical structures is a new field of photonic crystal engineering, in which Canada again boasts a world-level expertise, including Prof Sajeev John at the University of Toronto, and which will likely herald a wave of as-yet unimagined applications.

With this set of resources and experience, Canada and CRC are well-positioned for competitive advantage, especially in terms of potential applications for the new fs-pulsed grating technology, whether in telecom or in other domains of application. The group is also well-equipped to continue exploring for future advantages of direct modification of optical properties of materials.

2.2.5 Potential of this activity for future impact and relevance

This technology set, especially the femto-second descendant of traditional FBG technology, offers broad potential for a wide range of new applications, but the challenge will be that these applications may be less in the domain of telecom technology than in other sectors. Existing and future clients of CRC could find uses for the new types of grating in high temperature sensors, or in emerging technologies such as fibre lasers or fibre optic gyros.

Remote sensing is a growing market, and fibre-based detection approaches have many advantages in terms of weight, cost, connectivity etc. Non-contact optical sensing as well as fibre-based sensing techniques contributed to a $500M monitoring and measurement market in 2007, growing at a CAGR of about 35%. In 2008 the market for fibre lasers was around $300M and growing at about 65%/year. Increasing use of optical and photonic techniques in Health Sciences created a $3.2B market in 2006, with a CAGR of 14%.

Many of these applications could impact defence and security related markets which are also within the direct mandate of CRC, but they could also certainly impact many industrial opportunities in domains that fall outside the current CRC purview. The Panel feels that for the context of telecom applications, the maximum volume usage of FBG-type devices may well be passing its peak market size, as other (more electronic) approaches to compensation start to dominate.

2.2.6 *Major challenges facing this activity at this time*

The review Panel agreed on the excellence of this world-class technology, but recognised that it faces a major challenge in identifying deployment markets that fall within the tight telecom/defence/security purview of CRC. In terms of CRC's broader obligations to Industry Canada, the value of this activity to generate new business opportunities is substantial, and represents a unique and compact investment from prior CRC successes and positive reputation.

In an increasingly silicon-centric long haul telecom network, the opportunities for grating-based solutions are probably not a major growth sector, however the CRC team is to be applauded for their ingenuity in coming up with a valuable successor to the traditional FBG technology, built out of a solid understanding of key basic principles combined with emerging short pulse laser techniques. There are undoubtedly large markets for this new technology, but many of them are not net recognised.

2.2.7 *Recommendations regarding this activity*

Based on the strong reputation of this activity, and especially the high regard in which it is held by current and past clients around the world, the Panel recommends that:

1. CRC should not abandon this technology even though the telecom applications may be waning. Rather:
2. there should be an effort to find better resonance with the mandate, and examine the potential of other application domains beyond telecom including fibre lasers and fibre sensor-based applications.
3. In some cases this could result in future licensing of the new fs-pulse technology, or even transfer of the technology to commercial entities whose deployment could result in a new sustained stream of revenue generation for CRC.
4. New applications of significance could include the growing market of fibre lasers as sources of stable, robust, high power beams, in addition to the less well estimated market of fibre optic gyros. Compared to fibre lasers, fibre optic gyros have very similar technology dependencies and offer a lightweight, low cost, no-moving-parts solution to high precision navigational or orientational stability, frequently deployed in secure or military situations for which market data are not readily available.
5. The Panel encourages CRC to recognise the world-class status of this activity and to be patient as examination of new possible applications proceeds.
6. A logical place to initiate exploration of future development opportunities could be through dialogue with the existing community of very supportive and appreciative clients that depend on this service.

2.3 Capabilities of ROME group (Optoelectronic Packaging and Microelectronic Fabrication Technologies)

The ability to realise complex wafer structures and packaged hybrid combinations of devices has enabled the realisation of powerful new functions as development of electronics and photonics advanced together over the past couple of decades. In many cases the small-scale crafted structures then became designs that could be more cost-effectively and reproducibly manufactured in large-scale dedicated foundry operations that, by running at close to maximum capacity could achieve close tolerances and predictable characteristics.

A by-product of the technology downturn of recent years has been the availability of some items of surplus equipment which have become valuable resources for prototyping facilities in research and development labs, although some of the older equipment is now reaching the end of its useful life, at the same time as there is an emerging capability for externally-sourced prototyping.

The services provided by the ROME team are of value to internal as well as external clients and University groups who require 'unusual' processing steps on a customised basis, and the group works in the connected domains of electronic and optical device structures and module packages.

2.3.1 Summary of current capabilities

This activity combines 5 individuals and a substantial ensemble of processing equipment, many items of which will apparently require renewal or replacement over the next few years.

Equipment capabilities in the group allow for:

- Hybrid microwave Miniature integrated circuits on thin film ceramic substrates;
- Electronic packaging and component assembly for proof-of-concept prototypes;
- Optical packaging with solder bump and flip-chip processes;
- System-on-package implementations using multi-level metallization and spin-on dielectrics.

This facility supports a number of internal research programs in other CRC departments.

2.3.2 Risks and potentials evaluation

A detailed risk analysis questionnaire specific to the ROME activity was completed by internal CRC staff as well as by members of the external review panel. The questions presented are reproduced in Appendix 2 of this report, and the summarised results integrating both the internal and external inputs are reproduced in Appendix 3 of this report. Because of the nature and groupings of the questions, the small sample sizes surveyed (12 on average), and the large deviations in the responses, we will limit the analysis here to consideration of those responses that averaged in at least one of the extreme high categories, i.e: involving either Significant Impact, or High Likelihood, or both together.

For ROME, a total of 5 questions triggered a double high response, and a further 6 questions were judged high in at least one respect. All of these questions addressed risks, perhaps resonating with the concerns expressed by the Panel in reviewing this group and its dependency on outdated equipment.

The following 5 questions were all judged to be risks of significant impact and high likelihood of occurrence:
R3: Risk that process development specific to a given client may lack reproducibility unless it is developed in more depth beyond a 'proof of concept' stage.
F2: anticipates the risk that budget allocations will change, with adverse implications for the scope and extent of the group's activity.
F6: Similarly, this question considers the risk of little or no capital funding for renewal of aging and obsolescent equipment, highlighting the Panel's concern that maintaining such a facility to operate on a small scale is not a financially justifiable proposition.
F9: Considers how the risk of reduced funding will impact ability to purchase spares for the aging machines in ROME, and F10 observes that the activity is also vulnerable to cost increases associated with transport of chemicals, spare parts etc as needed to sustain the microelectronics fab operation.

Question P7 was scored with a large spread of results, but implied a significant degree of impact and medium occurrence likelihood, and referred to the risks of calibration difficulties with older equipment.

Questions R2, R5, R10 and F3 and F12 were judged as highly likely with moderate impact:
R2: risk that client needs move beyond existing capability;
R5: risk that mandate changes for CRC within SITT might change the role expected of ROME;
R10: represents the risk that ROME's capability may fall short of its mandate to *"meet key technical challenges of the 21st century for the knowledge-based economy"*.
F3: addresses the risk of mid-year budget changes as mandated from above, and
F12 considers how staffing priorities may affect the activity in any realignment of objectives exercise.

2.3.3 Client base and evaluation

Although in the past this group was able to provide services to a number of external SME groups in terms of prototyping device structures (Zenastra, Metrophotonics, Gain Microwave) the clientele is now predominantly internal to CRC (including RPCT for photonic structures) and local universities. Occasional contract work has also been done for DRDC and CSA.

External users appreciate the geographic convenience of this capability, although they feel they could get comparable service elsewhere if the need arose. Impact and excellence of the work were rated mostly high, albeit with some concerns over long turn-around times. When discussing alternative places to get the same services, clients suggested that costs would probably increase if they had to go elsewhere.

2.3.4 Evaluation of competitive position

This facility is especially useful to internal collaborators and to local university projects because of the geographical convenience and customised approach offered by the team. A difficulty arises when major items of processing equipment reach the end of their useful life and require replacement. Also, any microfabrication facility is an expensive proposition to maintain and operate, consuming large amounts of electricity, water, chemicals and gases which add up to a high loading of operational expense even independent of throughput. In some cases the services are provided at a very reasonable cost, which may be substantially less than the true market value of such a service.

Over the last decade there has been a substantial increase in the number of external commercial operations offering custom foundry services for wafer growth, processing, post-processing (sawing, vias, dicing, etc.) and packaging. These commercial operations tend to run at near-capacity and thus maintain optimum operation at minimum cost and with maximum reproducibility. Examples of commercial entities to explore could include: Universal Semiconductor (San Jose, California); Majelac Technologies (Allentown, Pennsylvania); Spire Semiconductor (Bedford, Massachussets); Covega Corp., (Jessup, Maryland); Photonic IC Corp., (Culver City, California); Alcatel-Thales III-V Lab (Paris, France). A January 2010 survey (http://www.stw.nl/NR/rdonlyres/89EE02D8-8B9E-42F4-99B2-38B7C108771F/0/GTIPprogramdescription.pdf) compiled by STW suggests multiple European options for 'Generic Opportunities for Integrated Photonics'. The company Vixar (http://www.vixarinc.com/) in Minnesota, manufactures vertical cavity surface-emitting laser chips based entirely on an out-sourced process. It is likely that many of the operations offered by ROME could now be provided by some of these external entities. In addition, Canada (NSERC and NRC) has made substantial investments in major processing capability at CPFC in Ottawa, NINT in Alberta, and NANOQUEBEC at l'université de Sherbrooke.

It appears to the Panel that without major investment and rejuvenation of the equipment on which ROME depends, the capability offered has great difficulty being competitive when compared to the external options, and whereas convenience might suffer if internal users had to out-source their assembly and process steps, the costs could largely be met by savings derived from decommissioning the existing equipment.

2.3.5 Potential of this activity for future impact and relevance

The panel feels that other than perhaps some of the printed electronics capability (ink-jet, screen printed ceramics etc), the facilities upon which this group depends are reaching the limit of their usefulness, and more cost-effective and consistent solutions could be achieved through external facilities.

It was noted that the group has had some collaboration with Xerox Canada in the domain of printed electronics based on organic inks, and there could be some value in sustaining some effort on this emerging activity to evaluate its potential benefit to electronic and photonic packaging functions.

2.3.6 Major challenges facing this activity at this time

This activity depends on out-dated equipment, and appears to have minimal clients who are willing to pay market rates for the service. Costs of maintaining such a facility are very high, and only justifiable if a facility is running at near-capacity.

2.3.7 *Recommendations regarding this activity*

The Panel finds it hard to justify the continued operation of this facility at the current level. Accordingly the recommendations are:

1. Audit the internal microelectronics processing capabilities against those available on a commercial basis;
2. Audit the internal microelectronics processing capabilities against those available on a restricted basis through Canadian university or national laboratory facilities;
3. address the need for alternative solutions to meet the demands of any internal or DND client groups that might still require services unobtainable elsewhere;
4. assuming that virtually all the needs can be met through other sources, proceed to close down most of this activity and minimise the financial load of maintaining the existing equipment, with the possible exception of:
5. sustaining a continued lower cost option to investigate for printed electronics, and possibly ink-jet interconnect substrates.

2.4 Capabilities of RPCT group (Photonic Component Technology)

This recently-created group addresses challenges relating to the integration of photonic functions on a common substrate, and brings together resources from an earlier Photonic Component Technologies team within ROMC.

The pursuit of integrated photonic functionality is much more difficult than the corresponding electronics transition from discrete to integrated components 50 years ago. For electronics, nature provided us with a substrate that was at once inexpensive, and ideal for making active devices (transistors), and also supported a technology for passive components and interconnect, facilitated by its ability to form a stable native oxide. Its ease of integration, and the degree to which integration has scaled over several decades, have resulted in a technological revolution unparalleled in history. In the case of photonics the evolution is not so easy, since the best active optical devices involve substrates that are costly and more difficult to work with. It is evident that photonics has many dimensions of performance advantage to offer, but we must remember that the field is still in its infancy as compared to the much more mature integration of electronics.

A major focus of this forward-looking group is to explore the potential of planar lightwave circuits (PLC), especially taking advantage of in-house expertise based on silica waveguides and other functions integrated onto silicon substrates. Although this means that most active functions (sources, detectors etc) can only be introduced in a hybrid form (since they typically involve III-V semiconductor structures as opposed to silicon substrates) it does provide a relatively economical approach that can realise many passive functions, alignment structures, and can take advantage of decades of learning in silicon microelectronics.

This research thrust is a common interest for groups all over the world, and a challenge for this team is to identify where their work can have the most unique impact, especially while responding to the needs of CRC's mandate.

In the near-term this activity addresses the search for economical solutions to high-volume low-margin demands of access photonics, where signals transition from the network environment to a more localised interconnection in user premises. This need has a focus directly in the purview of CRC's communication obligations. At the same time, economic solutions to these needs could quickly translate into new integrated functions for other applications, such as environmental sensors or medical detection devices, which would be of great benefit to Canadians, even beyond the communications sector.

2.4.1 Summary of current capabilities

This 9-person team, plus a visiting post-doc researcher, combines skills in design, fabrication, processing and characterization of photonic devices. This ensemble of expertise is relatively unique and is also well-respected for its reputation in these technologies.

Some of the work is founded on processing equipment that, as in the case of ROME, is nearing the end of useful life, and continuation of those services will involve replacement of expensive machines. Also the process steps for PLC presently involve transitioning wafers back and forth between the APT and MEF labs, creating a mutual dependence that may be compounded if, as suggested by the Panel, the complete ROME activity may no longer be viable. A difference for the RPCT perspective is that the prognosis for a healthy and productive future is much more positive than for the microelectronics resources. It may still be true here that external alternatives could be found for some of the process steps that depend on costly and elderly equipment.

An additional asset of this group is the shared heritage of FBG technology, such that integrated Bragg grating devices can be usefully combined into several new functional modules, especially in the area of RF photonics and other PLC elements.

2.4.2 Risks and potentials evaluation

A detailed risk analysis questionnaire specific to the RPCT activity was completed by internal CRC staff as well as by members of the external review panel. The questions presented are reproduced in Appendix 2 of this report, and the summarised results integrating both the internal and external inputs are reproduced in Appendix 3 of this report. Because of the nature and groupings of the questions, the small sample sizes surveyed (12 on average), and the large deviations in the responses, we will limit the analysis here to consideration of those responses that averaged in at least one of the extreme high categories, i.e: involving either Significant Impact, or High Likelihood, or both together.

As regards RPCT, 3 responses were judged to be of Significant impact and high likelihood, and these are:
R1: which considers the risk that the ROME process capability will no longer meet the needs for PLC fabrication, with associated implications for collaborations and other project commitments;
R5: also fears that some key capabilities in ROME will cease to be available to RPCT.
R12: Entertains the potential that CRC may be required to adjust to new mandated objectives, which would disrupt current research and force reorganization.

R16 was felt to be of significant impact and medium likelihood, and addresses the potential recognition to be derived from collaborations involving the PLC research, and so the need to maintain the associated expertise base.

Of moderate impact but high likelihood are:
R11: risk of realignment necessitated by changing needs of CRC/SITT/Industry Canada;
F6 and F12, which both express risks associated with reductions of funding for capital or operating expenses.

2.4.3 Client base and evaluation

RPCT does report having collaborations with local SMEs such as Optiwave, OneChip and OpNext, although survey inputs came from 2 academic groups and a collaborator at NRC. These clients express high appreciation for the excellence and impact of the RPCT group contributions, and cite the facility as being unique in Canada. It appears that although there are facilities elsewhere in the world to fabricate these exploratory structures, the ability to collaborate with the expertise in the CRC team is highly-valued. One of the clients surveyed hinted that uncertainties as to the future focus of research areas may be seriously inhibiting chances of ongoing collaboration.

The Panel felt that there could be value in expanding the group's network of contacts for increased awareness of other global activities in this topic. Introductions could be made to groups in other countries, for whom collaboration with Canada and with CRC would be seen as a very positive initiative. It was also felt that possible applications for this technology could be found in making integrated optical front-ends for high-end test and measurement equipment (manufacturers such as Agilent etc.) used in the telecom arena as well as other sectors. There is an urgent need here for solutions in the 40-100Gb/s data rate range.

Existing collaborations also include work with Montreal-based EXFO, showing existing value in the test/measurement sector, but likely in a very demanding context. The group themselves pointed out that global expertise in PLC capability is advanced in entities such as Alcatel-Lucent, or NTT in Japan. A CIPI-funded project with McGill University involved industrial support from OpNext as well as Montreal start-up Avensys/ITF.

2.4.4 Evaluation of competitive position

Three primary thrust areas summarise the group's main activities:
1. PLCs for optical signal processing;
2. RF photonics;
3. Innovations in planar lightwave circuits.

Positioning is aimed more at developing optimised building blocks, rather than trying to create full customized solutions.

The group themselves pointed out that global expertise in PLC capability is advanced in entities such as Alcatel-Lucent, or NTT in Japan. NeoPhotonics (a company based in San Jose, California as well as Shenzen, China) is a 2000 employee entity focussed on technology and applications of photonic integrated circuits.

RF photonics is an emerging discipline into which some of the products growing out of CRC's FBG technology have penetrated (for example, grating-based chromatic dispersion compensation modules manufactured by Teraxion for operation at 40Gb/s). It has some overlap with the topic of microwave photonics discussed in the next section.

The Panel felt that the skills and reputation of this group are very highly regarded, but that it could be very valuable in terms of refocusing the group's objectives to pursue a series of internationally-enabled discussions exploring possible collaborations with other countries having complementary strengths in this area.

2.4.5 Potential of this activity for future impact and relevance

The group can certainly provide services/collaborations of a type that are unique within Canada, but on a global scale the impact could be more appropriately focussed through the development of new collaborations as suggested above.

Ultrafast signal processing is very elegant and potentially a powerful technique, however it is not clear that it would find application in the high data-rate core of the telecom networks. For this reason it was suggested to examine developing more application opportunities in the high speed test & measurement sector, possible through partners such as Agilent, EXFO etc.

The expertise of the group offers promise of possible innovative IP generation in this topic of integrated photonics, which may or may not relate directly to the CRC mandate of communications and defense technology.

With regard to the thrust of RF photonics, the Panel noted that this is a topic that has been struggling to make a major impact for several decades, and in spite of the ingenuity of some of the approaches, has yet to find a unique high impact application.

2.4.6 Major challenges facing this activity at this time

Probably the greatest challenge for this group since its recent reorganisation is to clarify where it can re-focus for maximum impact based on the excellence of its skillset and reputation. Photonic integration will continue to be a research and development challenge for the next decade or two, and this group is well-positioned to be able to contribute significantly to that research, however an awareness enhanced by new relationships with similar groups in other countries could greatly aid both the activity and the strategic direction of the activity.

Within that re-focussed alignment of project objectives, the group will need to evaluate how to handle its processing needs, especially if the dependence with the microelectronics group is weakened or severed by proposed changes there. Again, a greater awareness of what is available externally could help to inform those decisions.

Proposed future investments in equipment needs should be tailored according to the new definitions of development activity.

As a resource base addressing new technological combinations, a challenge for the group may be in encountering spectacular potential innovations that may not have direct impact on the CRC telecom mandate, but rather may be candidates for IPR or technology transfer to external organisations.

2.4.7 Recommendations regarding this activity

The Panel is impressed by the ensemble of capability in this group, and understands that the group enjoys a very respected reputation in academic and other circles.

Major recommendations would be:

1. as part of the ongoing process to adapt the objectives of this group in the context of its recent reorganisation, it would be valuable to explore dialogue around possible relationships with similar groups in other countries, such as: Singapore, Israel, Sweden, Finland;
2. consider a focus to develop high bit-rate integrated front-end solutions for high speed test equipment such as manufactured by EXFO, Agilent, etc.;
3. Review the RF Photonics activity to determine whether it really has an identified user sector with the enthusiasm to provide an applications pull, and if not, to decide to refocus the resources more towards other needed objectives.

2.5 Capabilities of RSS group (Microwave Photonics Activities in the Satellite Systems Division)

As a sub-group within the Satellite Systems division, the Microwave Photonics activity is a recent addition targeting applications of photonics technologies to signal processing needs at microwave frequencies. Within Canada this appears to be a unique capability, and is of interest to external clients involved in military, space, and high bit-rate optical modulation systems. This represents a good fit to the CRC SITT mandated priorities and represents an expertise with strategic significance.

2.5.1 Summary of current capabilities

In addition to the manager, this team includes 3 experienced individuals and a visiting post-doctoral fellow shared with the RPCT group. Their location within the Satellite Systems division provides a system context that is distinct from colleagues with similar interests in RPCT, where the emphasis is more at a component level. This context probably helps in supporting the external interactions with commercial clients such as COMDEV and National laboratory concerns such as CSA.

The activity is supported by a laboratory equipped with a value of approximately $500k, and operating costs for the activity are quite modest. Prior discussions on consolidating this team with similar interests in RPCT or ROCE have been resisted with the intent of maintaining the system context for this work, however the management points out that really the present incarnation of the group is below critical mass, and requires some augmentation with new personnel if it is to continue to be effective.

The activity has had some dependence on ROME for fabrication capability, but is now meeting these needs elsewhere.

2.5.2 Risks and potentials evaluation

A detailed risk analysis questionnaire specific to the RSS activity was completed by internal CRC staff as well as by members of the external review panel. The questions presented are reproduced in Appendix 2 of this report, and the summarised results integrating both the internal and external inputs are reproduced in Appendix 3 of this report. Because of the nature and groupings of the questions, the small sample sizes surveyed (12 on average), and the large deviations in the responses, we will limit the analysis here to consideration of those responses that averaged in at least one of the extreme high categories, i.e: involving either Significant Impact, or High Likelihood, or both together.

The RSS analysis considered R3 as being of significant impact and highly likely to occur, describing the risk that the fabrication facilities offered by CRC are not adequate and thus generating a need to contract out the fabrication creating delays and additional cost to the project. This tends to resonate with the observations and recommendations of the Panel.

Question P1 was rated as significant impact and moderate likelihood, and addresses the possibility that equipment breakdowns could undermine deliveries to client's expectations.

2.5.3 Client base and evaluation

Over the last several years this activity has received a reasonable proportion of its funding from external projects at CSA. COMDEV is a major Canadian commercial entity involved in equipment for space-borne systems, and has collaborated with this group in a successful way, although no funding from COMDEV has been involved.

Both CSA and COMDEV feel that the CRC team brings strategic value to their projects, and foresee the degree of involvement either being sustained or increasing. They perceive this capability to be unique in Canada and valuable in terms of the geographic convenience of the facility. The group's contribution to these clients' projects is estimated to be high in terms of impact and very high in terms of excellence.

2.5.4 Evaluation of competitive position

The Panel found it difficult to evaluate the competitivity of this group when considered in the context of a field with some considerable history but relatively modest penetration of commercial markets beyond uses such as broadband cable TV distribution. Potential applications for microwave photonics frequently seem to be compromised by non-linearities of the fibre waveguide as well as the high cost of large area module functions integrated onto semiconductor substrates.

Although previous attempts to consolidate this group within more photonics-based parts of CRC have been resisted, the sub-critical mass of the present group remains an issue, and might be advantageously solved by amalgamating some activities as part of a priority-based restructuring, and might even offer new opportunities for cost reduction, e.g; by considering PLC-type platform solutions.

2.5.5 Potential of this activity for future impact and relevance

The expressions of validity from existing clients seem to prove that this group is delivering valuable work, although it would be good if the financial support forthcoming from the outside groups could mirror the high evaluation expressed in the surveys. It was mentioned in the review that Lockheed Martin are also interested in this technology, but that a preference would be to pursue such an engagement through the intermediary of a Canadian company such as COMDEV.

It seems that if the activity does indeed have the depth of value implied by the external client assessments, then it would be appropriate to develop a business relationship where investment flowing from the company would help to sustain or even expand the operation to the necessary dimension.

2.5.6 Major challenges facing this activity at this time

The biggest challenge appears to be the marginal size of the group, which has been struggling valiantly at an understaffed level for several years. In this context it would be very timely if external clients such as COMDEV or even Lockheed Martin could express their level of interest in more financially tangible terms.

2.5.7 *Recommendations regarding this activity*

The Panel recommends:

1. Re-examine possibilities of co-locating this group with other photonics activities (such as in RPCT for example);
2. engage discussions with external clients such as COMDEV or CSA, or even Lockheed-Martin, with a view to providing some support of a more tangible/financial nature.

3 Projected potential for impact across the Photonics activity

In terms of impact potential for the CRC photonics activity, the Panel considered impacts in the following contexts:

1. Direct impact of elements of the SITT core mandate:
    a. accelerating Canada's economic growth and innovation through development of ICT;
    b. achieving excellence in policies, standards, research, regulation; and
    c. advocating on behalf of a competitive ICT industry and Canadian ICT infrastructure.

2. Impact of value to other federal organizations requiring strategically significant expertise in photonics as applied to e.g:
    a. defence-related objectives;
    b. space program projects; or
    c. national security matters.

3. Impact deriving from innovations encountered in the pursuit of excellence in photonics, which may manifest in terms of ICT or non-ICT applications:
    a. Ongoing support of clientele derived through licensing of CRC-generated intellectual property now being used in the private sector both in Canada and internationally, such is the case for Fibre Bragg Grating technology;
    b. New technologies or intellectual property rights (IPR) emerging out of CRC photonics work, for example femto-second pulse-induced grating structures;
    c. Other capabilities, discoveries, understandings that are in some way unique to the CRC photonics team, but offer potential benefit to Canadian Industry or more broadly to the Canadian people.

The following five tables endeavour to capture the intersections between the various types of impact listed above, and the main areas of activity in each of the five groups reviewed. This offers a visual tool with which to compare varying contributions to near-term ICT needs, *vs.* more strategic functions or longer-term impacts of a less-specific but nevertheless potentially useful nature.

These entries are based on data available to the Panel at the time of the review, and it may be useful for CRC to consider how many more of these intersections could be completed based on a more detailed audit of client activities specific to each group.

In most cases the check marks in these tables will correspond to items mentioned in the text discussions of each group's activity in section 2.

The Panel also recognises that many of the interactions between these groups and the external technical community serve to establish and reinforce collaborations at various levels, which although not necessarily compensated by incoming revenues can be valuable to the fabric of the interchange network of expertise within the extended photonics community.

Table 3.1: Projected potential impact for RBON group activities

	Main activities:	Reconfigurable Optical Networks	WDM Passive Optical Networks	Virtual UCLP control environment	Network Planning & Optimization	GMPLS control plane survivability
Direct SITT mandate impacts	*Accelerate ICT development*			√		√
	Policies, standards etc	√		√		√
	ICT advocacy	√	√	√	√	
Other strategic impacts	*Defence impacts*					
	Space impacts					
	Security impacts	√		√		√
Excellence impacts in or beyond ICT	*Licensed IP clientele*					
	New IP license potential					
	Other unique capabilities	√		√		√

Table 3.2: Projected potential impact for ROCE group activities

	Main activities:	Optical Materials	FBG Tech & Applications	Fibre-based components	Exploitation of fibre comp.
Direct SITT mandate impacts	*Accelerate ICT development*	√		√	
	Policies, standards etc				
	ICT advocacy	√			
Other strategic impacts	*Defence impacts*		√		√
	Space impacts				
	Security impacts	√	√	√	√
Excellence impacts in or beyond ICT	*Licensed IP clientele*	√	√	√	√
	New IP license potential	√	√	√	√
	Other unique capabilities	√	√	√	√

Table 3.3: Projected potential impact for ROME group activities					
	Main activities:	**Hybrids on thin film ceramics**	**Packaging for proof-of-concept**	**Optical packaging**	**Multi-level system-on-package**
Direct SITT mandate impacts	*Accelerate ICT development*	√	√		√
	Policies, standards etc				
	ICT advocacy				
Other strategic impacts	*Defence impacts*	√	√		
	Space impacts				
	Security impacts				
Excellence impacts in or beyond ICT	*Licensed IP clientele*				
	New IP license potential				
	Other unique capabilities	√		(√)	

Table 3.4: Projected potential impact for RPCT group activities				
	Main activities:	**PLCs for optical processing**	**RF photonics**	**Innovative Planar Lightwave circuits**
Direct SITT mandate impacts	*Accelerate ICT development*	√	√	√
	Policies, standards etc			
	ICT advocacy	√		
Other strategic impacts	*Defence impacts*			
	Space impacts	√	√	
	Security impacts			√
Excellence impacts in or beyond ICT	*Licensed IP clientele*		√	
	New IP license potential	√	√	√
	Other unique capabilities	√		√

Table 3.5: Projected potential impact for RSS group activities

	Main activities:	Wideband variable phase shifter	Tunable microwave filter	Projects on hold
Direct SITT mandate impacts	*Accelerate ICT development*			
	Policies, standards etc	√	√	
	ICT advocacy			
Other strategic impacts	*Defence impacts*	√	√	
	Space impacts	√	√	
	Security impacts			
Excellence impacts in or beyond ICT	*Licensed IP clientele*			
	New IP license potential	√	√	
	Other unique capabilities	√	√	√

Comments on the Risks/Potential opportunities questionnaire process

The questions presented for the analysis of risks and potential opportunities stimulated a broad set of responses, but in a format that renders the data somewhat difficult to analyse and correlate. For a future exercise of this nature, it could be beneficial to group the questions more closely by category of analysis and to try and ensure that they complement and balance each other in a more coordinated manner. This could substantially facilitate the interpretation of the data collected.

Implications of Projected potential

In evaluating the potential contributions of the CRC Photonics activity it is important to identify a distinct domain of operation in which the projects will address work that is not being duplicated elsewhere, particularly in the laboratories of other government facilities (such as IMS-CPFC at NRC, or NINT in Alberta). At the same time it is important to try and make sure that the CRC capability remains active in areas of strategic significance such as support to national standards definitions and technical assistance on matters of national and public security, where for various reasons it might be inappropriate to allow such activity or knowledge to be developed in an uncontrolled environment.

3.1 Implications for RBON group

The Panel does not recommend discontinuation of this activity, rather it sees value in enhancing certain aspects, such as AIRON, UCLP, and GMPLS survivability aspects, for their more distinctive value in the commercial and strategic context vs. the WDM-PON activity and to some extent the Network Planning and Optimization activity. Such an adjustment of program priorities may enable the group to establish a stronger presence within standards communities, still using the experience of existing personnel.

The Panel is also keen to encourage the instigation of more fee-paying clients for consulting services or design assistance, and potential revenue from these sources could eventually be applied to adding staff in key areas.

Based on the data provided to the panel, anticipated capital investments in the next year or two were to be aimed at equipment enhancements for the all-optical network test-bed, however since the Panel feels that this is an area where it will be very difficult for CRC to remain competitive, some savings on high cost equipment investments should be possible. Involvement on the current HSVO (Health Services Virtual Organisation) and GSN (GreenStar Network) CANARIE projects should be able to continue, with the associated revenue benefits of those commitments.

3.2 Implications for ROCE group

The strength of this activity is in the combination of near-term licensing clients and support activities built around the marketable aspects of CRC's Fibre Bragg Grating invention. The group has established a global reputation as an authority in the domain of its invention and the clientele involved provides an excellent basis for exploring deployment of ROCE's longer-term capability in having developed a new type of grating fabrication process which enables some totally novel applications, potentially beyond telecom.

According to forward plans presented to the Panel, the ROCE group is using the initial part of the next 5-year period to explore the potential of applications for the new femtosecond-FBG technology, across the domains of telecom, defence and security. These milestones include development of fibre lasers as well as silica- and sapphire-based fibre sensors, both of which represent vigorous and growing market opportunities. Other than a proposed $236k capital investment in 2009-2010 which is financed by IPR revenues, the expectations of this group are mostly contained within the existing resource base.

The overall plan appears to be conservative, but with substantial potential for an upside based on possible revenues from new technology licensing agreements. The five-year term provides an ideal opportunity to explore these new directions, which with the assistance of a proactive business development resource (recommended below) could develop into another generation of self-supported research placing Canadian technology in a prominent and valued position.

The Panel applauds the intent to purse fibre laser development, and encourages consideration of a parallel activity on fibre optic gyros for their possible benefits in the Canadian defence sector.

The planned development of high-temperature sensor technologies based on fs-FBGs in sapphire also presents opportunities for new security markets as well as geophysical exploration contexts in which Canada has major investment in the Western Provinces.

This activity seems to offer great promise and ability to build well on the excellent reputation of its previous achievements.

3.3 Implications for ROME group

This group appears to be struggling with outdated equipment that will require expensive renovation if the activity is to continue. Justifications from clients seem to be focussed on convenience and economy of the services provided rather than on the availability of something unique. Indeed, in the view of the Panel, there are other places to get this type of technology, and as such the continued existence of this group (especially with the attendant investments for equipment upgrades) is hard to justify. If there was a steady stream of revenue from clients willing to pay market value for the services provided, it might be possible to show a benefit from the convenience attributes, but given that the service provided is essentially a subsidised alternative to external capabilities, it would be more logical to rationalise this activity down to the minimum capability needed to provide unique and in-demand services.

This change could imply complications for projects in other parts of CRC, where their dependence on the conveniently local ROME services will probably translate to a more lengthy and involved procedure, especially for very small sample volumes. However it does not appear to be viable to maintain this costly activity for a very small essential clientele, and the situation is only going to get worse as more of the equipment becomes unserviceable.

For these reasons the Panel advocates a careful analysis of all the users of the ROME facilities, to determine where alternative solutions can be found, and thus decide which items of equipment can already be decommissioned. Since a portion of the ROME usage is for non-photonics assemblies, it will be important to assess the impacts on those projects, and similarly to determine the optimum route for alternative fabrication/assembly options.

Within the considerations offered to the Panel, it is clear that the ROME team has given some thought to possible scenarios involving a 'wind-down' of the activity, and an example suggested is to relocate some of the still-usable equipment to a university or NRC lab, where possibly usage could be shared with other resources and operational overhead costs. Possible outcomes of this nature should be part of the scenarios presented in the analysis of these facilities. Even so, the emphasis in processing lines is trending increasingly towards the need for reproducibility, which typically comes with full line loading and up to date maintainable equipment.

Any implications for the redeployment of skilled staff involved may also need to be addressed in terms of possible comparable positions at other processing lines in Ottawa or at government laboratories elsewhere in Canada.

3.4 Implications for RPCT group

The Panel's conclusions regarding this activity were firmly positive in terms of the group's ability to research and develop innovative solutions based on integration of photonic functions. The subject is still developing and has a rich future of potential discoveries to be made, many of which could align with key aspects of CRC's mandate. However the Panel also felt that there would be great value in exploring some focussed collaborations with compatible labs in other countries, so as to maximise the originality and impact of the projects pursued at CRC, with additional benefits of flow-through of needs to other areas. Members of the Panel are willing to make the necessary introductions to facilitate exploration of these possible international connections.

As an example of where integrated photonic functions could offer performance and cost advantages of value to the telecom industry, the Panel envisaged possible collaborations with high-end test and measurement equipment manufacturers, where an integrated combination of optical detection functions with local signal processing might enable improved resolution instrumentation.

The Panel was less willing to be decisive regarding the RF photonics activity, and suggests that, in conjunction with the microwave photonics activity in the RSS group, it would be timely to review the potential user demand for those activities, with a possible view to consolidating them.

Given the recommendations with regard to the ROME activity, the Panel is conscious that some significant adjustment of fabrication methods used by RPCT will be needed, given the degree of resource and equipment sharing between the two groups. Forward-looking plans for RPCT anticipate some significant expenses in the near future for processing tools (e.g: $350k for an e-beam evaporator) to replace aging equipment in ROME. If as suggested above, external ways to provide those services can be found, then this major expense might be avoided. Proposed major expenses in 2012/13 ($250k optical DSP for 40-100Gb/s characterization) should be not necessarily dismissed, but reviewed in the light of:
a) new possible collaboration topics determined from the international search; and
b) the prevailing state of core network activity at that time.
Other major budget items earmarked for maintenance and equipment repairs should also be reconsidered if a shift is made to more externally-based fab/assembly processes.

3.5 Implications for RSS group

This very concentrated activity (3 employees) addresses a fascinating cross-disciplinary topic, concerning the possible benefits of signal interchange between electronic and optical waveguides. Since this appears to be one of the few Canadian groups working in this area (others include Prof Jianping Yao at uOttawa, and Prof Raman Kashyap at Polytechnique Montreal) and since the client base surveyed expresses strong support for the CRC work, it should be concluded that there is value in sustaining the activity.

The particular client base surveyed commented on the value of this group's work in applications of a strategic nature (space-borne and military equipment) which are less appropriately pursued in the less-controlled domain of a university lab, further emphasising the need to sustain this activity at CRC. However the isolated nature of this group and the fact that it is currently staffed sub-critical mass, with potential client projects on hold, suggests strong potential to rationalise the microwave and RF photonics activities within a single management structure, with the possibility of then applying more resources to the apparently viable and potentially lucrative needs of existing client projects. It was mentioned that more potential interest exists in the defence client sector, and a consolidated team might be better positioned to respond to such needs.

The team involved in this work appears to be highly productive and well respected, and is successful in attracting external financing towards its work. A challenge here is that the timescales for developing microwave photonics systems are somewhat protracted, and a few more years' work may be necessary before the true benefits are evident. Nevertheless, this type of work fits well to the mandate of CRC in respect of technologies with strategic potential, and within the 5-year planning window of CRC this is the type of project that should be seriously considered, since developments of this nature and scale are unlikely to happen in academia.

4 Panel recommendations

Recognizing the challenge of sustaining a strategic photonics activity within CRC, it might be useful to compare the operating model with similar organizations elsewhere. A similar intent is fulfilled to some extent by the inevitably much larger US-based Telcordia organization in New Jersey. Telcordia grew out of the BellCore activity that was a standards-oriented entity. Current staff at Telcordia frequently have multiple roles, being simultaneously academic staff at nearby universities, and in some cases having a parallel existence within strategically-focussed groups such as NSA (National Security Administration) where their expertise can be applied to consultations on matters of a highly confidential nature. Telcordia succeeds in maintaining a high level of visibility and excellence through participation at conferences, in working groups, and in some cases by letting contracts and collaborations, with the intent to transfer or encourage the incubation of new promising technologies. It also houses the expertise to provide contract consulting services to corporate sector clients, as well as licensing out intellectual property emanating from some of the longer range projects in progress within Telcordia. (see for example: www.telcordia.com/innovation/research/fy09-strategic-research-program_rpt.pdf). In the UK Qinetiq, which was previously the ensemble of national defence research establishments, has progressively migrated towards a similar combination of strategic in-house expertise and high-calibre revenue-generating consultation services, while still maintaining a framework able to respond on matters of national significance.

The CRC photonics activity shares many of the same intents as Telcordia, albeit on a smaller scale, and one key aspect of the uniqueness of the work at CRC is that it can address topics requiring a longer timescale of consideration than is normally tolerated in commercial laboratories. This special attitude (e.g. a five-year window of operational objectives) affords a special advantage that CRC management should strive to protect, since it is the type of context that can give rise to far-reaching discoveries such as the original Fibre Bragg Grating technology, and its emerging successor based on femto-second IR pulses.

With the recent demise of large industrial R&D labs in Canada, there is virtually no long-term research of a focussed nature happening in the country's commercial sector, and surprisingly the academic sector has also tended to foreshorten its timelines of interest into zones that appeal to the near-term needs of possible industry partners who could provide matching funding or support letters to grant applications. Work on photonics at the National Research Council (for example the Ultrafast photonics lab at the Steacie Institute, and the CPFC at IMS) provide good examples of long-range and pre-development work respectively, and it is valuable to ensure that the CRC activities continue to complement rather than compete with groups such as those.

General recommendation: Pro-active Business Development for Photonics capability.
The Panel feels that the powerful expertise set contained within the CRC Photonics groups could help to offset the costs of its existence by developing more opportunities for revenue-generating consulting services to external organisations. A path to identifying revenues of this nature could be developed by assigning a sales/marketing type of resource to pro-actively connect with the community of photonics users, and simultaneously:

- pursue new possible markets for CRC-generated IP;
- pursue opportunities for consultancy services based on the CRC photonics expertise;
- establish involvement in standards activities at which CRC subject matter experts would be key participants;
- collect information on market status, developments and needs, with which to help orient activities and longer range planning of the CRC activities.

The Panel's view was that a single skilled individual reporting to the VP level could establish a valuable presence in the community where these objectives would take seed (Photonics, Optics conferences, standards meetings, discussion groups etc) and provide a bi-directional role of promoting new business revenues as well as bringing back valuable information on market needs etc.

Group-specific recommendations (detailed earlier in section 2 of the report).

RBON group recommendations (see section 2.1.7):

1. Discontinue the WDM-PON activity;
2. minimise or discontinue the Network Planning and Optimization activity;
3. refocus available resources towards AIRON and UCLP activities (plus GMPLS survivability) and get more actively involved in standards, strengthening work on cyber-security;
4. by being informed on strategic aspects of communications infrastructure, be able to advise and support SMEs and other industry players;
5. target more paying clients for services rendered. Develop role with CANARIE and dialogue with major Canadian service providers;
6. Sustain but refocus this activity.

ROCE group recommendations (see section 2.2.7):

1. Do not abandon this technology even if telecom usage falls off;
2. explore other possible resonances with the mandate and beyond telecom;
3. aggressively pursue licensing possibilities for the fs-FBG technology for potential revenue generation;
4. continue to explore fibre lasers and additionally look at fibre optic gyros and other fibre sensor-type applications including technology licensing and transfer opportunities;
5. patiently explore the wide range of potential applications for this capability;
6. establish vigorous dialogue with existing FBG licensee community regarding new opportunities;
7. Sustain this activity.

ROME group recommendations (see section 2.3.7):

1. Audit the internal capabilities and needs vs. commercially or externally-available alternatives;
2. if necessary sustain a minimal part of the activity to meet any needs not obtainable elsewhere;
3. target closure of most of this activity and thereby reduce the additional financial obligations of operations, equipment maintenance, renewal and

replacement;
4. if necessary maintain a low cost capability for printed electronics.

RPCT group recommendations (see section 2.4.7):
1. Use Panel introductions to explore collaborations with similar groups in Singapore, Israel, Sweden and Finland;
2. develop possible solutions for integrated front-end units in high speed test and measurement equipment;
3. review the RF photonics activity and examine options to consolidate with the RSS-based microwave photonics group;
4. Sustain this activity.

RSS group recommendations (see section 2.5.7):
1. Re-visit option to consolidate this sub group with similar skills in RPCT;
2. pursue more financially supportive interest from external clients such as COMDEV, CSA and Lockheed-Martin;
3. Sustain this activity.

5 Summary

The Review Panel was impressed by the calibre of the work presented, and especially by the objectivity of the managers in their presentations and self-assessments. In particular, the Panel would like to commend Dr Bérubé for his openness in arranging and coordinating the review process. The insistence on a forward-looking focus made this a healthy and valuable exercise and enabled the Panel to project more decisive conclusions regarding the potential value of the various activities.

It is acknowledged that some perceptions of the role of CRC's photonics activity may differ from its actual mandate, and this can create some challenges as regards to content choices. The CRC lab is seen by many as 'a government lab that should be doing things not getting done elsewhere, especially if they have some 'strategic' value' as opposed to the more focussed SITT mandate for telecom, defence, security etc. Given the special timeframe (5 years) allowed to planning at CRC (which the Panel applauds) CRC has a type of autonomy to tackle some areas that other labs cannot, and these can range from more complex applications such as optical signal processing, to basic research such as fs-pulse induced changes of optical properties.

Within the types of work that this timeframe allows, there will arise some brilliant ideas and innovations that, though they may ultimately have applications not within the standard SITT remit, will nevertheless be valuable technologies that can benefit other aspects of Canadian society or industry. The Panel would therefore like to encourage a climate that is able to nurture this breadth of innovation, with the option to later transplant the seedling developments into an environment where they can flourish.

Canada is extremely rich in photonics technology expertise, as witnessed by the breadth and depth of topics covered in this review. However, in comparison to other countries with much more extensive national laboratory resources, Canada has to be very selective in which topics it can cover, and the Panel has tried to assist that selectivity, even though it may mean truncating some activities that still have inherent value.

The overall assessment suggests that, by some adjustment of project content, this photonics activity at CRC can be positioned for a further period of innovative contributions that will not only support the national position in terms of policy, security, and regulatory aspects, but will also generate collaborations that can encourage new entrepreneurial activities in a technology domain that will transform our lives over the next few decades.

Appendix 1: Questions used for on-line survey of CRC clients

1. Was the outcome of your involvement with the CRC team of strategic value to your organization and/or to Canada in any way? [Yes/No/please explain]

2. Does your involvement include payment contributions (cash and/or in-kind) to the CRC group for: [Yes/No]
   a) services,
   b) samples,
   c) software,
   d) advice/research conclusions, or
   e) other (please explain if yes).

3. If this CRC capability was not available to you, where would you have to go for comparable help?

4. How do you see this involvement developing over the next few years?
   a) potentially increasing,
   b) potentially decreasing,
   c) likely to stay about the same,
   d) don't know.
   e) other (please specify)

5. What is your view of the capability of the CRC team with which you are or have been involved:
   a) Not unique;
   b) Not unique but geographically convenient;
   c) Not unique but economically convenient;
   d) Unique in Canada;
   e) Unique in the world;
   f) Other (please specify).

6. Please tell us how you rate the following from previous contributions from the CRC team:
   a) Excellence of the contributions (rank 1 (low) to 5 (high));
   b) Impact on your requirements (rank 1 (low) to 5 (high));
   c) comments:

7. Please tell us how you rate the impact on your work of anticipated future contributions from the CRC team: (rank 1 (low) to 5 (high));
   comments:

Appendix 2: Question sets presented as risk analysis.

The questions sets listed below were compiled for each group reviewed, and were completed both on behalf of the groups themselves, as well as by members of the external Review Panel. The overall responses to the questions are summarised in Appendix 3, and discussed in the text of the report.

RBON QUESTIONS:

	Risk	Impact			Likelihood			Comments
		Low	Medium	High	Low	Medium	High	
P	**Labs and Equipment Risks (Labs/Equipment)**							
1	Risk that changes in government regulations could affect current lab configurations (safety standards)							
2	There is a risk of downtime and lack of output due to equipment failing. This risk is enhanced by the age of the critical pieces of equipment.							Proper maintenance can help prevent this and support contracts with advanced replacements can mimize the downtime. Replacement of aging equipment should be identified in the capital plan.
3	There is a risk of conflict between research groups and employees over shared resources and lab space							Anytime there is a limited resource, there is potential for conflict
4	There is a risk of capabilities not easily integrating with other CRC research groups and other communication technologies							Since the majority of our work is focused on optical based communications, it does not always integrate with other research groups working in other fields
5	There is a risk that lack of space could affect future equipment and testing capabilities. Any changes have to be made with space requirements in mind.							
6	There is a risk that power failures or accidents could damage expensive equipment							Random power failures have happened before causing downtime and costing money to repair
R	**Research Program Management Risks**							
1	There is a risk of CRC/SITT/Industry Canada needs changing and current CRC research not fitting into the plans for the future							The demands of SITT/Industry Canada can always change
2	There is potential that CRC will be asked to take on a new driving project/focus, which would disrupt current research forcing a re-org and re-task							The demands of SITT/Industry Canada can always change
3	There is a risk that lack of contribution to the scientific community through papers, collaborations, conference attendance will limit recognition and research losing peer respect from Industry							Unlike companies, the government is judged not only by products manufactured but by other factors such as efficiency, peer recognition of excellence and reputation
4	There is a risk that by not staying aware of industry trends, CRC's awareness of emerging technologies will be lost							
5	There is risk that current research and focus will be dramatically adjusted depending how CRC is realigned within SITT/Industry							
6	There is potential for cost recovery through intellectual property(IP) generation							With new technologies come intellectual property and business development. Potential is diminished as technology advances.
7	There is potential that current knowledge and expertise will continue to produce high quality research in whatever direction given							CRC has a well established reputation with knowledgeable staff over a broad range of communication technologies. It is a valuable asset for SITT.
8	Risk of being unable to meet the CRC mandate to "meet key technical challenges of the 21^{st} century for the knowledge-based economy"							If for some reason, we are unable to meet CRC's existing mandate it could have negative consequences. Moderate risk as current facilities and equipment are aging.
9	There is a risk of current technologies not staying relevant with changing technologies necessary for the realization of emerging communication systems							
10	There is a risk that current capabilities will be affected through health or other issues with staff. Some capabilities are limited to only one employee							
F	**Financial/Personnel Risks**							
1	There is risk with collaborations that their demands or need can change independent of our control A downturn in an industry, government financing, change in abilities can lead to changes in numbers and quality of collaborations.							If outside collaborations become a focus, results can be tied to factors beyond our control such as NSERC funding. These changes are usually slow and can be predicted as they are tied into funding cycles which are easily monitored
2	There is a risk current budgeting will be changing in the future							What we can or cannot do is directly affected by budgeting from Industry Canada. Since what we get or do not get is out of our control, there is not much we can do except make the most of any opportunities
3	There is a risk of yearly budgets being adjusted throughout the year							We have seen this before and needs to be managed accordingly.
4	There is a risk that power failures or accidents could damage expensive processing equipment							Random power failures have happened before causing downtime and costing money to repair.
5	There is potential that capital money will be made available for the replacement and purchasing of processing equipment							Capital money seems to appear at random intervals depending on external departments
6	There is a risk of capital funding for new or replacement equipment will not be available							Capital money seems to appear at random intervals depending on external departments
7	There is a risk that the current capital plan does not adequately prepare for future requirements							Since the money appears to come randomly, how it is awarded is not always tied directly to any program or desire to develop research abilities
8	There is risk in that any new capital is typically difficult to spend due to purchasing time frames and regulations							Many times required equipment cannot be bought within the allotted time frames. In recent history, capital money has not been allocated until the late fall or winter.
9	There is a risk that even though capital plans are in place, purchases are not according to needs instead they are done by what fits the money at the time.							Depending on allotment sizes and time frames many smaller pieces of capital equipment are bought instead of high need high cost items
10	There is risk in having capital money to buy equipment but no planning as to the associated costs for maintaining and supporting the equipment over time							Capital money is sometimes awarded but not always with consideration to the costs to maintain and support the equipment

11	There is a risk that decreasing budgets could lead to shortages in parts for equipment and limit ability to perform experiments							Use end of year money to stock up on parts, pump kits etc. Prepare lists of necessities
12	There is a risk that costs to run various programs and facilities will continue to increase							When faced with increased costs and fixed or decreasing budgets, the programs will have to be scaled down
13	There is a risk of losing personal due to other factors such as career change, sickness, or new employment							There is always a risk of losing staff for a variety of reasons
14	There is a risk of current staffing arrangements changing due to realignments or reorganization within CRC/SITT/Industry Canada							
15	There is risk within HR/Staffing. The ability to easily staff positions is very low under current conditions. Groups could be understaffed in a hurry if people were lost							If people did leave for whatever reason, the ability to restaff in a short period of time is not very good
16	There is a risk that employee motivation and desire will have direct affect on the amount of research being performed							Uncertainty and change can have a negative affect on peoples motivation
17	There are risks that moral (see employee survey results) and confidence in management will decrease with continuing lack of direction, decreasing budgets, confusion and speculation as to CRCs future position withing SITT/Industry Canada/Government of							
18	There is a risk of staffing changing due to retirement							Retirement within CRC is a risk. The retirement of existing staff is of higher impact as staffing position is currently difficult and the trend recently is to not restaff the positions of the people leaving.

ROCE QUESTIONS:

	Risk	Impact			Likelihood			Comments
		Low	Medium	High	Low	Medium	High	
P	**Processing,Labs and Equipment Risks (Labs/Equipment)**							
1	There are health and safety risks associated with having labs with high pressure gas-based and solid state-based high optical power laser systems							Risks are mitigated with training, use of eye protection, proper facilities, gas detection, emergency Response Team (ERT) team and other safety procedures.
2	There is a risk to equipment condition and health and safety issues if certain house services are lost or interrupted for a significant period of time							An important example of risks due to poor infrastructure is the failure of the ventilation system in the old 2B labs which resulted in the shut down of the excimer laser facility 5 years ago. Failure to repair the existing infrastructure due to cost, discovery of asbestos, and impending opening of the New Photonics Building, has had a serious impact on the unit research program. Some capabilities have been recently restored in other lab spaces but full capacity cannot be realized until the New Photonics Building is opened. There is a further risk to fs-laser system if uninterrupted power is unavailable
3	There is a risk of downtime and lack of production due to equipment breakdown.							High powered laser systems are complicated pieces of equipment. Increased maintenance and proper procedures are required inorder to reduce the impact of equipment breakdown. Vendor servicing of equipement is xpensive but also time consuming as work orders and parts need to be processed through PWGSC because of the cost. This has resulted in significant extensions of downtime and lack of production
4	There is a risk that the new building 2E will never be fully brought up to original specifications							Vibrational specifications need to be similar to the existing building 2B labs, ventilation needs to be functional, noise reduction would be nice but is not essential
5	There is a risk that during repairs of building 2E, damage could occur to equipment located in the labs and offices.							Equipment will be moved out where possible, will be enclosed in boxes by the site carpenter where not possible
6	There is a risk that power failures or accidents could damage expensive processing equipment							Random power failures potentially can damage equipment. Important equipment where this could be a problem are connected to Uninterrupted Power Supplies (fs laser, cryogenic freezer) and site generators. There is an issue if site generators go offline for any reason (ex. Thursday Feb. 25)
7	Further delays to Building 2E could result in damage to existing equipment							4 of 5 excimer systems have been in storage for 5 years. Potential that refurbishment of lasers will be needed. Costs unknown, original purchase price of stored equipment ~$600K. Meter long stage may need refurbishment (upto ~$50K)
								Presently forced to operate fs laser in overcrowded lab in 2B. Heat load in room is too large for HVAC to handle. Although airconditioning units have been installed, it is still a problem. Sustained operation of the laser in this environment will reduce the lifetime of the system according to the manufacturer. Original purchase price of the unit ~$950 K
R	**Research Program Management Risks**							
1	There is risk that CRC will loose its world class research status in photonics through lack of resources, realignment with SITT priorities; be overtaken by competitors							Presently CRC is the world leader in, for example, fs-laser generated gratings and their applications. Traditional entry barriers to the approach of fs-grating fabrication have been overcome due to reduction in costs and improved reliability of fs laser systems. Several other research groups around the world are now devoting considerable resources to catch up. We will loose our leadership in this area if resources are further cut or if forced to realign with SITT priorities other than supporting SME's
2	There is risk that any outsourcing of fabrication could result in factors outside of our scope of control directly affecting project timeliness.							Depending on the supplier, delivery time and quality or returned work could affects our research and we would have no direct control of these factors
3	There is a risk of current technologies not staying relevant with changing technologies necessary for the fabrication of emerging communication based devices.							Research program focused on fundamentals as well as development and licensing of next generation technology. Interaction with industry ensures that technology maintains its relevance

4	There is a risk that current capabilities will be affected through health or other issues with staff. Some capabilities are limited to only one employee							No critical capability is localized to a single individual. Redundancy of skills is maintained within the unit.
5	There is risk that current research and focus will be dramatically adjusted depending how CRC is realigned within SITT/Industry Canada							Value of research program being demonstrated by its excellence and for its support to Canadian SME's
6	There is a risk that lack of contribution to the scientific community through papers, collaborations, conference attendance will limit recognition and research losing peer							Research excellence of the unit is recognized externally through publications, patents, collaborations with and technology transfer to industry.
7	There is potential in continuing to provide excellent research and expertise on optical based communication technologies							A major focus of the research program is the fabrication of optical components for networks
8	There is a risk of CRC/SITT/Industry Canada needs changing and current CRC research not fitting into the plans for the future							The demands of SITT/Industry Canada can always change. Research has been demonstrated time and again to support Canadian SMEs
9	There is potential that CRC will be asked to take on a new driving project/focus, which would disrupt current research forcing a re-org and re-task							The demands of SITT/Industry Canada can always change. Reallocation of effort from areas where we are world class to areas where we are marginal will result in the loss of our world class status.
10	There is potential for cost recovery through intellectual property(IP) generation							With new technologies come intellectual property and business development. The fibre bragg grating patents are a perfect example of this. Potential is diminished as facilities age and technology advances. Establishment of tech transfer/incubation lab for ultrafast FBG could generate licensing and contracting-in revenues
11	There is potential that current knowledge and expertise will continue to produce high quality research in whatever direction given							CRC has a well established reputation with knowledgeable staff over a broad range of communication technologies. It is a valuable asset for SITT. Realignment of research away from where ROCE has made a significant impact will force us to play catch up with the rest of the world rather than the other way around. It will be much more difficult to be impactful.
F	**Financial/Personnel Risks**							
1	There is risk with collaborations that their demands or needs can change which is independent of our control A downturn in industry, government financing, change in abilities can lead to changes in numbers of clients and quality of collaborations.							Strength of the market will impact on the willingness of industry to purchase custom prototypes or license new technology. Creating a high profile for the technology through publications, conference attendance and marketing is important
2	There is a risk current budgeting will be changing in the future							What we can or cannot do is directly affected by budgeting. It is therefore imperative to identify funding sources, either OGD's or industrial partners willing to fund/license the innovations generated by the research
3	There is a risk of yearly budgets being adjusted throughout the year							We have seen this before and needs to be managed accordingly.
4	There is potential that capital money will be made available for the replacement and purchasing of new equipment							Capital money seems to appear at random intervals depending on external departments, making it difficult to plan effectively. Typically this is managed by having reasonably up to date quotations from vendors so that if money comes available is can be rapidly purchased, especially if it is on standing offer. It is more difficult to do this in a timely fashion if the acquisition needs to be processed by PWGSC
5	There is a risk of capital funding for new or replacement equipment will not be available							This could have a high impact as much of the equipment in the ROCE unit is middle aged (assuming a 20 yr lifetime)
6	There is a risk that the current capital plan does not adequately prepare for future requirements.							New developments often require acquisition of new capital equipment in order to maintain a state of the art laboratory.
7	There is risk in that any new capital is typically difficult to spend due to purchasing time frames and regulations							This has been mitigated as best as possible by having reasonably up to date quotations from vendors with equipment on standing offer so that when funds become available, equipment can be purchased in a timely manner. Unfortunately many of the equipment vendors do not have prenegotiated contracts (standing offers) with the federal government therefore equipment acquistions become much more time consuming because of PWGSC procedures and priorities making acquisitions sometimes impossible
8	There is a risk that even though capital plans are in place, purchases are not according to needs instead they are done by what fits the money at the time.							Depending on allotment sizes and time frames many smaller pieces of capital equipment are bought instead of high need high cost items.
9	There is risk in having capital money to buy equipment but no planning as to the support equipment, staffing and associated costs to run the equipment							Capital money is sometimes awarded but not always with consideration to the costs to maintain and operate the equipment. Consumable and maintenance costs for all the ROCE unit's high powered laser systems would be larger than the unit O/M if all systems were operating at their full capacity
10	There is a risk that decreasing budgets could lead to shortages in parts for equipment and limit ability to perform							Use end of year money to stock up on parts, pump kits, laser gases and optics etc. Prepare lists of necessities
11	There is a risk of costs to run various programs and faculties will continue to increased							Laser consumables, fiber optics and maintenance cost are rising. Some cost are recovered from contracting-in
12	There is a risk of losing personal due to other factors such as career change, sickness, or new employment							In the present environment, there is not much risk in loosing staff to industry. When the photonics industry turns around that will no longer be the case. To reduce the risk, technical expertise is shared leaving no individual in sole ownership of a specific capability
13	There is a risk of current staffing arrangements changing due to realignments or reorganization within CRC/SITT/Industry Canada							If the unit staff is halved, the research program will focus on its successes and tech transfer capabilities, if the unit is doubled, tech transfer capabilities will be expanded and markets developed along with expansion of the fundamental research program
14	There is risk within HR/Staffing. The ability to easily staff positions is very low under current conditions. Groups could be understaffed in a hurry if people were lost							The ROCE unit has been relatively stable, however it has been difficult to restaff vacancies due to budgetary considerations over the last couple of years. Issues from HR are minimal

15	There is a risk that employee motivation and desire will have direct affect on the amount of research being performed							Research within the unit is deadline driven. Financial incentives exist for the performance of contracting-in and licensing of technology.
16	There are risks that moral (see employee survey results) and confidence in management will decrease with continuing lack of direction, decreasing budgets, confusion and speculation as to CRCs future position withing SITT/Industry							This has not had a direct impact on the moral of the ROCE unit to my knowledge
17	There is a risk of staffing changing due to retirement							There is little risk of a member of the unit retiring within the next 5 years.

ROME QUESTIONS:

	Risk	Impact			Likelihood			Comments
		Low	Medium	High	Low	Medium	High	
P	Processing,Labs and Equipment Risks (Labs/Equipment)							
1	There is a risk of a toxic gas leak causing injury to personnel, environmental impact and embarrassment to the government							Risks are mitigated with training, standard operating procedures, proper facilities, gas detection, Emergency Response Team (ERT) protocols and other safety procedures.
2	There is a risk of a chemical spill causing injury to personnel							Quantities of chemicals in use at any given time are low, so spills are usually small and easily managed.
3	There is a risk of chemical spill or non-toxic gas release causing environmental impact and embarrassment to government							Risks are mitigated with training, standard operating procedures, proper facilities, gas detection, Emergency Response Team (ERT) protocols and other safety procedures. Quantities of chemicals in use at any given time are low, so spills are usually small and easily managed.
4	There is a risk of miscommunication between site services and lab personnel in regards to maintenance and lab access that could result in injury to personnel or damage to equipment							New communication procedures are being developed to mitigate this risk.
5	There is a risk that accidents or loss of site services (power failures, loss of nitrogen, vacuum, de-ionised water, etc) could damage expensive processing equipment or pose health and safety risk to personnel							Random failures have happened in the past, causing downtime and costing money to repair. If damage is extensive, important capabilities may be lost unless capital funding is made available to replace the equipment
6	There is a risk of downtime and lack of production due to equipment malfunction. This risk is enhanced by the age of critical pieces of processing equipment							This is mitigated by appropriate preventive maintenance, adequate funding and proper procedures
7	There is risk of equipment going out of calibration to affect process results such that process requirements are not met							As equipment and facilities age, calibration is increasingly difficult to maintain. This leads to poor process repeatability and may impact our ability to maintain the process capability.
8	There is potential that technological shifts could render process capabilities that were previously developed for other users in the recent past to become important to industry again							Process knowledge is maintained by process documentation, run sheets and institutional memory.
9	There is risk that changes in federal governmental regulations could force changes to lab operations and operating procedures							Changes in regulations may require additional funding to meet the requirement of more stringent health and safety procedures. Where additional funding is not available, resources must be shifted from other projects.
10	There is risk that limitations in lab space could affect our ability to incorporate new process capabilities							When plans are made for new equipment, the planning process must define the anticipated location to ensure that space is available for the equipment before making commitments to use it. This may mean removing older equipment to make room for new.
R	Capability and Process Management Risks							
1	There is a risk that poor communication between clients and Facility management may prevent client needs from being anticipated early enough to adequately address the needs in a timely manner.							Better communication and documentation with clients regarding future process needs would better integrate and align the facility within CRC and other client needs
2	There is a risk that processing capabilities do not keep pace with client needs							Limitations in equipment, manpower and funding prevent us from upgrading and documenting process capabilities. Current client demands can be met with existing resources but resources may not be available to address new requirements
3	There is a risk that processes previously developed for clients may not be easily repeatable or reproducible when they are needed.							Many processes are developed for one-off client requests to evaluate proof of concept devices on a 'best effort' basis; these process requirements are often not repeated. As a result, process development stops when the process is deemed 'good enough' rather than fully developed and documented.
4	There is a risk that increases in client needs could create a workload that exceeds the capacity of staff to address requirements in a timely fashion. This will create delays in research programs of all Facility clients.							For example heavy device assembly, external client startup companies, or CRC budget changes forcing groups to have work more completed in-house.
5	There is a risk that current demands and needs for facilities will change as CRC's mandate and position within SITT changes.							While reviews of all research programs are underway, the programs at CRC that make use of the MEF capabilities (particularly the photonics research) are being closely examined. The outcome of this review and resultant changes in client direction will have a strong impact on the future role of the facility.
6	There is potential in purchasing or developing technologies unique to CRC, which then assist MEF clients in their research							New technologies and capabilities can sometimes bring in collaborations and clients. CRC may be positioned to offer a mix of capabilities that is unavailable at any single location elsewhere, to the benefit of Canadian industry.

7	There is risk of day to day variation in process results due to personal issues							Many fabrication processes rely on the talents of skilled technologists rather than automation and control for success. Success is dependent on the technologist performing the required task in exactly the same way each time. Thus, results may be subject to vagaries of personal issues affecting the technologist's behaviour.
8	There is potential for taking advantage of process flexibility not available to industrial fabrication facilities to adapt processes to meet new requirements							Where fabrication processes rely on skill of operators rather than automated processes, there is greatly increased flexibility for modifying process conditions, materials and techniques as needs warrant. This flexibility allows the MEF to address many process requirements that would not be possible in an industrial setting.
9	There is a risk that current capabilities will be affected through health or other issues with staff. Some capabilities are limited to only one employee							This can be mitigated through cross-training of staff.
10	Risk of being unable to meet the CRC mandate to *"meet key technical challenges of the 21st century for the knowledge-based economy"*							Many combinations of other documented risks with lesser impacts (any process, equipment, personnel or financial aspects) could cumulatively result in the perception that the Microelectronics Facility contributes to preventing client researchers from meeting CRC's mandate. This would cause embarrassment to management and the government, to the detriment of Facility staff and clients.
F	**Financial/Personnel Risks**							
1	There is risk that the demands, needs or capabilities of collaborating partners can change independently of our control. A downturn in an industry, government financing, change in abilities can lead to changes in numbers, effectiveness and quality of collaborations.							Where we are dependent on outside collaborations for key processes, results can be tied to factors beyond our control. Some of these changes are slow and can be predicted (as they are tied into funding cycles which are easily monitored). Industrial collaborations are subject to changes in management priorities, which in turn are dependent on market forces.
2	There is a risk that budget allocations will change in the future							What we can or cannot do is directly affected by budgeting from Industry Canada. Since the funding we receive or do not receive is outside of our control, there is not much we can do except make the most of any opportunities.
3	There is a risk of yearly budgets being adjusted throughout the year							Mid-year adjustments to budgets make it difficult to plan effectively for the year.
4	There is potential for cost recovery through contracting-in or generation of Intellectual Property							and component prototyping services that are available for contracting-in, resources (availability of staff and equipment) permitting.
5	There is potential that capital money will be made available for the replacement and purchasing of processing equipment							Capital money seems to appear at random intervals depending on external departments. Where capital funding is made available with sufficient time to acquire relevant capital assets, this can represent an opportunity to improve and upgrade capabilities.
6	There is a risk that capital funding for new or replacement equipment will not be made available							Availability of capital funding seems to be dependent on political whim rather than proper financial planning of priorities and requirements. Many items deemed urgent on the 5-year capital plan have been listed for over 5 years. As equipment ages or becomes technologically obsolete, capabilities are lost when the equipment is not replaced. Lack of capital funding prevents us from acquiring the capabilities deemed necessary to address emerging technological needs.
7	There is risk that new capital may be made available but that purchasing rules prevent us from taking advantage of the opportunities.							Often, capital funding is released in a timeframe where it is impossible to acquire process equipment (which often requires lead times of 12-14 weeks to manufacture and deliver). In recent history, capital money has not been allocated until the late fall or winter, too late to pass the many hurdles required of government purchasing regulations for capital assets. As a consequence, opportunities for capital upgrades are allocated on the basis of what can be delivered within the limited time frame available rather than to operational priorities.
8	There is risk in having capital money to buy equipment but no planning as to the support equipment, staffing and associated costs to actually run the equipment.							When capital funding is made available for the purchase of equipment, increased O&M funding is not provided to cover the costs of installation, training of staff and running costs of the new asset. This prevents us from taking full advantage of the capability represented by the new capital asset.
9	There is a risk that decreasing budgets could lead to shortages in parts for equipment and restrict process capabilities							Lack of funds for required supplies and appropriate maintenance causes equipment – and process capabilities - to degrade.
10	There is a risk that costs to run various programs and facilities will continue to increase							With changes in the transportation laws and the reduction of semiconductor research within Canada, the availability of certain chemicals/lab supplies is decreasing and costs increasing. Where lab equipment is aging, costs to repair and maintain it constantly increase, especially when equipment nears the end of its projected life and parts become scarce.
11	There is a risk of losing personnel due to factors such as career change, sickness, retirement or new employment							Staff turnover inevitably causes delay to programs as processes dependent on the skill of operators must be re-established and institutional memory is lost.
12	There is a risk of current staffing arrangements changing due to realignments or reorganization within CRC/SITT/Industry Canada							This may represent opportunities for either growth or decline in services, depending on the priority placed upon associated research goals.

13	There is risk within HR/Staffing. The ability to easily staff positions is very low under current conditions. Groups could be understaffed in a hurry if people were lost							Institutional pressure to maintain a limited, fixed number of FTE positions within CRC creates pressure not to restaff vacancies to gain flexibility in realigning staff to new priority areas.
14	There is a risk that employee motivation and desire will have direct affect on the amount of research being performed							Uncertainty and change and can have a negative affect on peoples motivation.
15	There are risks that morale (see employee survey results) and confidence in management will decrease with continuing lack of direction, decreasing budgets, confusion and speculation as to CRCs future position within SITT/Industry Canada/Government of Canada							Low morale causes loss of productivity and laissez-faire attitude towards research and institutional goals

RPCT QUESTIONS

	Risk	Impact			Likelihood			Comments
		Low	Medium	High	Low	Medium	High	
P	Processing,Labs and Equipment Risks (Labs/Equipment)							
1	There are health and safety risks associated with having labs with chemical and gas based processes							Risks are mitigated with training , proper facilities, gas detection, emergency Response Team (ERT) team and other safety procedures.
2	There is a risk of conflict between research groups and employees over shared resources and lab space.							Interdependencies based on historical lab set up and clients. Need for review of responsibilities and optimization for current and future needs.
3	There is potential that new developments and improvement in processing supplies such as gas quality could lead to corresponding improvements in materials and devices							While this could happen, it's not ground breaking nor confined to CRC only. Anyone buying new material would benefit from the same improvements.
4	There is a risk new transportation of dangerous goods regulations will continue to affect supplies of processing chemicals, potentially increasing costs and/or limited availability of essential chemicals and gases.							This risk is associated with the dangerous and toxic gases/materials used in the MOCVD lab, closely followed by the processing gases used in the APT lab.
5	There is a risk to equipment condition, processing ability, and health and safety issues if certain house services are lost or interrupted for a significant period of time							Nitrogen is essential for the operation of the processing equipment and labs. If the supply is interrupted for a significant period of time, equipment can be compromised. Health and safety issues are mitigated through backup bottles but all processing ability would be lost. Electricity is another critic service as some processes involve many day run times. Ensure backup systems in place, UPS for key equipment and bottled gases.
6	There is a risk of downtime and lack of production due to equipment breaking.							Increased maintenance and proper procedures can help prevent this. Consider maintenance agreements to minimize downtime
7	There is a risk that the new building, building 2E will never be fully brought up to original specifications							Flexible approach to using existing space and facilities,.
8	There is a risk that during repairs of building 2E, damage could occur to equipment located in the labs and offices.							As with any construction project accidents can happen. Maintain good communications with facilities staff and protect equipment appropriately.
9	There is a risk of RPCT capabilities not easily integrating with other CRC research groups and other communication technologies.							Identify key roles for photonics in various communications technologies, pursue areas of overlap and communicate with other research groups to align.
10	There is a risk that power failures or accidents could damage expensive processing equipment							Random power failures have happened before causing downtime and costing money to repair.
R	Research Program Management Risks							
1	There is risk that the materials processing by the microelectronics facility will not meet the needs for the fabrication of planer lightwave circuits and other silica based devices							Metallization and lithography processes carried out in MEF are critical to photonic light-wave circuit based devices, problems here can have a large impact on research goals and collaboration agreements. Groups have different priorities and work drivers. Need to define service provider/client or collaborative research relationship. Review of interdependencies required to minimize risks to RPCT research goals
2	There is a risk that if current in house abilities are not sufficient, no alternatives currently exist.							If the work that is done in MEF does not meet the needs of the group, no pre-established alternatives exist. Investigate options to have key processes done on fee-for-service basis elsewhere. Establish contract arrangement with another lab to address needs.
3	There is risk that any outsourcing of fabrication could result in factors outside of our scope of control directly affecting project timeliness.							Depending on the supplier, delivery time and quality or returned work could affects our research and we would have no direct control of these factors. Small volumes would make us low priority.
4	There is a risk of current technologies not staying relevant with changing technologies necessary for the fabrication of emerging communication based devices.							Regular capital investment to future proof fabrication capabilities on an ongoing basis, rather than waiting till several key pieces of equipment become obsolete. Examples would be a shift to nano-scale devices and the need for e-beam or similar lithography. Some of this could be mitigated through through collaboration with other institutions who have the capability.
5	There is a risk that capabilities within the MEF that are key to RPCT research will not be replaced, repaired or recalibrated due to differing priorities.							Capital planning for MEF should prioritize client needs.
6	There is a risk that current capabilities will be affected through health or other issues with staff. Some capabilities are limited to only one employee							Remove single point of failure in output chain by training staff for multiple tasks and having flexible approach to assigning work.
7	There is risk that current research and focus will be dramatically adjusted depending how CRC is realigned within SITT/Industry Canada							Encourage staff to learn new areas and have a broad view of emerging technologies. Provide sufficient funding for training and conference attendance.

8	There is a risk that a lack of contribution to the scientific community through papers, collaborations, conference attendance will limit recognition and research losing peer respect from industry							Unlike companies, the government is judged not only by products manufactured but by other factors such as efficiency, peer recognition of excellence and reputation. Maintain budgets for conference travel and ensure science-based opportunities for researchers.
9	There is potential in continuing to provide excellent research and expertise on optical based communication technologies and networks.							PLCs and other device fabrication platforms can evolve to meet the challenges of increasingly integrated devices and components. There is continuing scope for innovation in optical communication technologies and networks.
10	There is potential that new technologies in the millimetre and THz frequency spectrum will benefit from optical based devices such as photonic lightwave circuits.							Photonics is an important enabling technology in emerging personal and machine-to-machine communications applications As frequencies move to 60 GHz and beyond, the speed limits of electronic signal distribution are being reached, and optical signal processing and distribution will become increasingly attractive.
11	There is a risk of CRC/SITT/Industry Canada needs changing and current CRC research not fitting into the plans for the future							Value broad base of expertise so realignment can be done without major loss of momentum
12	There is potential that CRC will be asked to take on a new driving project/focus, which would disrupt current research forcing a re-org and re-task							Value broad base of expertise so realignment can be done without major loss of momentum
13	There is potential for cost recovery through intellectual property(IP) generation							With new technologies come intellectual property and business development, but potential for exploitation is diminished as facilities age and technology advances. Maintain core expertise and equipment and exploit opportunities in a timely manner.
14	There is potential that current knowledge and expertise will continue to produce high quality research in whatever direction given							CRC has a well established reputation with knowledgeable staff over a broad range of communication technologies. It is a valuable asset for SITT. Support research staff financially organizationally - high morale will translate into high quality research.
15	Risk of being unable to meet the CRC mandate to *"meet key technical challenges of the 21st century ..."* Our Laboratory's R&D focus is on photonic component technologies that "add value" or enhance the performance of broadband network systems and applications. As part of CRC – the federal government's Centre of Excellence for communications R&D – our mission is to meet key technical challenges of the 21st century for the knowledge-based economy.							Maintain core expertise and equipment. Continue to encourage and support scientific excellence.
16	There is potential that current and new collaborations regarding photonic light-wave circuit based research will bring recognition to the group.							Maintain core expertise and equipment and market expertise to clients and partners
F	**Financial/Personnel Risks**							
1	There is risk with collaborations that their demands or need can change independent of our control A downturn in an industry, government financing, change in abilities can lead to changes in numbers and quality of collaborations.							In outside collaborations, results can be tied to factors beyond our control such as NSERC funding. These changes are usually slow and can be predicted as they are tied into funding cycles which are easily monitored
2	There is a risk current budgeting will change in the future							Can reduce dependency on IC funding through contracting in.
3	There is a risk of yearly budgets being adjusted throughout the year							Flexible approach to spending throughout the year
4	There is a risk that power failures or accidents could damage expensive processing equipment							Random power failures have happened before causing downtime and costing money to repair. Work closely with facilities staff to minimize risks
5	There is potential that capital money will be made available for the replacement and purchasing of processing equipment							Capital money is allocated too close to year end to be spent appropriately. Capital plan should be tied to research priorities with timelines
6	There is a risk of capital funding for new or replacement equipment will not be available							Keep equipment in good repair and have up-to-date replacement plan in place.
7	There is a risk that the current capital plan does not adequately prepare for future requirements.							Capital money is allocated too close to year end to be spent appropriately. Capital plan should be tied to research priorities with timelines
8	There is risk in that any new capital is typically difficult to spend due to purchasing time frames and regulations							Many times required equipment cannot be bought within the allotted time frames. Equipment is normally not constructed until contracts are given and since assembly and delivery can take months, contracts need to be started before the end of summer. In recent history, capital money has not been allocated until the late fall or winter. Assign capital funds at start of fy
9	There is a risk that even though capital plans are in place, purchases are not according to needs instead they are done by what fits the money at the time.							Depending on allotment sizes and time frames many smaller pieces of capital equipment are bought instead of high need high cost items.
10	There is risk in having capital money to buy equipment but no planning as to the support equipment, staffing and associated costs to run the equipment							Capital money is sometimes awarded but not always with consideration to the costs to maintain and operate the equipment. Examples can be seen with the ultafast lasers, SEM, and APT lab equipment. Capital planning should have depreciation and maintenance cost components
11	There is a risk that decreasing budgets could lead to shortages in parts for equipment and limit ability to perform experiments							Use end of year money to stock up on parts, pump kits etc. Prepare lists of necessities
12	There is a risk of costs to run various programs and faculties will continue to increased							With changes in the transportation laws and the reduction of semiconductor research within Canada, the availability of certain chemicals/lab supplies is decreasing and costs increasing.
13	There is a risk of losing personal due to other factors such as career change, sickness, or new employment							There is always a risk of losing staff for a variety of reasons
14	There is a risk of current staffing arrangements changing due to realignments or reorganization within CRC/SITT/Industry Canada							
15	There is risk within HR/Staffing. The ability to easily staff positions is very low under current conditions. Groups could be understaffed in a hurry if people were lost							If people leave, the ability to restaff in a short period of time is limited by process and HR priorities.
16	There is a risk that employee motivation and desire will have direct affect on the amount of research being performed							Uncertainty and change and can have a negative affect on peoples motivation.

17	There are risks that moral (see employee survey results) and confidence in management will decrease with continuing lack of direction, decreasing budgets, confusion and speculation as to CRCs future position withing SITT/Industry Canada/Government of Canada							
18	There is a risk of staffing changing due to retirement							Retirement within CRC is a risk. The retirement of existing staff is of higher impact as staffing position is currently difficult and the trend recently is to not restaff the positions of the people leaving. Succession planning for key positions.

RSS QUESTIONS

	Risk	Impact			Likelihood			Comments
		Low	Medium	High	Low	Medium	High	
P	**Processing,Labs and Equipment Risks (Labs/Equipment)**							
1	Risk that equipment will break and that projects will be delayed resulting in failing to meet client's expectations.							
2	Risk that not sufficient funding be provided/obtained to properly maintain lab facilities							
R	**Research Program Management Risks**							
1	There is a risk that the administrative paperwork requested to the manager to continuously justify its research program prevents him/her from properly managing his/her research program activities.							
2	There is a risk that the priority of internal projects change over the year due to external client's requests to address urgent matters or due to industry contracting-in activities not initially planned or due to the need to provide support to new licensees of IPs. This risk is also associated to the possibility to be unable to meet collaboration commitments as							
3	There is a risk that the fabrication facilities offered by CRC are not adequate and thus generating a need to contract out the fabrication creating delays and additional cost to the project.							
4	There is a risk that external factors result in a shift in technology direction making a project less relevant.							
5	There is risk that collaborators in external organizations do not deliver what was promised on time or within the agreed scope.							
6	There is risk that corporate 'irrational' decisions impact the proper execution of the research program under the context of a research result oriented program within a process oriented larger organization.							
7	There is risk that insufficient administrative support (i.e. finance, procurement, HR, etc.) be provided impacting the timeliness of both internal and external clients projects.							
8	There is a risk that the value metric to assess projects will change based on a change of management style and that a new packaging/re-alignment of projects will be required, if possible.							
F	**Financial/Personnel Risks**							
1	There is a risk that funding allocation be provided too late in the year and will impact the progress of projects							
2	There is risk that external programs providing funding for projects are terminated impacting the completeness of projects in a suitable time.							

Appendix 3: Summarised Risk Questionnaire responses

Note: for the following summaries, (*) indicates that there was a wide variation in the responses as shown averaged here, and in cases where there was a tie, results were rounded up. Response references correspond to questions detailed in Appendix 2.

RBON RESPONSES:

Risk Map RBON Summary

Impact	Low (1)	Medium (2)	High (3)
Significant (3)	R4		
Moderate(2)	P2,P4,P6 R3,R10 F4,F13	R1,R2,R5,R6,R7,R8,R9 F1,F2,F3,F5*,F6*,F7,F8 F9*,F10,F11,F14,F15, F16,F17*,F18*	F12
Minor (1)	P1,P3,P5		

Likelihood

ROCE RESPONSES:

Risk Map ROCE Summary

Impact	Low (1)	Medium (2)	High (3)
Significant (3)		P3 R11	R10
Moderate(2)	P1,P5*,P6 R2,R4,R6 F12	P2,P4,P7 R1,R3,R5,R7,R8,R9 F1,F2,F3,F4,F5,F6,F7, F8,F9,F10,F13,F14,F15 F16	F11
Minor (1)	F17		

Likelihood

ROME RESPONSES:

Risk Map ROME Summary

Impact		Low (1)	Medium (2)	High (3)
Impact	Significant (3)	P1,P2	P7*	R3, F2,F6,F9,F10
Impact	Moderate(2)	P3,P8,P10 F4,F5*	P4,P5,P6*,P9 R1*R4*,R6,R7*,R8,R9* F1,F7*,F8*,F11,F13,F14 F15	R2,R5,R10 F3,F12
Impact	Minor (1)			
		Likelihood		

RPCT RESPONSES:

Risk Map RPCT Summary

Impact		Low (1)	Medium (2)	High (3)
Impact	Significant (3)	P1	R16	R1,R5,R12
Impact	Moderate(2)	P3,P4,P8 R6 F4,F5,F13	P2,P5,P6,P7,P9,P10 R2,R3,R4,R7,R8,R9*,R10, R14,R15 F1,F2, F3, F7,F8,F9,F10,F11,F14,F15,F16, F17*,F18*	R11 F6,F12
Impact	Minor (1)	R13		
		Likelihood		

RSS RESPONSES:

Risk Map RSS Summary

Impact		Low (1)	Medium (2)	High (3)
	Significant (3)		P1	R3
	Moderate(2)		P2 R1,R2,R4,R5,R6,R7,R8 F1,F2	
	Minor (1)			
		Likelihood		

End of report.