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Instrumentation

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Background

Instrumentation technology has undergone spectacular advances. Smart sensors with distributed processing intelligence, high-speed optical communication and sensing have found rapid applications in many industrial sectors. For nuclear environments, however, safety constraints impose careful assessment procedures when adopting such new systems. Continuous assessment is needed, not only to benefit from the increase in performance of new technology, but also to avoid working with obsolete equipment. The latter may become hard to find and very expensive.

There is a clear need for advanced state-of-the-art instrumentation in *remote handling operations and in monitoring networks*. New, more challenging remote handling tasks are quickly appearing due to the ageing of nuclear installations: these installations need more maintenance and repair interventions, and eventually have to be dismantled. All these operations were not foreseen at design time, and hence more sensors are needed on the remote handling equipment to deal with uncertainty. Also waste management becomes ever more important. Monitoring networks are needed to continuously examine the state of waste sites. Their long-term reliability needs set unprecedented requirements on the measuring networks.

Objectives

The project aims at evaluating the potentials of new instrumentation technologies under the severe constraints of a nuclear application. It focuses on the tolerance of sensors to high radiation doses, including optical fibre sensors, and on the related intelligent data processing needed to cope with the nuclear constraints.

Programme

The project involves the assessment of a representative set of sensitive measurement systems used under radiation environment. Evaluation of design upgrades as well as the conduct of extensive tests under radiation, using the gamma and neutron irradiation facilities of SCK•CEN, are the important parts of the work. Particular attention is devoted to the assessment of optical fibre components and their adaptability to radiation environments. This work involves also developments on specific data analysis strategies and man-machine intelligent interfacing to compensate for the limitations of the more simple, but robust, radiation-hardened transducers, and allow for more reliable process perception in spite of sparse data. The research is partly covered by several contracts with Electrabel, the European Commission (Fusion Technology), ESA (space applications) and INTAS (collaboration with Russia). One doctoral research work is also on going on this subject.

Achievements

Photonics for the nuclear environment

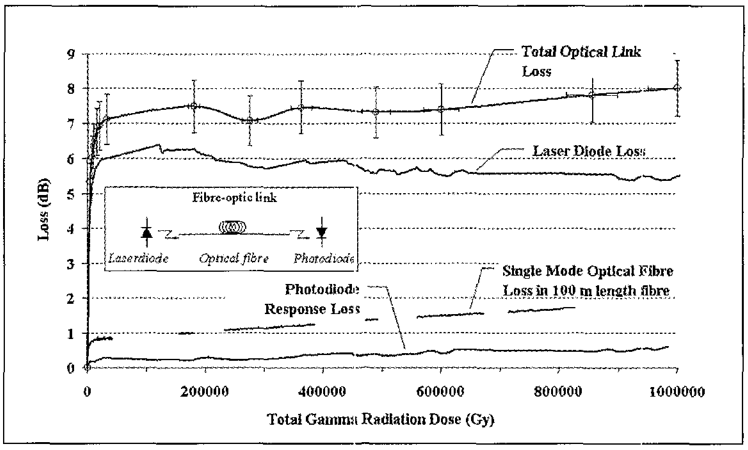
Nuclear infrastructure, including power plants, waste disposals, reprocessing plants and thermonuclear fusion reactor installations can benefit from the unique advantages of fibre-optic communication and sensing systems. The deployment of such systems in nuclear environments has been limited up to now, mainly due to reliability and safety constraints. In particular, the influence of ionising radiation on photonic devices is a main source of concern. In that respect, and in a continuing efforts to assess novel technologies in nuclear environments, we investigated the radiation response of state-of-the-art fibre optic devices such as optical fibre sensors, fibre Bragg gratings, vertical cavity surface emitting lasers (VCSELs), light emitting diodes (LEDs), photodiodes and special types of telecommunication optical fibres.

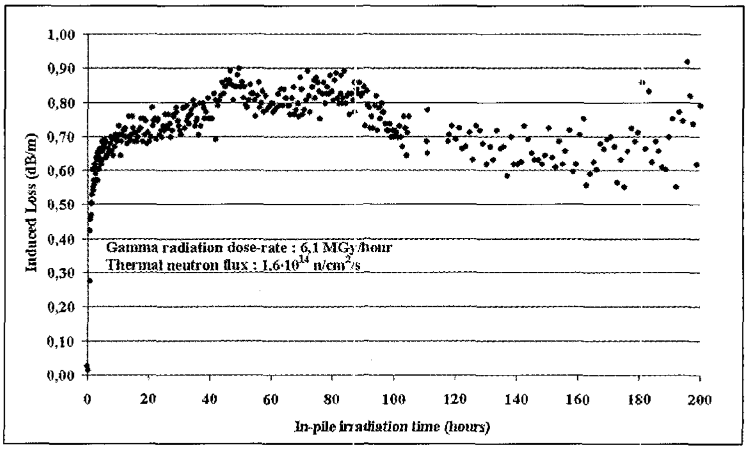
When considering optical communication links, one traditionally combines an optical source, such as a laser diode, an optical fibre and an optical detector, such as a photodiode. Under radiation, laser diodes suffer from a decreased output power. Ionising radiation produces an increase of the attenuation in optical fibres and photodiodes might show a decreased sensitivity and an increased dark current. Fig. 1 shows the loss contribution to a 100-meter long link from these individual elements as a function of total dose, when exposed to a dose rate of 3 kGy·h-1. The fibre is an ultra-low radiation-induced-loss pure-silica-core single-mode fibre. The photodiode loss is expressed in terms of photocurrent loss at a given optical input power. We evidenced that the optical loss of the laser diode is mainly due to the lens on the laser diode package. The photodiode still remains the weakest element in the optical link. Unlike the other components, it stops functioning properly at a total dose of 1 MGy.

The in-pile application of optical fibres also remains a challenge with a wide perspective, for instance for plasma diagnostics in fusion applications, etc. Our experiments show that for dedicated fibre types, the resulting attenuation after 200 hours of reactor operation at a gamma dose-rate of 6.1 MGy/h and a thermal neutron flux of $1.6{\cdot}10^{14}$ n/cm²/s can be lower than 1 dB/m (Fig. 2).

The use of optical fibres is also seriously considered for radiation dose measurements in nuclear power plant facilities. The methodology relies on two distinct approaches. The first one considers a robust modelling of the behaviour of standard optical fibres to account for combined total dose, dose rate and temperature effects on the optical power budget. We showed that it is possible to reconstruct the dose from radiation induced attenuation data at a standard fibre-optic wavelength of 1310 nm. This work is performed in collaboration with CEA. The second approach makes use of specially doped optical fibres, with a response tailored to account only for a total dose effect, minimising the influence of dose rate and/or temperature variations. Doped optical fibres were investigated in collaboration with the Fibre Optics Research Centre of Moscow. Current efforts aim at optimising the fabrication process of these fibres and finding the correct measurement wavelengths. Both approaches are now applied for the development of distributed fibre-optic dose monitoring, dedicated to cable ageing management systems, in collaboration with Tractebel-Electrabel.

Optical fibre Bragg-gratings (FBGs) have a rapidly growing area of application, as filter elements in Wavelength Division Multiplexing systems and as temperature and strain sensors. An essential characteristic of such gratings is their Bragg resonance wavelength λ_B, which is defined by the grating period Λ and the effective refractive index n_{eff} : $\lambda_B = 2{\cdot}\Lambda{\cdot}n_{eff}$. Radiation can influence the performance of the grating via a change of λ and n_{eff}. However, the sensitivity of λ_B to radiation should depend on the fibre chemical composition, drawing conditions, and the FBG parameters and writing conditions. We showed that it is possible to optimise the FBG's response to radiation and that the temperature sensitivity coefficient is not affected by radiation. Using such FBGs, we have constructed, for the first time, a multicomponent force sensor. The FBGs replace the classical strain gauges on the sensor body. Eight of such FBGs are multiplexed on a single fibre, which allows a considerable simplification of the sensor construction. Fig. 3 shows the eight multiplexed signals returned by these FBGs, with the sensor body construction in the inset.





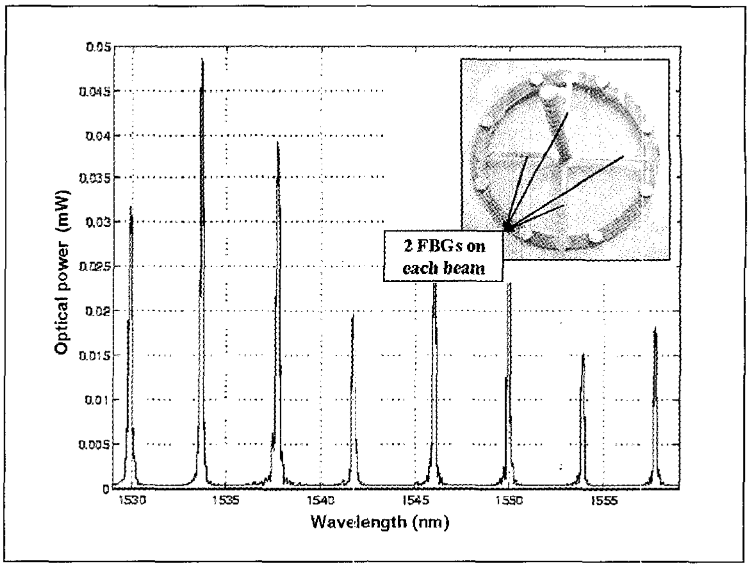


Fig. 1. Optical fibre link loss at a wavelength of 1310 nm as a function of total ionising radiation dose. Fig. 2. Induced loss at 850 nm in an aluminium coated optical fibre during in-pile irradiation.
Fig. 3. Signals from eight multiplexed fibre Bragg gratings on themulticomponent force sensor body (in the inset).

Radiation effects on glasses for space applications

Our know-how in radiation effects on optical devices allows us also to participate in other research programmes such as evaluating the influence of space radiation on spaceborne optical systems. We started a research programme funded by the European Space Agency (ESA), in collaboration with Matra Marconi Space (France) and the Cyclotron department of the VUB. The goal of this research is to define an adequate methodology to assess the effects of space radiation on glasses used in optical satellite payloads. So far one assumed that to avoid space radiation effects, conventional glass types could simply be replaced by their cerium doped counterparts, which show a significantly lower radiation induced absorption. However, these cerium-doped glasses now prove to show much larger radiation induced refractive index changes.

Radiation tolerance of remote sensing systems

Components of remote sensing systems, mainly designed for sensor-based control of remote manipulators, have been further assessed and tested in representative gamma and neutron environments under high dose-rate backgrounds. Several irradiation campaigns were conducted in the BR2 and BR3 gamma irradiation facilities (RITA, BRIGITTE and GEUSE), as well as in the BR1 reactor. Most of these irradiation tests were related to fusion reactor relevant conditions during maintenance shutdown (typical total doses of 1 to 100 MGy).

Particular attention was put on the assessment of prototype multiplexing circuits based on the COTS (Custom Off The Shelf) approach, ultrasonic distance sensors (under neutron irradiation) and cable insulating materials.

The management of umbilical links to remote systems is often a major source of unreliability. Multiplexing techniques can reduce the number of cables and improved insulation allows for cables to keep their electrical and mechanical characteristics for a longer period. Basic parts of *multiplexing* circuits (a comparator and a JK flip-flop) have been designed. The design is done in such a way that even with heavily degraded transistors (90% drop in gain value) the circuit still remains functional. The degradation of the transistors has been modelled in SPICE, based on irradiation tests performed in the past. The circuits have been simulated and prototypes tested up to a total gamma dose of 22 MGy to validate the simulated results have been done. The obtained results show that the circuits do not undergo any significant degradation in performance, and that their output values stay well within the limits of standard logical values

Accelerometers are useful tools to increase the safety of remote handling. They are widely used for vibration analysis and thus allow for early failure detection and timely corrective actions in case of emerging malfunctions of the machines such as stalling or jerking of the motors. A series of accelerometers, manufactured by Bruel & Kjaer, have previously been assessed under gamma radiation up to 100 MGy. The same type of sensors have been irradiated under fast neutron flux as well up to a total fluence of $1.15 * 10^{17}$ n/cm^2. The results show a decrease of about 20% of the power spectrum of the accelerometers.

A study for the improvement of *cable insulation* has been started in collaboration with Kabelwerk-Eupen, focusing on halogen free materials. In 1999, suitable candidate materials for cable insulating material have been identified and tested. The objective if to produce a prototype hybrid cable. This hybrid cable should contain instrumentation wires, power lines and optical fibre lines

Our collected know-how on radiation tolerance has been confirmed by the continuation of our co-ordination work within the European Fusion Programme and is used furthermore to answer an increasing number of consultancy requests, coming from the fusion programme community, the different SCK•CEN projects and the industry.

Sensor based control strategies

The performance of radiation-tolerant sensors is limited compared to industrial state-of-the-art sensors, in terms of quality and quantity of the data returned. Therefore, the objective of this part of the Instrumentation department's work is to compensate for these limitations with software algorithms that assist the human operator in using these sensors and in interpreting the returned data.

In the past, we have developed a number of statistical algorithms for the consistent reasoning with uncertain and incomplete sensor data. The first is an algorithm for active, task-directed sensing, i.e. an algorithm that determines what information is missing to complete the current task, and how to get this information with the available sensors. The second is an algorithm for data fusion. This algorithm recursively fits a model through the sensor data, taking into account the uncertainty on each of the measurements. The third algorithm is an algorithm for model selection. This algorithm lists all possible models that can explain the measurements, and determines how well each one fits the data.

This year, we have applied those algorithms to the geometric modelling of a (part of) a fusion reactor, using only the measurements of a touch probe installed on a robot. Estimations of the intensity of the radiation field show that cameras will not survive for longer than a few minutes to half an hour inside the reactor torus. Therefore, we introduced the *blind man's approach* to geometric environment modelling. Rather than showing the operator of a remotely controlled robot live camera images, our approach is to show life synthetic 3D images of a model of the reactor, while ensuring that this model is consistent with reality. Since the reactor torus is a well-known environment, to achieve this, it suffices to verify and/or update this model with a few carefully chosen measurements of the probe on the robot. This is very similar to the blind with their white cane who determines their position in an internal model using a few well-chosen explorations.

The bulk of this development is completed this year as an EC project in the nuclear fusion programme. A demonstration of the system is planned on the mock-up of the ITER Divertor Test Platform operated at ENEA Brasimone by the end of 2000.

Scientific partners

CIEMAT	Centro Investigaciones Energéticas, Medioambientales y Tecnologicas (Madrid, Spain)
CEA	Commissariat à l'Energie Nucléaire (Saclay, France)
ERM/KMS	Ecole Royale Militaire / Koninklijke Militaire School (Brussels, Belgium)
FORC	Fibre Optics Research Centre (Moscow, Russia)
FhG	Fraunhofer Gesellschaft (Euskirchen, Germany)
FPMs	Faculté Polytechnique de Mons (Mons, Belgium)
	Kabelwerk Eupen, Belgium
—	Kurchatov Institute (Moscow, Russia)
MMS	Matra Marconi Space (Toulouse, France)
ULB	Université Libre de Bruxelles (Brussels, Belgium)
VUB	Vrije Universiteit Brussel (Brussels. Belgium)

Scientific output

Sponsor

EC	European Commission (Fusion Technology Programme)
ESA	European Space Agency
INTAS	International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union

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