

I. Research & Development – Oil & Gas

Important driving forces behind the research and development at IRIS for environmental O&G activities are represented by the European policy to obtain sustainable development for industrial activities, and in particular by the 'zero harmful discharge' regulation for the oil industry operating on the Norwegian Continental Shelf.

The 'zero harmful discharge' regulation has required major improvements of the methods for how environmental effects could be assessed, both in terms of measurement and prediction capabilities. The environmental prediction capabilities have been developed within frameworks of environmental risk assessment, and the measurement methods have been developed for integration in the industry's monitoring programmes. The main focus has been on potentially long term effects in organisms living in the water column, and capacities for both environmental prediction and monitoring have been developed in the North Sea maritime area. Further research has aimed to transfer these capacities to other conditions, such as cold waters in the Arctic and the deep sea areas, and to other geographical regions.

Another R&D target has been to develop capability to evaluate and treat oil industry discharges, ranging from cutting piles to oil spills. Biodegradation processes and -remediation techniques have been studied for sea bottom sediment and coastal beach areas.

In order to meet the future challenges, one of the major focus areas is to develop integrated environmental monitoring solutions for marine operations, which includes measurements of parameters at different levels of biological organization for assessment of effect.

A selection of projects (ongoing and completed):

ENVIRONMENTAL IMPACTS

iMARE / sensoMare - An integrated system for marine environmental monitoring (2007 – 2009)

The objective of iMARE is to contribute towards increasing the expertise held by scientists/authorities and by industry, with the aim of preventing potential environmental damage in marine areas where hydrocarbon exploitation activities are being performed.

The research project will integrate existing environmental technologies and aims at developing new methods with continuous monitoring of key environmental parameters. The new tools to be developed are expected to be of wide range application in particular in the Barents Sea and other sensitive offshore areas.

Planning of a long-term strategic research programme in the field of integrated marine environmental monitoring, "iMARE", was initiated in June 2007. Until the end of 2009, a pre-project (Kjeilen-Eilertsen et al. 2009), and a sub-project, sensoMARE, addressing parts of the original iMARE concept has been carried out.

A main objective of the iMARE/sensoMARE 2009 activities has been to review and evaluate candidate techniques, platforms and instrumentation with a real potential as monitoring tools for petroleum industry discharges and operations in the southern Barents Sea (Goliat area).

Furthermore, it has been a goal to relate such new monitoring approaches to Ecosystem Based Management (EBM) strategies for the future, and also to visualize the necessary and important link between current biological effect measures such as biomarkers, biota available in the area and the likely discharge scenarios.

Financing: Eni Norge AS

BIOSEA I JIP programme (2002-2004)

Biomarkers were evaluated and established as global tools for monitoring impacts of oil and gas activities offshore. Further, data were generated to be able to tie the selected biomarkers to risk evaluation. In order to achieve this it was necessary to study biomarker signals and biological fitness comparatively in laboratory oil exposures. This research covered laboratory studies with chronic oil exposures where biomarker signals and fitness effects were measured in model fish and in ecologically relevant species of bivalves, crustaceans and fish. Selected suites of biomarkers were field validated and field background levels were measured in wild caught animals.

Financing: Eni Norge AS and Total E & P Norge AS

BIOSEA II JIP Risk Assessment and Biomonitoring in the Arctic (2006-2009)

The objectives are to build a scientific basis for a risk based PW environmental management, and to define acceptance criteria and threshold levels for environmental effects and biomarker signals in Arctic waters.

Financing: Eni Norge AS and Total E & P Norge AS

SIP Biosensor (2006 -2009)

Development of biosensors for real-time monitoring in the marine environment and possible integration with established methodologies (biomarkers, bioassays and chemical techniques).

Financing: The Research Council of Norway

DRILLING DISCHARGES

Effects of drilling discharges

Drilling discharges spread over large areas and particles remain suspended in the water column for a long time. Between 50 – 100.000 tons of barite (weighting material contained in the drilling mud) are discharged in the North Sea each year.

The effects of water based drilling mud on *bivalves* and *fish* were investigated in the first two projects below. A third and ongoing project focus on the effects of mud on cold water *corals*.

Effects of drilling mud discharges on water column organisms and filter feeding bivalves (project 1: 2004-2005; project 2: 2006-2008)

The effects of water based drilling mud on *bivalves* and *fish* were investigated. The objective of the two projects was to find out whether metals from the mud were

taken up by fish and filter feeding bivalves and to investigate the possible effects of the drilling mud on these organisms. A special exposure system was designed and cods, scallops and mussels were exposed to different concentrations of drilling mud with barite/ilmenite as weighting material. The parameters studied ranged from effects on feeding and growth to DNA and tissue damage. An aim was to find out whether ilmenite could be a more environmentally friendly alternative to barite. Financing: The Research Council of Norway.

Drilling in the Arctic (2008 - 2011)

This ongoing project focuses on the effects of mud on cold water *corals*. Impact of water-based drilling mud in the Barents Sea: a study using the epibenthic coral species *Lophelia pertusa*. The project will contribute to a better knowledge of the long-term impact of offshore drilling activities on ecologically relevant species (the coral *Lophelia*). Monitoring tools based on biological effects (biomarkers) will be used on an ecologically important species (the coral *Lophelia*) to document the possible long term impact of offshore drilling activities in the Barents Sea.

Financing: The Research Council of Norway – PROOF

Impacts of metals from drill cuttings and mud to marine water column (2002)

The project was a pre-study addressing problems related to many piles of contaminated drilling discharge in the North Sea, an issue becoming pertinent as more oil oilfields enter decommissioning phase. The issue is particularly relevant for “new” exploration areas a like the Arctic and the deep-sea where the environmental sensitivity is uncertain.

Financing: The Research Council of Norway – PROOF

Offshore drill cuttings piles (1996 – 2005)

Piles of drilling mud and drill cuttings on the sea floor around oil installations have been seen as an environmental concern in the North Sea, particularly by Norway, Great Britain and Holland, and have received considerable attention for more than a decade.

In the period from 1996 to 2005, projects carried out by IRIS have focused on the following: Mapping of size and location of cuttings piles; sampling and analyses of physical, biological and chemical characteristics; assessment of microbiological activity in the cuttings pile, and the potential for natural degradation of hydrocarbons; independent assessment of treatment technology; estimation and measurement of toxicity and effects from cuttings piles; and recommendations for treatment planning.

IRIS established a cross-specialist team including chemists, engineers, GIS-mapping specialists, oceanographers, ecologists, toxicologists, microbiologists and social scientists. IRIS performed desktop, lab and field studies for both the authorities and industry, and contributed to the development of policy and treatment plans for cuttings piles, and assessed the need for further research in this area.

High profile projects which IRIS has participated in include decommissioning plans for the Ekofisk field, UKOOA drill cuttings programme projects (three consecutive phases), and for OLF the identification of treatment and management methods. Financing: UKOOA (United Kingdom Offshore Operators Association), OLF (Norwegian Oil Industry Association), ConocoPhillips (Ekofisk), BP

ERMS-programme (2002-2006) **Environmental Risk ManagementSystem**

ERMS is the continuation of the DREAM programme (1998-2002), resulting in a DREAM/EIF model for Drilling Discharges and Sediment – an environmental risk-based decision support tool.

Financing: Statoil, Total E & P Norge , Eni Norge AS, ConocoPhillips, Shell, ExxonMobil, Petrobras, BP

OIL SPILLS / COLD WATER (Arctic and deep sea)

Spill remediation (2008 – 2009)

IRIS Biomiljø and Biologge AS started in 2008 a 2-year project. The project is part of oil companies' work to improve coastal and shoreline oil spill response, with particular focus on cold waters and arctic areas. The project goal is to develop products for increased microbial degradation of petroleum oil spills across open-water surfaces.

Financing: Eni Norge AS and Statoil

Arctic Effects (2007 – 2008)

Study of the long term effects on the Arctic ecosystem from accidental discharges. The project aims at investigating the possible long term effects of oil drifting in the arctic ice fauna. Biomarkers have been used to document the effects.

Financing: The Research Council of Norway

NDP - Norwegian Deep Water Programme (2003-2007)

The project was financed by an oil company consortium. The objective was to develop knowledge and capacity to assess environmental risk of e&p operations in deep sea areas, in order to provide decision support. Important focus was put on deep sea specific factors like *low temperature* and *high pressure*, and risk aspects were compared at shallow and deep sea conditions. The key question was if existing principles/tools for environmental risk assessment can be used for deep sea oil activities and what would be additional needs? The project was divided into activities studying:

- *Physical/chemical fate*: Plume behaviour from deep water blowouts.
- *Bioavailability*: Uptake of PAH
- *Biodegradation*: Biodegradation data of oil at different pressures
- *Valuable ecological components & target resources*: Identification and pre-test of animals for effect studies.
- *Biological uptake and effects*: Effect studies. Exposure of animals at high pressure in a continuous flow system in order to determine uptake and effect.

Financing: ConocoPhillips, Statoil, Total E&P Norge AS, Eni Norge AS, BP, A/S Norske Shell

NDP Deep water degradation

The objective of the project has been to establish knowledge and the importance of pressure and low temperature on the biodegradation potential of microorganisms in the marine environment.

Coldwater programme (1999-2001)

Development of methods for monitoring biological effects of oil related activities in cold waters, either in deep water or in the Arctic. Since marine species in cold water can be particularly vulnerable to pollution, and in addition little is known about deep water ecosystems, a biological effect monitoring approach has been chosen to develop sensitive methods to monitor these areas.

Financing: Total E & P Norge AS

Offshore environmental monitoring in West-Africa (1999-2004)

Special focus has been on fundamental understanding of the deep-sea ecosystem, including cold seep communities, of the West African continental margin. IRIS has in addition established baseline level of biomarkers in native fish and megafauna both in areas with oil production activity and in pristine areas offshore Gabon, Congo and Angola in collaboration with IFREMER for Total. During the period 1999-2004 IRIS participated with biomarker investigations in 6 different environmental surveys in the area.

Financing: Total E & P Norge AS

Eureka Project BIOREN (1992 – 1998)

The objective of this 6 year programme was to develop new formulations for enhanced oil biodegradation (bioremediation) of oil spills in shorelines, at environmental conditions ranging from temperate to arctic. The project involved experimental studies in various systems including laboratory tests and field experiments.

Industry partners: Total E & P Norge AS, Norwegian Applied technology, Institut français du Pétrole.

ECOPEL (2002-2003)

The Erika oil spill affected a large area along the western coastline of France. Following this, the – French Ministry of Research initiated RITMER, a network for research and technological innovation on accidental marine pollution events and their ecological consequences. Within this context IRIS Biomiljø participated in a 2-year project, ECOPEL, managed by CEDRE in France. The main objective of ECOPEL was to contribute to the revision of the GESAMP-Marpol and European classifications, mostly from a physico-chemical point of view, through an experimental approach, consisting of tests with several chemicals using realistic conditions and partly carried out at a pilot scale (floating mesocosm unit deployed at sea). IRIS conducted laboratory experiments in continuous flow conditions with marine organisms (mussels and fish) exposed to styrene. Several biomarkers were measured and their suitability as biomonitoring tools for chemical spill was evaluated.

Financing: The French Ministry of Research

PRODUCED WATER

Produced Water JIP (2006-2009)

The Produced Water - Joint Industry Project - is a program financed by two oil companies. The scope is to validate techniques suitable for monitoring of Produced Water discharges and to establish effect levels for a range of relevant biological effects in marine organisms, including reproductive effects in fish. Both controlled large scale laboratory exposures with authentic PW, field exposures with caged organisms and collection of feral organisms has been included. *The design of the program is closely linked to the “Water Column Monitoring” imposed by the Norwegian environmental authorities.* One important sub task is to use biomarker based monitoring to document the environmental benefit of new cleaning technology.

Financing: ConoccoPhillips, Total E&P Norge AS

Pollutant exposure and effects in fish related to discharge of produced water in the North Sea oil industry (2003-2005)

The two projects above address produced water (PW) effects in fish. Emphasis is put on the effects PAH and alkylphenols, since these chemicals are well represented in PW and both are of concern with regard to possible impact on offshore fish stocks. The main objectives are to develop better and more sensitive biomarker tools and to provide relevant field data on analyses of fish collected at the Tampen field – a region where large volumes of PW are discharged.

Financing: The Research Council of Norway - PROOF

Improved SPAD GCMS method for determination of alkylphenol exposure to fish

Financing: Total E & P Norge AS

Comparative Cod Exposure (2005)

The main objective of the project was to develop an exposure system for water exposure using authentic produced water and to produce material of fish that made it possible to compare and assess chemical uptake and biological responses in organisms exposed to oil related compounds. Several institutions in Norway received material for analysis.

Financing: The Research Council of Norway - PROOF

GC/MS Determination of produced water related PAH and alkyl phenol-metabolites in marine Fish (2002-2003)

Offshore produced water (PW) discharges may potentially lead to polyaromatic hydrocarbon (PAH) and alkylphenol (AP) contamination of downstream fish populations. The contamination will, if it occurs, be at very low environmental levels. There is therefore a need for sensitive exposure markers in marine fish that can be used for detection/biomonitoring of PAH and AP contaminants. The scope of this project was to pursue this need by developing more sensitive detection tools based on GC/MS analyses of PAH and AP constituents in fish bile. The project was the first study in a series of follow-up projects which in sum have resulted in considerable progress in this field and which have been reported in several peer review publications.

Financing: The Research Council of Norway – PROOF

Validation and Biomarker Bridges: Integration of Biomarkers in Environmental Risk Assessment (2003-2010)

Industry has developed environmental risk assessment tools based on biological effect data derived from laboratory tests. These effect results need to be *validated* in the field for their ability to express effects of environmental concern, but most of the effects studied in laboratory tests cannot be measured directly in the field. *Biomarkers* are useful parameters to build the *bridge* that can link data from laboratory and field, and thus also link the tools for risk assessment and field monitoring. This is the principal aim of these *two projects*, and once achieved it will allow comparison of field monitoring with environmental risk data.

Financing: The Research Council of Norway - PROOF

Proteome Expression Signatures (PES) in fish as a diagnostic tool to evaluate the environmental impacts of offshore oil & gas exploration (2005 -

The principal objective of the project is to develop a proteome based diagnostic system for cod in Environmental Risk Assessment (ERA) and Environmental Monitoring of produced water. The project will aim to identify the structure of key diagnostic proteins that express the effects of the different PW components in order to develop suites of biomarkers. The new biomarkers based on proteome changes will be correlated with functional disorder in order to provide a better environmental monitoring system and input to the ERA model

Financing: The Research Council of Norway

Biosensor project (2006 – 2008)

The objective was to evaluate two biosensors for rapid screening of biological samples exposed to produced-water related compounds: A DNA biosensor and a horseradish peroxidase biosensor.

Financing: The Research Council of Norway and Total E & P Norge AS

Strategic Institute Programmes (SIP) (1996 – 2004)

SIP 1 Application of biomarkers in environmental monitoring 1996 – 1999

SIP 2:Hormone disruption in Marine Invertebrates 2000 - 2004

Two research programmes in the field of biological effect monitoring with biomarkers. Biomarker methods are now incorporated in almost all projects with the offshore industry. The first strategic institute programme was dedicated to development and implementation of marine environment biomarkers. The second programme was focused on problems related to substances which are similar to hormones, and their possible effects on marine invertebrates. Chemicals with properties that are like those of hormones are considered to be a major problem in all animal groups, and the extent of the problem is so far unknown. There are few methods available for studying these effects in marine invertebrates. It is thought that components in raw oil such as phenols, and production chemicals may have this type of property. (Alternative category III)

Financing: The Research Council of Norway

IDREMER (Bioaccumulation, Biomarkers, DREAM pre-project)

The objectives of the programmes was to develop competence, methodology and capacity to be able to monitor and predict environmental impact of discharges from oil and gas industry offshore in different geographical areas and environmental conditions (North Sea, The Arctic and Deep Sea Areas)

Financing: Total E & P Norge AS

DREAM programme - Dose related Risk and Effect Assessment Model for chronic discharges (1998 – 2002)

This is a modelling tool for risk evaluation of continuous discharges from oil installations offshore. This tool integrates sub-models combining the spread of chemicals, the fate of chemicals (physical properties chemistry) and their breakdown, as well as uptake by organisms, bioaccumulation, biological effects and risk. The IRIS participation in the project covered: Effect studies with long term exposures of model fish (sheepshead minnow) and copepods to produced water components (PAHs and alkylated phenols) for the development of DREAM.

Financing: Statoil, Total E&P Norge AS, Eni Norge AS

BASELINE / DECOMMISSIONING

Biomarkers in decommissioning

Field testing and evaluating biomarker methods in connection with the phasing out of an abandoned field.

Financing: Total E & P Norge As

PETROLEUM RELATED

MIOR - Microbial Improved Oil recovery

A number of projects on MIOR have been carried out in IRIS the last 15-20 years. Project focusing on describing the microbial population dynamics in the Ekofisk chalk Reservoir and its potential for improved oil production was carried out from 2003-2008. The aim has been to understand the microbial mechanisms and processes and on the basis of this, develop strategies and external growth processes to stimulate oil production. The overall objective has been to develop model and simulation tools for microbial processes in the reservoir. A follow-up study on mechanisms, with focus on biofilm and growth rates was initiated in 2010.

Financing: The Research Council of Norway (RCN) and ConocoPhillips has financed the projects targeting Ekofisk.

Other projects have been financed with support from several oil companies such as BP, Saga and Shell, and the RCN.

The MEOR projects have been carried out as collaboration between IRIS Petroleum og IRIS Biomiljø.