Norwegian Centre of Excellence

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

2016 ANNUAL REPORT

Norwegian University of Life Sciences

Norwegian Centre of Excellence

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

DESIGN & LAYOUT: Signe Dahl, NMBU & Quentin Mennecart

COVERPAGE, OUTSIDE: Fieldwork in Fukushima, Brit Salbu

COVERPAGE, INSIDE: Tuntreet at NMBU, Signe Dahl

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

The Research Council of Norway has established CERAD Centre for Environmental Radioactivity, to provide new scientific knowledge and tools for better protection of people and the environment from harmful effects of radiation (2013-2023).

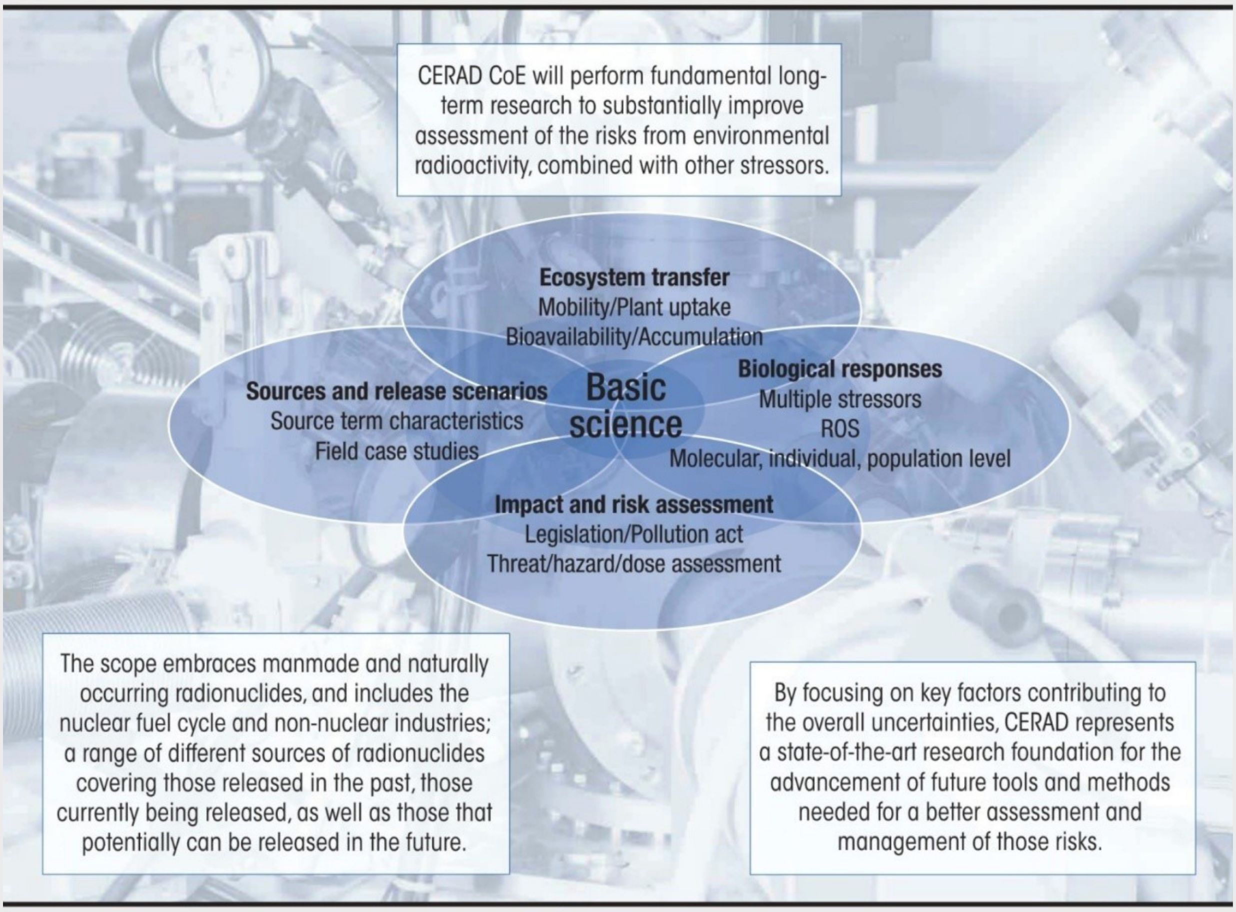

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Table Content CERAD COE Annual Report 2016

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

CERAD CoE - In Short 2016

CERAD PARTNERS	
NMBU	Norwegian University of Life Science
NRPA	Norwegian Radiation Protection Authority
MET	Norwegian Meteorological Institute
NIPH	Norwegian Institute of Public Health
NIVA	Norwegian Institute for Water Research

SCIENTIFIC RESULTS	NUMBER
Total scientific articles 2013 - 2016	117
Scientific articles published 2016	39
Scientific articles in press	7
Books/Monographs 2016	2
Technical/Scientific reports 2016	2
Book chapters 2016	3
Scientific presentations 2016	102
Popular science/Media 2016	8

FUNDING 2016	MILL. NOK
RCN funding	16.0
In kind, Direct	2.25
In kind, Personnel	27
Other research projects (NMBU/Isotope Laboratory)	7.5
Total	52.75

HUMAN RESOURCES - PART TIME PERSONNEL	
Professors; researchers	69
PhD	17
PhD dissertation	5
PostDoc	7
International guest scientists	2
International scientific network	10
Technicians/administration	12
Total	117

CERAD CoE - In Short 2016

In 2013, CERAD CoE initiated long term basic research to improve the ability to accurately assess the radiological impact and risks from environmental radioactivity, also combined with other stressors. By focusing on key factors contributing to the uncertainties, CERAD represents a state-of-the- art research foundation for the advancement of tools and methods to better manage those risks. The scope includes man-made and naturally occurring radionuclides that were released in the past, those presently released, and those that potentially can be released in the future from the nuclear fuel cycle and from non-nuclear industries. Using a holistic scientific approach, the CERAD research focuses on different source term and release scenarios, ecosystem transfer of radionuclides, biological uptake and effects in organisms exposed to radiation combined with other stressors such as metals and UV radiation under varying temperature/ climate conditions, to assess overall environmental impact and risks. The assessments will include possible impact not only on man and non-human organisms, but also economic and societal consequences, quite unique in an international context. Based on the strategic research agenda (SRA) major research achievements have been obtained during the years. Subsequently, the revised SRA and associated priorities cover new challenges to be focused during 2017-2021. As the present research effort of CERAD has made significant contributions to the development of radioecology internationally, it is believed that the revised CERAD research focus for the next period will play a major role when priorities are set on the international arena in the years to come.

MG Group

From left to right:

Research Director Deborah H. Oughton, Deputy Director Per Strand, Center Director Brit Salbu, Education Director Lindis Skipperud

Photo: Quentin Mennecart

Comments from the Center Director Brit Salbu

Four years of the CERAD´s life has passed, and I am very pleased to see that fruits are being harvested from the research effort initiated in 2013. The development of the CERAD research has been successful, both with respect to the identification of key research areas, achievements obtained so far, and to the integration of a scattered crowd of about 70 part time scientists representing expertise within different fields of science, different scientific culture and priorities, as well as different institutions. By focusing on common goals, hypotheses and research questions, a holistic long-term research program on source terms and release scenarios, ecosystem transfer, biological responses forming the basis for impact and risk assessments has been developed. Thus, the scientific programme of CERAD is much more ambitious than anything hitherto attempted within radioecology in Norway, and no single partner could achieve obtained results without the strong support from other partners or international collaboration.

The Centre has already made important progress towards its goal of reducing the overall uncertainties in impact and risk assessments associated with environmental radioactivity, combined with other stressors. Based on the Strategic Research Agenda (SRA, 2013 - 2016) as well as the revised SRA (2017-2021), the research effort focuses on 4 key Research Areas (RA) that includes 8 focused research topics (Umbrellas). A series of highlights and novelties have been achieved since 2013:

• *RA1 Particle sources and effects:* Based on the unique NMBU particle archive and close international collaboration, the characterization of different nano/micrometer sized particles using the most advanced technology (e.g., synchrotron XAS, CT-tomo, AMS) represents the-state-of-the art worldwide. The 3D image of CoNP accumulated at the *C. elegans* embryos were selected as ESRF Beauty of Science, 2015.

• *RA2 Dynamic ecosystem transfer:* Among highlights achieved, most impact internationally is attributed to the development of the dynamic ERICA tool for the Fukushima impact assessment, as 3 White papers to the UN General Assembly was prepared by a UNSCEAR committee, chaired by the CERAD Deputy director

• *RA3 Biological responses*, including Radiosensitivity, Combined Toxicity and Transgenerational effects. Based on CERAD's unique gamma irradiation facility and the unique Biological Effect Toolbox, a series of test organisms have been exposed to gamma radiation and to a combination of other stressors. Highlights are particularly obtained for salmon, zebrafish, daphnia and genmodified mice where it has been possible to link a range of endpoints spanning reproduction, development, gene-expression and epigenetics.

• *RA4 Risk assessments*, including case studies. The most comprehensive case, a potential release from waste tanks at Sellafield and deposition in Norway, links potential release and deposition to ecosystem transfer and impact and risks (health, environment, economy and society). Emphasis is put on key factors contributing significantly to the overall uncertainties when a series of models from the source to the risks are coupled. We were pleased to see that the EU CONCERT 1st Call text 2016 corresponded very well to the CERAD concept (EU CONFIDENCE project awarded).

We believe that the research achievements and highlights summarized in the present volume, reflecting the scientific progress, should be of national and international interest.

To support the research, the infrastructure has been renewed during the past years (e.g., the EU-DoReMi supported climate controlled gamma facility, new controlled isotope fish laboratory, a unique Gamma – UV climate chamber box, new ICP-QQQMS, XRF instruments). Improved access to international advanced platforms has been obtained (e.g., synchrotrons in France, Germany, Australia, AMS in Spain and Australia, CT- tomo in Poland). The research is also supported by a series of expeditions to a series of radioactive contaminated sites such as the exclusion zones in Chernobyl and Fukushima, as well as to sunken submarine sites in the Arctic in collaboration with Russia. As the CERAD politics include collaboration and co-financing of the activities with other organisations nationally and internationally, a series of EU projects have been funded since 2013 (e.g., STAR, COMET, RATE; NanoREG, SHAMISEN, CONCERT EJP). Four EU CONCERT projects were also accepted in 2016. Several projects have also been granted by RCN, two in 2016, and from other Nordic and national funding organizations (e.g., SiU, Framsenteret, NKS).

CERAD includes NMBU (5 departments, all faculties) and 4 partners (NRPA, MET, NIVA, NIPH). Jorunn Hestenes Larsen is the new head of administration, while Anja Nieuwenhuis is still part of the CERAD administration. In 2016, Professor V. Kashparov, Ukraine and Professor T. Hinton, Japan became Adjunct Professors (Prof-II) at NMBU. In February 2016, a successful CERAD conference was organised at the Norwegian Academy of Science and Letters with more than 75 participants, including representatives from CERAD's international network (SAC) and national stakeholders (RAC).

An essential ingredient in CERAD is researcher training and education (MSc, PhD) to provide an attractive research environment, and to produce candidates that are internationally competitive. We are therefore very pleased to have recruited a total of 22 PhDs and 7 PostDocs to CERAD since 2013. The EU supported NMBU MSc in Radioecology is unique in Europe, as well as the established Research School. The course modules in English are run intensively to make access possible for students from abroad. EU projects (DoReMi and CONCERT) have contributed to MSc course modules, and the STAR/COMET E&T platform developed by NMBU (www.radioecology-exchange.org/) is the international link to education in Radioecology. Based on close collaboration with other universities, Memoradum of Understanding (MoU) agreements concerning research and E&T have been established with a series of universities and research institutes (e.g., Fukushima University, National University of Life and Environmental Sciences of Ukraine), forming a valuable recruitment base for PhD. Courses have also been given abroad (e.g., COMET field courses in Poland and Ukraine).

CERAD plays an active role on the international arena (e.g., ICRP, UNSCEAR, IAEA, IUR). More than 100 conference presentations were given in 2016. During the years, a series of CERAD supported conferences and workshops have been organised nationally and internationally (e.g., ICRER Conference, Barcelona, Spain, 2014, the IUR Consensus conference, Miami, 2016). CERAD MGs are board members of the ALLIANCE and NERIS platforms, CERAD Deputy director is the vice president of the ALLIANCE, and President of the International Union of Radioecology (IUR) from 2016. In 2014, the CERAD Director was awarded the IUR 4th V. I. Vernadsky price. In 2016 CERAD Director was awarded the Chernobyl 30 year memorial medal and a Honory Professorship at National University of Environment and Life Sciences, Kiev, Ukraine.

It is a pleasure to be the head of CERAD, a research organization with highly competent scientists producing highlights, in close collaboration with a strong international network including the Scientific Advisory Committee, with the support of national stakeholders included in the Relevance Advisory Committee.

CERAD Director,
Professor, Brit Salbu
Photo: Gisle Bjørneby

Comments from the Chair of the CERAD Board 2016 Halvor Hektoen

The SFF programme (Centre of Excellence) gives Norway's best scientists the opportunity to organize their research in centres and thereby be able to reach ambitious scientific goals through collaboration within and across disciplines. High scientific quality is the main criterion for the selection of the centres. CERAD will undergo mid-term evaluation in 2017 on the basis of scientific quality, impact, international and national coorperation and standing, research education activities and organization among other criterias.

Since CERAD was established in 2013, there has been a substantial growth in research activities and scientific publications of the highest quality. The first year was focused on building a robust research organization and bringing the different collaborative research groups together. Focus on team building has been prioritized through all years. This investment has shown to be a great success. The broad collaboration between the national partners and leading international research groups has placed CERAD in the research front.

CERAD is a preferred international partner, and the obtained leading position has opened access to advanced research infrastructure such as syncrotrons in France, Germany and Australia. The close collaboration with universities in Ukraine and Japan has given CERAD exclusive possibility to send expeditions to radioactive contaminated sites within the exclusion zones of Chernobyl and Fukushima, and in collaboration with Russia, CERAD has also been invited to be part of expeditions to sunken submarine sites in the Artic. To underline the international focus of CERAD, it is also satisfactory that members of CERAD's Management Group are appointed members of several international organizations.

CERAD's strength is the interdisciplinary approach which covers all aspects of interest regarding risk assesment such as radioactive particle sources, nuclear forensic, transfer of radioactivity in the ecosystem, toxicity to organisms, animals and humans, and finally societal consequences. This basic knowledge is crucial for reducing uncertainties and to conduct better risk assessments of environmental radioactivity from past or presently released sources, or from sources released in the future.

CERAD has fulfilled its goal to establish educational programmes and research education. The master program in radioecology gives the opportunity for students from Europe and other countries to come together with an international group of experts as lecturers. In total more than 20 PhD students and post-doctoral fellows are engaged through the CERAD research areas.

CERAD has undoubtedly lived up to the requirements of a centre of excellent research. It has been a great pleasure to be part of the CERAD Board together with representatives from our four partners, Norwegian Institute of Public Health, Norwegian Meteorological Institute, Norwegian Institute for Water Research and Norwegian Radiation Protection Authority. Thanks for the enthusiastic engagement and collaboration. On behalf of the board, I am also grateful for the contribution from our international collaborators, and the huge effort from all researchers, research leaders, and the administration.

The chair of the CERAD board 2016, Prorector, Professor, Halvor Hektoen
Photo: Gisle Bjørneby

Highlights from the first four years of CERAD CoE

CERAD CoE performs long-term basic research to improve the ability to accurately assess the radiological impact and risks from environmental radioactivity, also combined with other stressors. The Centre has already made important progress towards its goal of reducing the overall uncertainties in impact and risk assessments associated with environmental radioactivity, combined with other stressors (see pages 15 to 47 for more detailed information). Based on the Strategic Research Agenda (2013-2016), the research effort has focused on 4 key Research Areas (RA). Among a series of highlights and novelties that have been achieved since 2013:

- **RA1 Particle sources and effects.** Based on the unique NMBU particle archive and close international collaboration, the characterization of different nano-micrometer sized particles using the most advanced technology represents the-state-of-the art worldwide. The 3D image of cobalt nanoparticles accumulated at the *C. elegans* embryos was selected as ESRF Beauty of Science, 2015.

- **RA2 Dynamic ecosystem transfer.** A series of fieldwork and lab experiments have been performed. Among highlights achieved, most impact internationally is attributed to the development of the dynamic ERICA tool for the Fukushima impact assessment, as totally 3 White papers to the UN General Assembly was delivered from a UNSCEAR committee chaired by the CERAD Deputy director

- **RA3 Biological responses**, including Radiosensitivity, Combined Toxicity and Transgenerational effects. Based on CERAD's unique gamma irradiation facility and the developed Biological Effect Toolbox, a series of test organisms have been exposed to gamma radiation and to a combination of other stressors. Highlights are particularly obtained for salmon, zebrafish, daphnia and gene-modified mice where it has been possible to link a range of endpoints spanning from reproduction, development, to gene expression and epigenetics, also reflected in the publication list.

- **RA4 Risk assessments**, including Potential Nuclear Events. The most comprehensive case, a potential release from waste tanks at Sellafield and deposition in Norway, links potential release and deposition to ecosystem transfer and impact and risks (health, environment, economy and society). Emphasis have been put on key factors contributing significantly to the overall uncertainties when 8 different models from the source to the risks are coupled. We were pleased to see that the EU CONCERT 1st Call text 2016 corresponded very well to the CERAD concept (EU Confidence project awarded).

CERAD plays an active role on the international arena (e.g., ICRP, UNSCEAR, IAEA, IUR). The first years of CERAD, 124 articles are published/ in press. More than 100 conference presentations were given in 2016, and CERAD has supported conferences, workshops and courses organised nationally and internationally (see courses page 63 and attachment). CERAD MGs are board members of the European ALLIANCE and NERIS platforms, and CERAD Deputy director was elected President of the International Union of Radioecology 2016. In 2014, the CERAD Director was awarded the IUR 4th V. I. Vernadsky price, and 26. April 2016 the Chernobyl 30 year Memorial Medal (see more pages 51 and 52). She was also appointed Honorary Professor at National University of Environment and Life Sciences, Kiev, Ukraine, in 2016.

As the present research effort of CERAD has made significant contributions to the development of radioecology internationally, it is believed that the revised CERAD research focus for the next period will play a major role when priorities are set on the international arena in the years to come.

Organization of the research, management and administration of CERAD

CERAD is organized according to the application: The CERAD Board, the Management Group and the Extended Management Group including the Research Area leaders, The Scientific Advisory Committee and The Relevance Advisory Committee (Fig. 1). CERAD includes in total more than 100 part- or fulltime personnel, including close to 70 scientists, from all five partner institutes (see list of personnel page 67). The CERAD NMBU consist of scientists from five different departments within all three faculties.

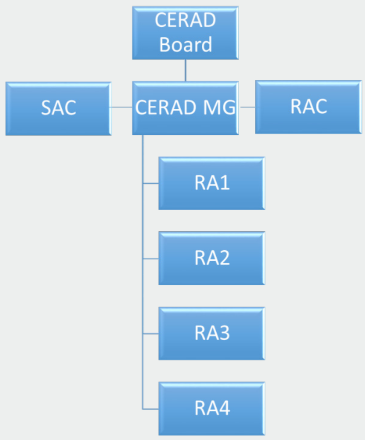

***Figure 1:** The CERAD research organization 2016*

The CERAD Board

The CERAD Board has 8 members, representing all partners and the scientific staff from all the partner institutions, where NMBU Pro-Rector of Research is chair and CERAD Management Director acts as secretary for the board. The CERAD Deputy Centre Director, Research Director and Education Director take part as observers only. The board meets twice/year to secure cooperation within CERAD, financial issues as well as effective well-functioning collaboration between the partners. The CERAD Board members for 2016 have been:

- Pro-rector Halvor Hektoen, NMBU, Chair
- Director Ole Harbitz, NRPA, Deputy chair
- Department Head Jan Vermaat, NMBU/IMV
- Division Director Toril Attramadal, NIPH
- Deputy Managing Director Tor-Petter Johnsen, NIVA
- Research Director Øystein Hov, MET
- Scientist Dag Anders Brede, NMBU
- Centre Director Brit Salbu, CERAD

CERAD Research Management

The CERAD Management Group (MG) is responsible for running the research management of the Center and consist of the CERAD principal investigators, headed by the CERAD Director, and the Management Director. The CERAD MG reports to the CERAD Board. Management Director is in charge of the day-to-day running, including budgeting, according to decisions made by Centre director and MG:

- CERAD Director: Brit Salbu, Professor, NMBU
- Deputy Centre Director: Per Strand, Department of Nuclear Safety and Environmental Radioactivity, NRPA / Professor II, NMBU
- Education Director: Lindis Skipperud, Professor, NMBU
- Research Director: Deborah H. Oughton, Professor, NMBU
- Management Director: Anja Nieuwenhuis, NMBU

The Extended MG includes MG and the Research Area (RA) leaders (2 leaders per RA, RA1-4), representing all CERAD partners. The RA leaders report to CERAD MG and CERAD Research Director. The CERAD research area leaders in 2016 were:

- **RA1:** Ole Christian Lind, NMBU + Jurek Bartnicki, MET
- **RA2:** Justin Brown, NRPA + Hans-Christian Teien, NMBU
- **RA3:** Peter Aleström, NMBU + Ann-Karin Olsen, NIPH
- **RA4:** Knut Erik Tollefsen, NIVA + Astrid Liland, NRPA

The research focus and priorities are based on the Strategic Research Agenda (SRA) and the defined Research Areas (RAs) developed from 2013 until 2017 by the Extended MG (Fig. 2). The total research budget is decided annually by the CERAD Board, and the CERAD scientist groups apply for funding to solve specific problems (subprojects).

The Extended MG meet once a month, to follow the progression of the funded research, to report findings that should be pursued (more funding from Flexfund needed), to suggest new or changed research topics, and to secure that the research is of international standard. Thus, the research management is quite flexible and research question directed; innovative ideas can be tested and most subprojects are interdiscip-linary and inter-institutional in collaboration with international scientists.

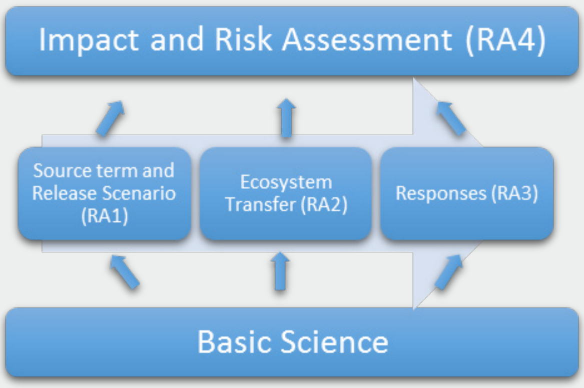

***Figure 2:** The research areas (RA) linked together*

CERAD Scientific Advisory Committee

CERAD Scientific Advisory Committee (SAC) is CERAD´s international scientific network, headed by the CERAD Research Director and includes 10 internationally well–merited scientists from 9 countries (USA, Ukraine, Slovenia, Belgium, Sweden, Canada, Australia, France/Japan, Ireland). SAC members have been actively involved in the development of the Strategic Research Agenda (SRA) and meet once a year at the CERAD annual conference. The Scientific Advisory Committee (SAC), CERAD international network 2016, has been:

- Dr. David Clarke, Glenn Seaborg Institute, LLNL, USA
- Professor Valeriy Kashparov, National University of Life and Environmental Sciences of Ukraine, Ukraine / Professor II, NMBU
- Professor Koen Janssens, University of Antwerp, Belgium
- Professor Peter Stegnar, Jožef Stefan Institute, Slovenia
- Professor Carmel Mothersill, McMaster University, Canada
- Professor Colin Seymour, McMaster University, Canada
- Professor Tom Hinton, Fukushima University, Japan / Professor II, NMBU
- Dr. Clare Bradshaw, Stockholm University, Sweden
- Professor Janet Bornman, Curtin University, Australia
- Dr. Marcel Jansen, University College Corc, Ireland

CERAD Relevance Advisory Committee

CERAD Relevance Advisory Committee (RAC) is headed by the CERAD Deputy Director and includes representatives from key Norwegian stakeholders/end-users (five Norwegian ministries/ directorates in 2016). The RAC meets once a year at the CERAD conference. In 2016 the RAC consisted of:

- The Ministry of Health and Care Services, Lisbeth Brynildsen
- The Ministry of Climate and Environment, Ingvild Swensen
- The Ministry of Foreign Affairs, Johnny Almestad
- Norwegian Radiation Protection Authority, Kristin Frogg
- The Ministry of Trade, Industry and Fisheries, Lars Føyn

CERAD Research

Research Groups and Collaboration

Rather than operating with separate research groups at the 5 different partner organizations, CERAD has integrated its research activities around four Research Areas (RA), led by Principal Investigators (MG Directors) together with RA leaders from all CERAD partners, and with the participation of key scientists from across CERAD in each RA. The MG Directors (Brit Salbu, Per Strand, Lindis Skipperud, Deborah Oughton) act as PIs and actively participate in research across all four areas, with responsibility for coordinating and ensuring the fulfillment of the planned research activities.

Research Area 1 – Source Term and Release Scenarios (RA leaders: Ole Christian Lind, NMBU/IMV and Jurek Bartnicki, MET). Partners: NMBU, MET, NRPA

Research Area 2 - Dynamic Ecosystem Transfer (RA leaders: Justin Brown, NRPA and Hans-Christian Teien, NMBU/IMV). Partners: NMBU, NRPA, NIVA

Research Area 3 - Biological Responses (RA leaders: Peter Aleström, NMBU/Vet and Ann-Karin Olsen, NIPH). Partners: NMBU/IMV, NMBU/IPV, NIPH, NMBU/Vet, NIVA, NRPA

Research Area 4 - Risk Assessment and Ecosystem Approach (RA leaders: Knut Erik Tollefsen, NIVA and Astrid Liland, NRPA). Partners: NMBU, NRPA, NIVA, NMBU/HH

Further details can be found in the Table "Research Projects 2016" (page 14), which lists recent subprojects carried out under the research areas. Full descriptions of the four Research Areas and their associated key umbrella projects and umbrella leaders are given in the following section "CERAD Research Areas: Objectives, Achievements and Highlights", together with the main PhD and PostDoc positions associated with each area. The research highlight sections provide additional information on the individual CERAD scientists contributing to each research area.

Collaboration across the Research Groups

By structuring its research activities according to science rather than partner location, the CERAD Research Areas foster a very high degree of collaboration and integration between partners within the groups and across the research areas (see Research Projects 2016, page 14). All research areas include participation of at least three CERAD partners. NMBU and NRPA participate in all research groups, while umbrella projects are led by scientists from all CERAD partners, to ensure that the specialist competence of individual partners, and CERAD's 69 part-time scientists, is used for the maximum overall benefit of CERAD research.
Further evidence of the high degree of collaboration can been seen in the research highlights (see later sections) and the research papers produced (i.e., Publication list). The majority of papers produced have participants from more than one partner, and many are co-authored with international scientists. Furthermore, CERAD PhD students benefit from co-supervision from different partners as well as SAC members.

Evolution of the CERAD Strategic Research Agenda

Additional information on the CERAD Research Areas can be found in the CERAD Strategic Research Agenda (SRA), which presents the CERAD research focus, hypothesis and approaches to testing those hypotheses (e.g., http://cerad.nmbu.no). In addition to describing key challenges within individual research areas, the SRA also forms the basis for decisions about needs and priorities for personnel, experiments, and equipment within CERAD. The original SRA was structured around four overarching Research Areas: RA1 Source Term and Release Scenarios; RA2 Ecosystem Transfer, RA3 Biological Effects, RA4 Risk Assessment, together with a transient research area focusing on RA5 UV Exposure. The intention was that, when the UV research area had consolidated their joint scientific fundament, the group would merge into the other research areas. By the end of 2014, CERAD had supported subprojects ranging from small pilot studies to large projects involving all partners. To focus and to better stimulate cross-partner activities within the research areas, an updated SRA was produced for 2015-2016, with an emphasis on eight large umbrella projects, covering the needs in RA1-4:

- **UMB1** – Particle sources and effects;
- **UMB2** – Dynamic transfer;
- **UMB3** – Radiosensitivity;
- **UMB4** – Combined Toxicity and Cumulative Risk;
- **UMB5** – Transgenerational effects;
- **UMB6** – Ecosystem approach;
- **UMB7** – UV/ionising radiation and dosimetry; and
- **UMB8** - Case Studies and Scenarios.

The current SRA (2017-2021) presents an overview and evaluation of CERAD research activities and achievements over the past 4 years, and sets priorities for the next five year period. In accordance with the original research plan, UV research has now been merged unto the four RAs and their associated umbrellas.

The following sections present a brief summary of the four CERAD research areas and their major achievements over the past 4 years. This is followed by a selection of research highlights from each area. Full references for the work carried out can be found in the list of scientific articles in appendix A of this and previous CERAD Annual Reports. A summary of the research priorities for the next five years can be found in the SRA 2017 – 2021.

CERAD Research Director, Professor, Deborah Oughton
Photo: Quentin Mennecart

CERAD research projects 2016	Project leader	NMBU*	NRPA	NIVA	NIPH	MET
Research Area 1						
Particle Characterisation	OCL	X				
Atmospheric and Marine Modelling	HK	X	X	X		X
Research Area 2						
Dynamic Transfer - daphnia	TG	X		X		
Dynamic Transfer - salmon	HCT	X				
Dynamic Transfer - reindeer	LS		X			
Dynamic Transfer - rodents	RG		X			
Arsenic Analysis	LS	X				
Fieldwork Tracer	DHO	X	X			
Research Area 3						
Toolbox/radiosensitivity - mitochondria/mice	AKO				X	
Toolbox - ChIP	LL	X				
Toolbox/Radiosensitivity - ROS/Plants	JEO	X				
Radiosensitivity - daphnia	TG	X		X		
Radiosensitivity - salmon	HCT	X				
Radiosensitivity - nematodes	DAB	X				
Radiosensitivity - earthworms	EL	X				
Mix tox - lemna	KET	X		X		
Mix tox - salmon	HCT	X		X		
Mix tox - nematodes	DAB	X				
Mix tox - mice/cells	AKO				X	
Mix tox - earthworms	EL	X		X		
Transgeneration - mice	AKO	X			X	
Transgeneration - zebrafish	PA	X				
ChiP - daphnia	JT	X		X		
UV/gamma	TC	X	X	X	X	
Research Area 4						
Cosms - aquatic and terrestrial	TH	X	X			
Western Norway - Economic impact	SN	X				

* NMBU includes five departments at three faculties.

Research Areas: Objectives, Major Achievements and Research Highlights

Research Area 1 – Source Term and Release Scenarios

A series of nuclear/radiological and non-nuclear sources have contributed, are contributing or can contribute in the future to the release of radionuclides to the environment. Following nuclear events, a major fraction of refractory radionuclides such as uranium and plutonium will be present as particles, ranging from sub-microns to fragments. Thus, particles are an essential part of the source term, and particle characteristics are essential for the ecosystem transfer, accumulation and effects. To improve the predictive power of impact assessment models, key research questions for RA1 are:

- How do release scenarios impact the source term; radionuclide and multiple stressor composition and speciation, in particular the nm - µm sized particle characteristics?
- What is the relevance of particles and colloids to air/water transport, deposition, ecosystem transfer and exposure models?
- Can a common dose concept be developed for UV and ionizing radiation?

Research Area 1 comprises three umbrella projects:

Umbrella 1A: Particle Sources (O.C. Lind, NMBU/IMV): The main research focus is to improve advanced techniques for characterization of particles (synchrotrons, micro-CT, AMS) from the unique NMBU archive, to link particle characteristics to specific sources and to link particle properties to ecosystem transfers (RA2) and biological effects (RA3). The underlying hypothesis is that failing to address the speciation of radionuclides can result in significant errors in the assessment and modelling of the environmental impact of radioactive contamination, since particles show marked differences in behaviour from the – often presumed – ionic species on which models are based.

Umbrella 1B: Dispersion Modelling: Atmospheric and Marine (J. Bartnicki, MET): The main objective is to improve atmospheric and marine dispersion models for predicting transport of radioactive releases (e.g., implement particle codes) and to enable identification of unknown sources contributing to radioactive releases. As most atmospheric and water dispersion models suffer from large uncertainties due to poor parametrization, emphasis is put on source term input codes, improved resolution and probability of transport from a given source. Improvements of marine modelling is focused on coupling Lagrangian transport models (e.g., LLM species, colloids and particles) to the ROMS ocean model.

Umbrella 1C: UV/Ionising Radiation and Dosimetry (T. Christensen, NRPA): Dosimetry is a central task in CERAD and covers both UV and ionizing radiation. It includes the implementation of dosimetry systems, characterizing and monitoring dose during irradiation experiments, and improving field dosimetry and wildlife dosimetry by using passive dosimeters combined with GPS monitoring. Research includes development of a common dose concept for ionizing and UV radiation, to utilize the UV–network and the UV–dose maps in areas affected by radioactive fallout or NORM for risk assessment purposes.

Major Achievements 2013-2016

Particle Sources: Key efforts have focused on the characterization of particles originating from different sources and release scenarios. Results show that particle composition depends on the source, while the release scenarios influence particle properties important for ecosystem transfer. CERAD data has been summarized in the 2nd edition Plutonium Handbook (Geickels *et al.*, in press). Research showed that radioactive particles and colloids influence transport (Wendel *et al.*, 2015), that particles can be retained in biota (mussels, snails, nematodes) and cause skin damage and effects on a molecular level (Jaeschke *et al.*, 2015), and that exposure of fertilized salmon egg to U nanoparticles can delay hatching.

Advanced synchrotron based analytical techniques have been further developed, such as 2D and 3D XRF, XRD and XAS for micro and nanometer-sized particules in close collaboration with the University of Antwerp. Particle characterization at the nm scale has been explored using state-of-the art technology, at the recently installed nanometer resolution synchrotron beam lines at ESRF, Grenoble and Petra III, Hamburg. The localization of nm particles surrounding nematode embryos was selected as "The beauty of science" by ESRF in 2015 (Cagno *et al.*, 2015). CT-tomo has been performed in Poland, and AMS in Spain and Australia.

Air and marine transport modelling: The application of long-term deterministic meteorological data and meteorological ensembles has contributed to a better understanding of climatological and meteorological impacts on transport and deposition of radioactive particles. Efforts have been put on the inclusion of particles codes into the air and marine transport models, and to improve the resolution of the modelling. Data on particle characteristics from the NMBU Particle archive has been used as input variables. Probability estimates based on real time meteorological observations during the last 33 years have been performed, demonstrating that sources in UK represent a higher risk to Norway than dumped objects in the Arctic (Bartnicki *et al.*, 2016). For "worst case scenario" associated with a potential Russian nuclear submarine accident at Kola, the implementation of particle codes demonstrated that not only aerosols, but also radioactive particles can reach Norwegian territory in a relatively short time.

Modelling the marine dispersion of fallout from the Fukushima accident revealed that much of the discrepancies between estimates from five different ocean models were due to differences in how mesoscale transport was parameterized. Marine modelling has been improved by the inclusion of a particle code/speciation and by implementing small-scale resolution. Parameterization of small-scale vertical mixing and lateral stirring by the oceanic eddy field has been utilized for the historic 99Tc releases from Sellafield. Focus has also been put on transformation processes affecting radionuclide species in mixing zones such as estuaries. There is currently no integrated model that takes into account source term, atmospheric transport and deposition, catchment run-off to estuaries and further marine transport.

Dosimetry: Work has focused on laboratory experiment dosimetry, where sources of errors for external exposure include irradiation geometry, scatter conditions, tissue heterogeneities, and set up reproducibility. Dosimetry calculations associated with internal exposure of test organisms exposed to tracers or particles, as well as in biota collected during fieldwork are ongoing, including evaluation of the uneven distribution of doses at the micrometer scale. Passive dosimeters have been mounted on GPS collars of moose and reindeer in order to improve assessment of doses to wildlife. In 2017, dynamic GPS dosimeters will also be applied to brown bears within the Scandinavian Bear Project.

CERAD has developed a unique gamma + UV climate chamber to study combined effects of these stressors (See also UMB3B). Dosimetric evaluations are ongoing with the aim to consolidate a common dose concept of gamma and UV exposure. A risk factor has been developed for UV and visible light exposure of sensitive persons, by which patients can be guided with respect to outdoor exposure. Using the UV-network data in risk assessment of human and environmental exposures, a UV-dose map has been constructed and could be used in combination with a radioactive fallout map, in case of an accident or at NORM sites. Albedo models have also been implemented to account for snow and land cover.

PhD and PostDocs: *PhD M. Simonsen (MET, NMBU/IMV), PhD J. Antonio (NMBU/IMV), PhD Lisa Rossbach (NMBU/IMV); PostDoc E.L. Hansen (NRPA)*

Research Highlights: Source Term and Release Scenarios

RETENTION OF RADIOACTIVE PARTICLES IN BIOTA

O.C. Lind, B. Salbu (NMBU/IMV), R. Garcia-Tenorio, I. Vioque (University of Seville), S. Cagno (NMBU/IMV, SCK•CEN), K. Janssens, G. Nuyts, F. Vanmeert (University of Antwerp), J. Jaroszewicz (NMBU/IMV, Warsaw University of Technology)

Objectives: To demonstrate radioactive particle retention in biota that may be of relevance for the human food pathway and to characterize the exposure to biota.

Methods: Snails were collected from the Palomares site and samples subjected to digital autoradiography, gamma spectrometry, nano-CT, bench-top micro-XRF, and synchrotron radiation based submicron XRF at beamline P06, Petra III, Hamburg.

Results: The results showed that Palomares snails (*Sphincterochila candidissima*) are exposed to radioactive U/Pu particles originating from the Palomares nuclear accident as well as NORM particles through ingestion of soils. U/Pu and U/Th containing particles were identified in snail faeces. Furthermore, a long-term retention of radioactive particles was demonstrated by utilizing a combination of nano-CT and bench-top micro-XRF analysis that revealed a U/Pu particle embedded within the shell of one of the soil dwelling snails (Fig. 3 and 4). Such retention in biota would be expected to influence the long-term dose to the animals.

Figure 3: *Snail shells from Palomares.*

Conclusion: Radioactive particle retention in biota calls for better exposure characterization in impact assessments of particle contaminated areas, in particularly when the biota is of relevance for the human food pathway such as the local gastropod delicacies of Palomares.

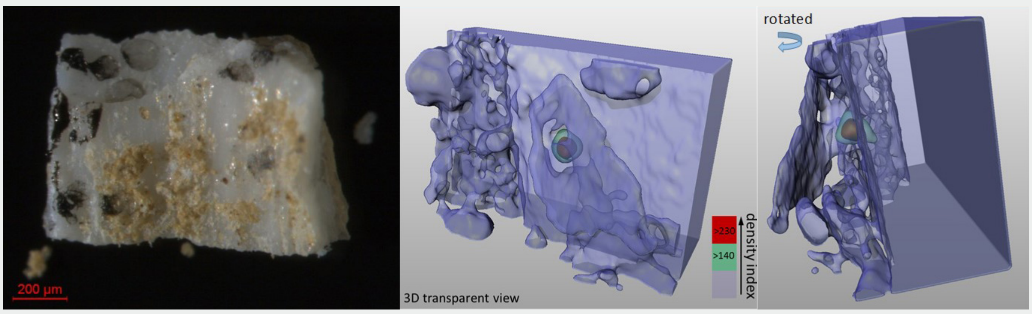

Figure 4: *Retention of a U/Pu particle in snails at Palomares. A) Piece of snail shell contaminated with ^{241}Am. B) Nano-CT rendering of the shell piece showing the 10 µm U/Pu particle as high absorption material (reddish brown). C) The tomographic rendering in C rotated to show the particle partially embedded within the shell.*

RADIOACTIVE PARTICLES CAN CARRY A SERIES OF RADIONUCLIDES AS WELL AS A RANGE OF STABLE TOXIC ELEMENTS

O.C. Lind (NMBU/IMV), S. Cagno (NMBU/IMV, SCK•CEN), K. Janssens, G. Nuyts, F. Vanmeert, J. Van Beeck (University of Antwerp), J. Jaroszewicz (NMBU/IMV), B. Salbu (NMBU/IMV, Warsaw University of Technology)

Objectives: To characterize particles from contaminated sites with respect to the internal heterogeneous distributions of radionuclides and other toxic elements, of relevance for environmental impact assessments associated with particle-contaminated sites.

Methods: Samples from contaminated sites were screened for heterogeneities using digital autoradiography. Particles were isolated and characterized using a series of advanced nano- and microanalytical techniques (digital autoradiography, ESEM-EDX, nano-CT, bench-top micro-XRF, synchrotron 2D/3D XANES/XRF/XRD).

Results: Heterogeneous distributions of radionuclides in soils and sediments reflect the presence of radioactive particles. Based on digital autoradiography, single particles were isolated. Based on ESEM-EDX, specific element enriched spots were localized, while the use of micro-XRF provided quantitative mapping of a series of elements, as shown for Hg and U (Fig. 5). Digital autoradiography, ESEM-EDX as well as micro-XRF serve as a preparatory means for nano-CT and synchrotron radiation techniques. Based on the unique particle archive and experience from >20 years of particle research, particle characteristics such as composition depend on the releasing source, while size distributions, crystallographic structure and oxidation state also depend on release scenarios. Based on recent NMBU/CERAD projects on particles associated with TENORM sites and accidental release sites, heterogeneous distributions of radionuclides and toxic trace elements in soils and sediments should be expected on a macro-level as well as on a µm scale.

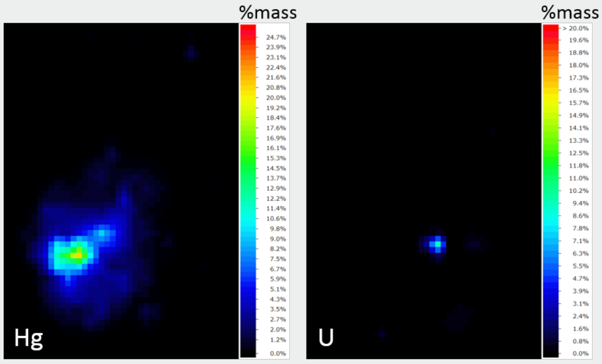

Figure 5: *Micro-XRF (M4 Tornado, Bruker Nano) quantitative mapping of Hg and U in a heterogeneous particle isolated from Ottawa River sediments originating from the Chalk River nuclear site. Elements identified include: Cr, Ni, Cu, Zn, As, Zr, Hf, Mo, Hg, Pb and Th as well as U. Bar 1 mm.*

Conclusion: Radioactive particles can carry a series of radionuclides of radiological concern. Particles can also carry a range of stable elements, representing a multiple stressor issue. Thus, information on the extent of particle contamination and the potential mobilization of particle-associated contaminants is considered essential for assessing ecological risks in particle-affected areas.

References:

Lind, O.C. *et al.* // Journal of Environmental Radioactivity. 2013, 123, 63-70.

Salbu, B. *et al.* // in: Walther, C., Gupta, D.K. (Eds.), Radionuclides in the Environment - Influence of chemical speciation and plant uptake on radionuclide migration. Springer International Publishing, 2015, pp. 1-36.

SYNCHROTRON X-RAY NANOIMAGING SHOWS UPTAKE AND SPATIAL DISTRIBUTION OF METAL IONS AND NANOPARTICLE IN INTACT ORGANISM

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Objectives: Synchrotron X-ray nanoimaging techniques have enabled the investigation of spatial elemental distribution and speciation including oxidation states and crystallography with nanometer resolution. The objective of the current project was to investigate uptake, internal distribution, fate and toxicity of metal ions and nanoparticles at the cell level in an intact organism. To achieve this we employed the nematode *Caenorhabiditis elegans*, a model organism featuring a transparent body, short life cycle and ideal size (1 mm) for this purpose.

Methods: Exposure of the full life cycle of the nematode *C. elegans* (ISO10872, 2010) to Co-NP or Co ions (17-17000 µg/L). The effect endpoints were development, growth, fertility, reproduction and mortality. Tissue and cell distribution and fate of the NP were analysed using CT, 2D XRF tomography at the ESRF ID16A synchrotron nanobeamline.

Results: Co-NP were readily ingested by *C. elegans*, but nematodes were able to develop normally and reproduce at NP concentrations of up to 1.7 mg/L. Toxic effects/reproduction failure were seen only at the highest exposure concentrations of NP (17 mg/L). High resolution phase contrast renderings (3D) and elemental maps (2D and 3D) were obtained of the whole body, organs and tissues (Fig 6). The elemental maps allowed the visualization of Zn and Fe granule containing organelles and demonstrating that Co^{2+} ions accumulate in intestinal cells. Co NP were found to be abundant in the intestines of exposed and subsequently depurated animals. The Co NP associated to intestinal epithelium, but were also translocated outside the intestinal lumen. Indeed, individual Co NP-aggregates were located inside uterus in the vicinity of developing embryos.

Conclusion: This study has established a state-of-the-art nm-resolution non-invasive image analysis for the investigation of internal distribution of essential elements as well as toxic metals in an intact animal using *C. elegans* as a model. This approach will facilitate nm resolution characterization of radionuclide uptake and exposure in tissues or in intact animals.

References:

This work was selected as Beauty of science in the ESRF News, July 2015.

Cagno S. *et al.* // Analytical Chemistry (submitted).

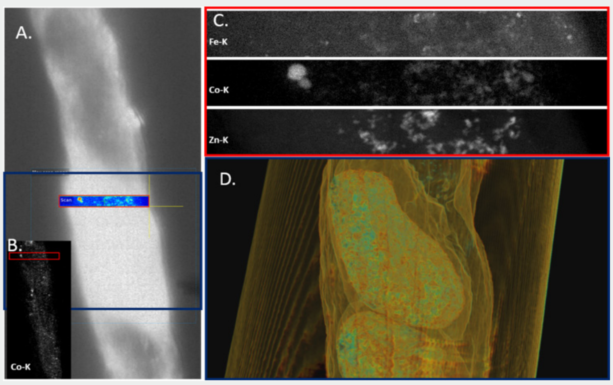

Figure 6: *Two dimensional X-ray mapping of Co in an exposed non-depurated nematode intestine and surrounding tissues. (A.) Optical microscope view with the mapped areas indicated (rectangles). (B.) Coarse 2D-XRF element map of Co using 400 nm step size. (C.) Fine 2D-XRF element mapping of Fe, Zn, and Co, (40 nm step size) majority of Co associated with intestinal tissues but also located in proximity to embryo. (D) 3D reconstructed phase contrast nano-CT (50 nm3 voxel size) showing abundant Co-NP in the intestine and inside the uterus proximal to embryos.*

FROM SELLAFIELD TO NORWAY - WORST CASE SCENARIO

H. Klein and J. Bartnicki (MET)

Objectives: A hypothetical accident at the Sellafield nuclear facility has always been of concern for Norway, because of typical meteorological conditions with prevailing westerly winds in the region. Such conditions indicate a high probability of atmospheric transport of the radioactive cloud to Norway in case of an accident. Therefore, we aimed to quantify the probability of radioactive fallout reaching Norway in case of such an accident and to quantify the maximum deposition levels assuming a worst case scenario.

Methods: A long term (33-years) historical meteorological database was used to perform simulations with the SNAP model, assuming aerosol transport. The SNAP model was run twice a day for the entire period and deposition calculated for each model run. Next, the statistical analysis was performed and the worst case meteorological scenario selected.

Results: Based on the results of SNAP simulations, maps of probability of arrival were created (Fig. 7) and the statistics of the transport time analysed. The probability of deposition in western part of Norway is very high (25-40 %), but it is also relatively high for southern Norway (15-25 %). The very high probability area over the Western coast of Norway is due to very frequent and intensive precipitation, which causes effective wet deposition of radionuclides. The worst case meteorological scenario occurred on the 13th of April 1984. The deposition map for this scenario is shown in Fig. 8. The deposition on the western coast of Norway for this scenario is very high, but deposition over the entire southern Norway is also significant.

Conclusion: The probability of arrival to Norway from a hypothetical accident at Sellafield is high. Such an accident, in the worst case meteorological conditions, can pose a serious threat to western Norway, as well as to the southern part of Norway.

References: Heiko K. and J. Bartnicki // Proceedings of the 35th International Technical Meeting on Air Pollution Modelling and its Application. Chania, Greece. 3-7 October 2016 (accepted for publication in the book).

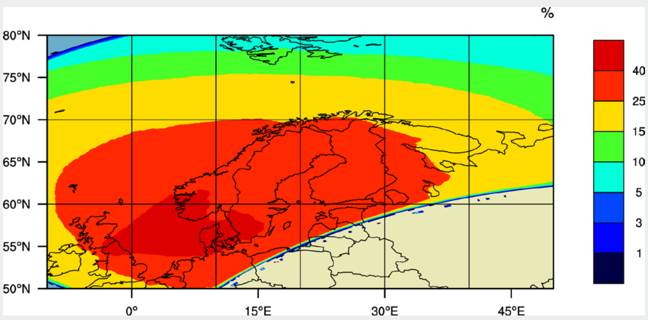

Figure 7: Map with probability of arrival of radioactive cloud to a given location from a hypothetical accident in the Sellafield nuclear facilities.

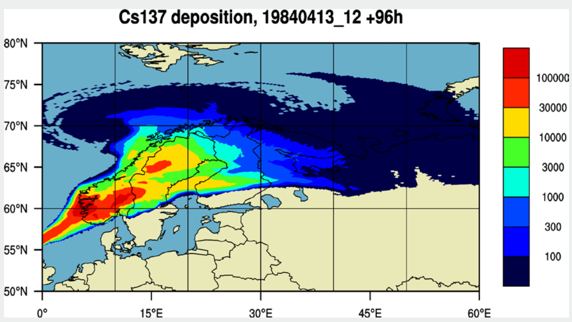

Figure 8: Deposition map for Cs-137 from the worst case scenario for hypothetical accident. Units: Bq.m^{-2}.

"WORST PLACE SCENARIOS" FOR NUCLEAR ACCIDENTS IN THE NORTHERN MARINE ENVIRONMENT

J. Brown, M. Dowdall, A. Hosseini, P. Strand (NRPA)

Objectives: The North and Nordic Seas contains some of the world's most important fishery resources and is an area of significant traffic involving nuclear powered vessels and transports of nuclear and radioactive materials. Consumer awareness to even rumors of radioactive contamination imparts a special vulnerability to this region. The effective assignation of emergency resources, design of monitoring programs and provision of information regarding accidents relies upon an a-priori analysis of potential impacts. The objective of the work was thus to complete a sensitivity analysis regarding potential impacts on the most important regional fishery (selected as the Lofoten area) with a view towards development of a system capable of providing information regarding potential contaminant dispersal from any point within the North and Nordic Seas.

Methods: A 3D hydrodynamic oceanographic model called NAOSIM formed the basis for this analysis. An adjoint of that model, called ADNAOSIM, was used to determine the sensitivity of the output (ie. water concentration at Lofoten) to the geographical location of the input (i.e. the release point). In a similar way as a backtrajectory calculation, all sensitivities in the region of interest are provided by a single run of ADNAOSIM, which propagates the sensitivity information backwards in time from the target area.

Results: The simulations indicate that the area is potentially vulnerable to releases of radioactive materials over a much wider area than was previously considered (Fig. 9).

Conclusions: The scientific output of databases and maps will allow us to assess relatively rapidly, in advance, individual transports of radioactive material, (potential routes and various accident scenarios) before the transports actually take place.

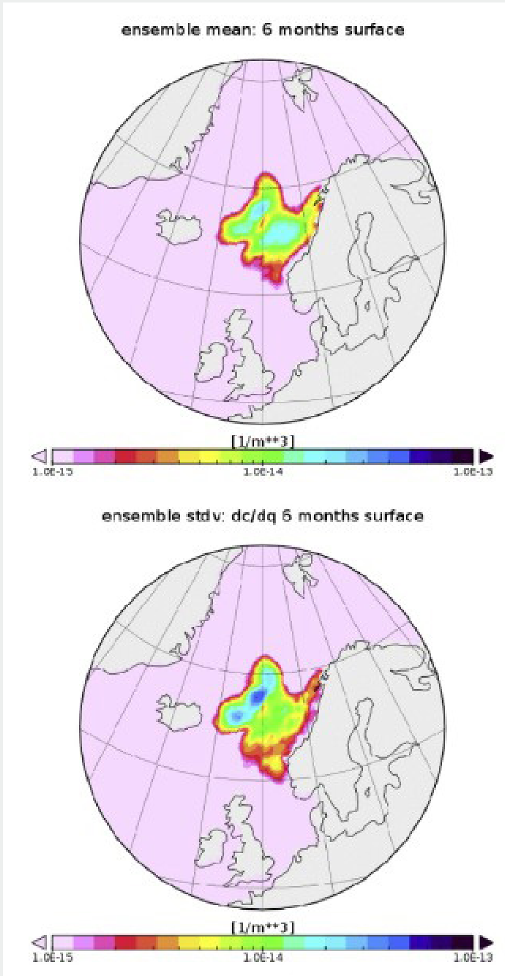

Figure 9: *Maps of the sensitivity of the target area within six months of a surface release*

References: Kauker, F. *et al.* // Environmental Modelling & Software 77, 2016, 13-18

Research Area 2 - Dynamic Ecosystem Transfer

The overall objective of RA2 is to improve the parameterisation of radionuclide transfer in the environment through a systematic implementation of dynamic approaches and to refine extrapolation methods. The initial strategy involved the formulation of three research themes encompassing bespoke research questions and hypotheses. It was anticipated that addressing these themes would facilitate a reduction in uncertainty and allow better characterization of variability in the parameters defining radionuclide transfer. The research focused especially on:

- Mobility of radionuclides, taking speciation into account;
- Uptake and accumulation in organisms – influence of environmental factors, and
- Uptake and accumulation in organisms – influence of biological factors, covering naturally occurring radionuclides, as well as transuranics and fission products.

RA2 was considered an important link between all other RAs with the requirement to couple information between Source Term and Release Scenarios (RA1) and transfer, the efficacy of studying transfer in tandem with biological response (RA3), coupling toxicokinetics to toxicodynamics, and the fact that transfer forms an integral part of Risk Assessment (RA4). Thus, RA2 includes fieldwork performed in Norway or other countries, and is focused on improved understanding of dynamic transfers in relation to aquatic ecosystems and terrestrial ecosystems, to replace transfer constants based on equilibrium concepts with time functions. Comprehensive data related to Pu – isotopes and speciation, mobility and dynamic ecosystem transfer in the environment has also been summarized in the new revised 2nd Plutonium Handbook (Geickels *et al.*, in press). Since 2013, RA2 has focused on improving models towards a more dynamic approach instead of assuming equilibrium conditions and steady-state, and to link speciation, mobility, transfer and biological uptake to effects in environmental organisms.

Major Achievements 2013-2016

<u>Fieldwork:</u> During the first years of CERAD, several fieldworks have been performed, studying mobility, transfer and biological uptake of radionuclides in the environment along with other contaminants (i.e. metals) to identify actual Kds, concentration ratios (CR) and transfer coefficients (TF/TC/Tag, BCR). Field expeditions to both NORM sites and sites contaminated from nuclear accidents have been performed, including both aquatic and terrestrial environments. NORM sites include both U-rich sites (i.e. sites with alum shale) and a Th-rich Fen site in Norway. A series of fieldwork at accidental contaminated sites have been performed during the years, including extensive expeditions to the Barents and Kara seas (USSR K27 and K159 submarines), Palomaris, Spain, as well as to exclusion zones in Chernobyl, Ukraine and Fukushima, Japan, representing different source terms and ecosystem transfers and allowing comparative studies to be performed.

<u>Dynamic transfer studies:</u> Mobility of radionuclides has been studied in several cases and in different ecosystems. To date, most work has been focused on aquatic ecosystems, including in situ fractionation of radionuclides and metals in water (e.g., NORM sites, Chernobyl, Fukushima), investigation of radionuclide species in runoff (e.g., Chernobyl exclusion zone, Bondar et al., 2015), in-lab fractionation of species in water (e.g., changes in the U-speciation when exposed to UV radiation using FFF-ICP-MS), and identification of biomolecules in biological fluids and tissues (HPLC-ICP-MS). Extensive work has been put on uptake of uranium-species in Atlantic salmon, from fertilized eggs to swim-up, including the influence of environmental factors (pH, major ions, metals, temp) on the speciation of U and uptake in salmon (Gilbin *et al.*, 2015). When fertilized eggs were exposed to U nanoparticles, hatching was delayed. The influence of biological factors on radionuclide transfer was explored by taxonomic relationships corresponding to radiocaesium transfer to marine

biota and through dynamic model inter-comparison (Vives i Batlle *et al.*, 2016). Controlled model experiments with daphnia and salmon have allowed the dynamics of U uptake, distribution and depuration to be characterized. Extensive model experiments with Atlantic salmon have also allowed quantification of U distribution among tissues, demonstrating that gill deposition acts as a source to the liver. Recent results indicate that the uptake of radionuclides in fish is significantly lower than expected, when "clean" fish are installed in a contaminated Chernobyl lake during the autumn-winter season.

Mobility studies in terrestrial ecosystems include investigations of transfer of stable analogues to plants and animals at a reference site in Tjøtta, Norway (Thørring *et al.*, 2016), and transfer of radionuclides to birch and pine in the Chernobyl and Fukushima exclusion zones. The studies in Chernobyl have shown very high uptake of Sr-90 from ground water, through birch and pine, to lichens growing on tree surface. Transfer of NORM nuclides along with metals have been studied from soil to plants and to earthworm in U-sites and in the thorium rich Fen area in Norway (Mrdakovic Popic *et al.,* 2014), as well as in Chernobyl and Fukushima. Based on extensive fieldworks in 2016, the mobility and transfer of radionuclides in terrestrial ecosystems will be investigated in more detail in 2017.

<u>Linking transport models and ecosystem transfer:</u> The key efforts have been to develop methodologies that provide a link between deposition, ecosystem transfer and ecosystem effect models. This includes the application of the dynamic ERICA tool for the Fukushima impact assessment, which was used in three White papers to the UN General Assembly from a UNSCEAR committee chaired by the CERAD deputy (e.g., see UNSCEAR, 2014, Strand *et al.*, 2014; Vives i Batlle *et al.*, 2014). Other examples, include the provision of a system characterizing potential contaminant dispersal and transfer to Norwegian fisheries from any point within the NE Atlantic (Kauker *et al.*, 2016) and (transfer based) risk indices for managing incidents involving the transport of nuclear materials in Northern Seas (Brown *et al.*, 2016c). With regards to links with modelling in RA2 and RA4, dynamic transfer modelling has been an important factor for assessing impact from hypothetical releases from dumped nuclear objects in the Arctic (Bartnicki *et al.*, 2016; Brown *et al.*, 2016b). Ongoing studies on reindeer in the Jotunheimen area of Norway have allowed transfer to be modelled accounting for spatial and temporal factors. To improve knowledge on transfer of radioactive iodine, controlled I-131 tracer experiments with fistulated cows been performed to improve the biokinetic model. Field experiments with I-131 tracer were also initiated at NIBIO's facilities in the west coastal area and inland in 2016, focusing the influence of climate/precipitation on transfer of iodine isotopes. Although dynamic transfer models have not, as yet, been included in standard assessment methodologies, the ongoing activities of Umbrella 2, in relation to extrapolation methods, have facilitated the further development of the ERICA Tool (Brown *et al.*, 2016a).

PhD and PostDoc Positions: *PhD F. Wærsted (NMBU/IMV), PhD C.B. Strømme (NMBU/IMV), PhD M. Kleiven (NMBU/IMV), PhD E. Alvarenga (NMBU/IMV, NIBIO; PostDoc S., Nehete (NMBU/IMV), PostDoc P. Lebed (NMBU/IMV).*

Research Highlights – Dynamic Transfer

URANIUM SPECIATION, UPTAKE AND TOXICTY IN ATLANTIC SALMON (SALMO SALAR L.)

H.C. Teien, D.A Brede, Y.A Kassaye, T. Hertel Aas, O.C. Lind, Z. Keke, L. Skipperud, B.N. Sone, D.H. Oughton, B.O., Rosseland, B. Salbu (NMBU/ IMV), H. Thørring, L.K. Jensen (NRPA)

Objectives: To study the bioavailability and toxicity of uranium (U) towards fish at different life stages and the influence of competing cations, U toxicity experiments were conducted with Atlantic Salmon (*Salmo salar L.*) juvenile parr and embryos.

Methods: Atlantic Salmon juveniles parr were exposed (96h) to depleted uranium (DU) at 5-7 nominal concentrations in range 2 to 100µM for acute toxicity tests (OECD, 1992), while salmon eggs were exposed (90 days) to DU in the range of 0.2 to 4.2 µM (OECD 2013). Speciation (size fractionation), tissue accumulation (gill, liver, egg) and induced toxicity of DU as a function of varying water concentrations of H^+, Ca^{2+}, Mg^{2+}, Na^+ and K^+ were studied in juveniles, while in very soft EPA water only for embryos. XRF imaging at Petra P06 and nano-CT was used to determine the U distribution in gills and eggs, respectively.

Results demonstrated that U was predominantly present as low molecular mass species, <10 kDa independent upon pH and water concentration of ions tested. U accumulated in fish gills and was transported to liver. Concentration of U in both tissues increased with U concentration in the water and with decreasing pH (Fig. 10). XRF imaging demonstrated U correlation with cartilage, an internal source as liver uptake increased after transfer of fish in clean waters.

U concentration in gills (independent of water quality) correlate with effects (Fig. 10 and 10 bis). Changes in gene expression were observed at gill concentrations >0,034µM U/g dw gill. Ion regulation dysbalance and stress response (change in blood plasma Cl and blood glucose) occured at gill concentrations >0.21µM U/g dw gill, progressing into mortality at gill concentrations >0.34µM. The LC50 value increased dramatically from 4.2 to 108 µM U with increase in pH 5.2 to 7.8, respectively. Thus, U bioavailability and toxicity is highly dependent upon pH and U speciation.

Exposure of eggs, from fertilization until hatching demonstrated time dependent uptake of U. Developmental effects arised at ≥2 µM U. Moreover, a 100 % mortality occurred at three fold lower concentration than the juvenile stage LC50. Thus, early developmental stage of atlantic salmon was more sensitive to U compared to juveniles. Using comet assay DNA damage and genotoxic effects were evident at ≥2µM U. Changes in ROS enzyme activities (CAT and GPx) demonstrated that oxidative stress defense was affected. Alevins

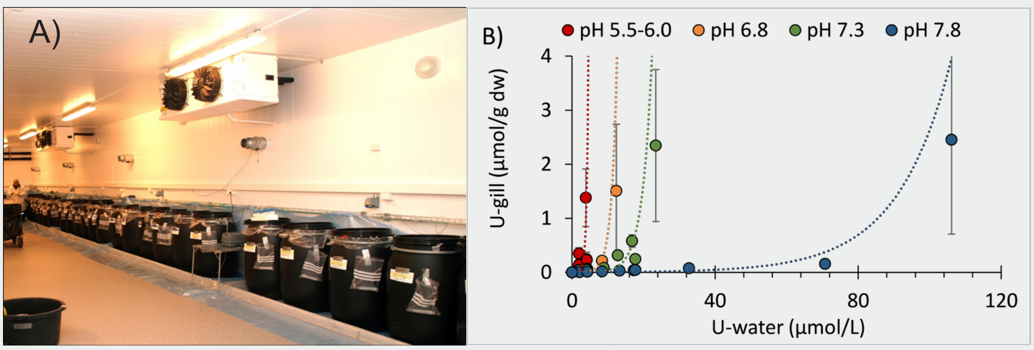

Figure 10: *A) Design juvenile exposure, B) Relationship between U in unfiltered water and accumulation in gills*

from eggs exposed to 2μM U or lower developed to swimup and start feed, despite that the concetration of U in small juveniles were significantly elevated 6 months after the end of the exposure.

Toxic mode of action (MOA) identified by differentially expressed genes of juvenile gills were related to ROS, DNA/protein damage, mitochondrial disturbance, ion transport, immune system. Thus, the identified MOA at molecular lever was linked to physiological effects and reduced survival at high concentration.

Conclusion: The findings highlight that uptake and toxicity of U is dependent upon speciation where pH is a key factor. U uptake is geneotoxic, and causes ion dyshomeostasis. It would appear that embryogenesis is more sensitive towards U than the juvenile stage, and that the body retenitontime of U seems to be very long.

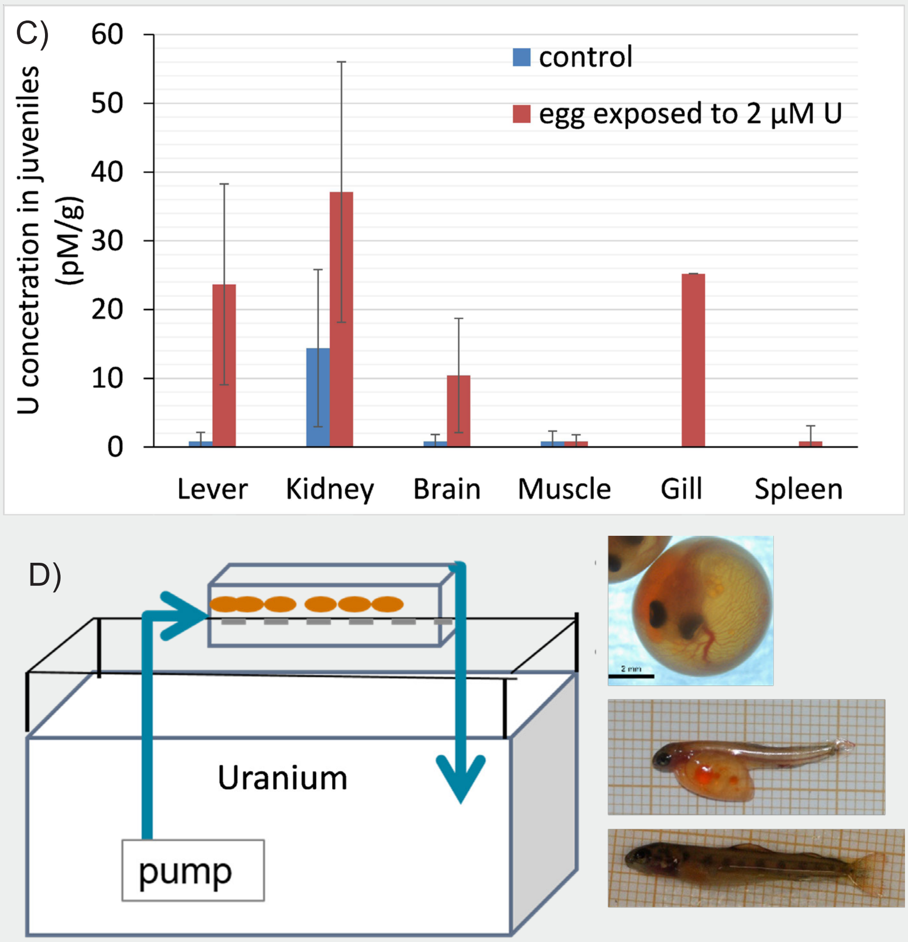

Figure 10 bis: *C) Design egg exposure, D) U-tissue concentration in developed juveniles of U exposed eggs.*

EXPOSURE, EFFECT AND RISK OF NORM AND METALS - CASE ROAD AND TUNNEL CONSTRUCTION IN ALUM SHALE AREAS

L. Skipperud, H.-C. Teien, F. Meen Wærsted (NMBU/IMV), K.E. Tollefsen (NIVA)

Objectives: To assess the mobility, uptake and effects of naturally occurring radionuclides and metals from alum shale, in order to evaluate environmental impacts and risk.

Methods: Fieldworks have been carried out at tunnel- and road construction sites in Gran (Rv4), Norway, both before construction started and while it was ongoing. Fractionated water, sediments, fish organs, benthos, soil and plants were samples. Time dependent uptake of U and metals in fish organs from alum leachate waters were studied in the lab. Radiological risk to environmental organisms was assessed using ERICA tool (http://www.erica-tool.eu/) and the cumulative risk assessment (CRA) of NORM and metals predicted by the NIVA risk assessment database (www.niva.no/radb).

Results: Concentrations of U and other metals varied but were higher in the affected area compared to the reference site, and in certain cases above the threshold of regulatory concern (WHO drinking water guideline and Environmental Quality Standards, EQS). Fish studies showed uptake of U, Cd and Mo in gills, liver and kidney. Biota samples taken after construction started tended to be higher. The Po-210 concentrations were low, but calculated concentration factors (CF) were above world averages for freshwater fish. No effects were observed in the fish, probably due to uptake of U, Cd and Mo not reaching critical levels in the near-neutral pH and high level Ca^{2+} water. Collection of benthos during construction work, showed elevated levels of metals in mayfly, a generally lower diversity of species and a higher proportion of tolerant compared to sensitive species (ASPT Index score). The ERICA Tool indicated that radiological exposures were low, except in one site where the level exceeded the screening dose rate of 10 µGy/h for crustaceans and benthos. Since the cumulative risks associated with metals (especially Zn, Ni, Co) suggested a risk for crustaceans, there is a potential for multiple stressor effects (radiotoxicity and chemical toxicity) in crustaceans. Future activities will focus on experimental evaluation of the risk predictions associated with freshwater crustaceans (*D. magna*).

Conclusion: During the road and tunnel construction increased uptake of radionuclides and metals in aquatic biota was observed, and detrimental effects were seen on the benthic community. These results were in agreement with the impacts estimated by the risk assessment tools (CRA and ERICA tool), supporting further use of such tools in risk assessments. Both tools showed a potential risk towards crustaceans and the benthic community, including both radiotoxicity (radionuclides) and chemical toxicity (metals) (Fig. 11).

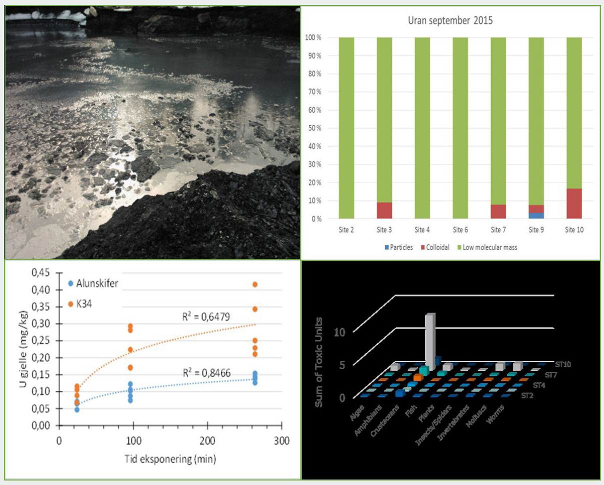

Figure 11: Alum shale deposit at Rv4(up left), speciation of uranium in water (up right), uptake curves for uranium on fish gills (down left), and the cumulative risk assessment output (down right).

Acknowledgement: We acknowledge the funding from Norwegian Public Roads Administration (NPRA) through the Nordic Road Water (NORWAT) project as well as CERAD.

MODELLING RADIOCAESIUM TRENDS IN REINDEER

L. Skuterud, H. Thørring, M. Ytre-Eide, T. Hevrøy (NRPA)

Objectives: The vulnerability of the lichens – reindeer – humans food-chain to radiocaesium contamination has been known since the nuclear weapons test era (Fig.12). The Chernobyl fallout had dramatic consequences for reindeer husbandry in Norway, with average concentrations of ^{134}Cs+^{137}Cs in the most contaminated herds reaching around 40,000 Bq/kg. Several countermeasures and actions were initiated to alleviate the consequences for the reindeer herders. These actions did e.g. reduce the radiocaesium dose to the herders by 90% during the first years. The current project is developing a dynamic model for ^{137}Cs in reindeer, which improves our understanding of the long-term dynamics and will be the first model to help authorities and reindeer herders manage the still ongoing post-Chernobyl situation in Norway.

Methods: The project focuses on the Vågå herd in southern Norway. Deposition track histories are obtained for 20 GPS collared reindeer by matching GPS position with ^{137}Cs deposition data. Combining these with ^{137}Cs transfer factors for different dietary components and accounting for seasonal changes in diet and metabolism, the ^{137}Cs intake and concentration levels in individual reindeer are modelled.

Results: Fig. 13 shows model results and corresponding results of live monitoring of collared reindeer in autumn and winter. The model results compliment observed levels when fungi are not abundant in large quantities. Future improvements will include modules to account for intake of fungi and long-term dynamic time trends for the complete post-Chernobyl period. The final model will therefore also be applicable to future contamination events.

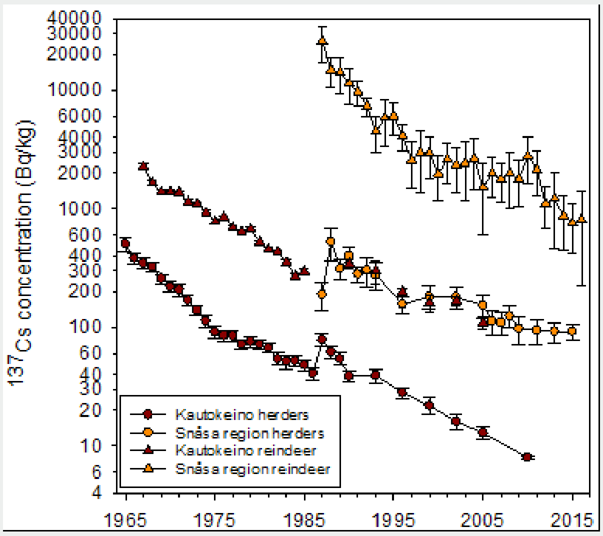

Figure 12: *Concentrations of ^{137}Cs in reindeer and reindeer herders in Kautokeino (northern Norway) and the Snåsa region (central Norway).*

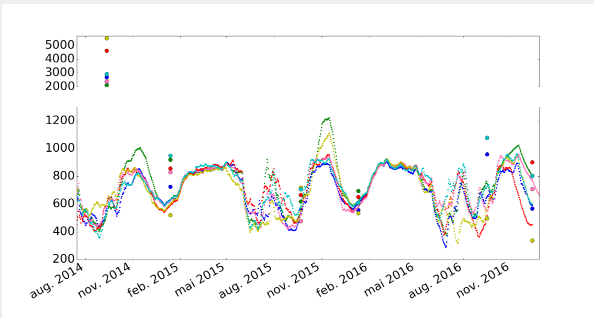

Figure 13: *Measured (dots) and estimated (curves) ^{137}Cs concentrations in reindeer from summer 2014 to December 2016 (only 6 reindeer shown for clarity). The elevated concentrations observed in Sep. 2014 were due to very high fungi abundance. Autumn 2015 there were almost no fungi, while some fungi was available in autumn 2016.*

ASSESSMENT OF FUKUSHIMA-DERIVED RADIATION DOSES AND EFFECTS ON WILDLIFE

P. Strand, J. Brown, A. Hosseini (NRPA)

Objectives: Following releases from the nuclear accident at the Fukushima-Daiichi Nuclear Power Station, FDNPS, contention has arisen over the potential radiological impact on wildlife. Under the auspices of the United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR, a suite of recently developed approaches was applied with the objective of calculating exposure and thereafter inferring effects on wildlife through comparison with compiled dose/response relationships.

Methods: Radiation doses for non-human organisms were estimated using the ERICA Tool, a process comprised of the selection of representative species (derived primarily from ERICA reference organisms) and radionuclides. The assessment was conducted using measurements of activity concentration in plants and animals directly whenever this was practicable and such data were given preference over using soil and/or water activity concentration in tandem with a transfer model.

Results: Dose rates of 300 μGy/h were estimated using an equilibrium based approach for soil dwelling organisms in Okuma Town during the intermediate phase (first 3months) of the accident. Through application of a kinetic model, a maximum dose rate of 370 μGy/h (0.2 Gy accumulated over 30 days) was estimated for Deer, slightly higher than corresponding values derived using an equilibrium-based approach. The highest dose rates for the entire marine assessment were calculated for the intermediate phase using monitored radionuclide concentrations in seawater, via two dynamic models. The maximum dose rate for fish, using the D-DAT model, of approximately 140 μGy/h occurred within the first month in the Northern drainage channel (Approx. 30 m North of at the FDNPS).

Conclusions: The Fukushima-Daiichi nuclear accident and subsequent radioactive releases into the environment led to estimated exposures for the intermediate phase that may have exceeded the corresponding benchmarks for some organisms such as macroalgae (cf. accumulated dose of 7 Gy with generic benchmark of 4.8 Gy) over a geographically constrained area and short periods (Fig. 14). Although alterations to population integrity are deemed unlikely, more subtle effects at the individual level may have occurred for radiosensitive and/or sedentary species living in high deposition areas. Despite the highest exposures being calculated for the marine ecosystem, maximum doses estimated for the terrestrial environment were of the same order of magnitude.

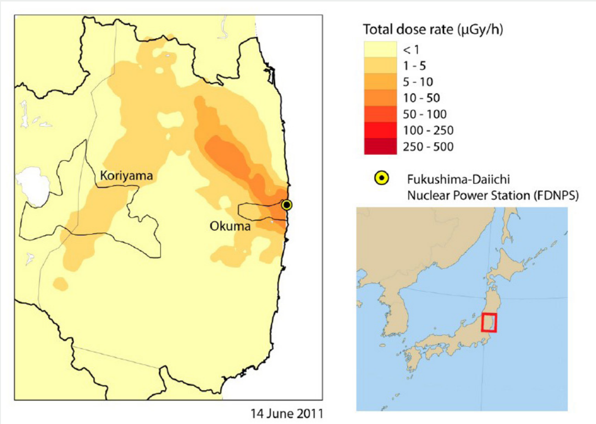

***Figure 14:** Interpolated map of total weighted absorbed dose rates for a large mammal*

References: Strand, P. *et al.* // Environ. Sci. Technol. Lett. 2014, 1, 198−203.

Strand, P. *et al.* // Journ. Environ. Rad. 2017 169-170,159-173.

IODINE-131 TRACER EXPERIMENTS: FIELD AND ANIMAL UPTAKE STUDIES

D.H. Oughton and B. Salbu (NMBU/IMV), in collaboration with: A. Brandt-Kjelsen, H.-C. Teien, L. Skipperud, M.N. Petersen (NMBU/IMV), E. Prestløkken, K. Hove, K. Sivertsen Storli (NMBU/IHA), and T. Seerhusen, M. Myromslein (NIBIO)

Objectives: To evaluate the impact of diet on iodine biokinetics in fistulated cows, and climate and nutrient levels on transfer to crops, using the tracer I-131.

Methods: Animal uptake study: A single acute dose of iodine tracer was either administrated to the vein of 4 fistulated cows as $^{131}I^-$ or as $^{131}IO_3$ via the rumen (Fig. 15). The cows were fed a diet (4 mg stable I/kg DM) of either rapeseed cake or soybean in a 2x2 Latin square design. Rapeseed from bioenergy industries contains compounds competing with the blood-milk transfer of I. Field tracer study: artificial rainwater containing $^{131}I^-$ was sprayed onto wheat and grass at 2 NIBIO field sites; West coast with naturally high I levels and Inland with low I levels. Partitioning between crops (grain/plant) and soil was followed for 8 weeks (Fig. 16).

Figure 15: Professor Knut Hove, NMBU/IHA, preparing the tracer for I-131 injection, and about 18 scientists, PhDs and engineers from IMV, IHA and the Centre of animal research contributed to the experiment.

Photo: Marit N. Pettersen

Results: Animal uptake study: The biokinetic study of ^{131}I in cow showed that the rapeseed in the diet significantly reduced transfer of ^{131}I from blood to milk. Thus, I-deficient milk is produced when rapeseed is used as feed, as previously suggested (Haug *et al.*, 2012). By increasing the rapeseed levels in diet, up to 90 % of ^{131}I could be removed from milk. Field tracer study: The transfer of ^{131}I to crops, and partitioning between soil, plant and grain varied between the two sites and between crop type and cover. Changes in distribution of the ^{131}I between plant, soil and different crop part could be followed during the 8 week period.

Conclusion: Both studies have important implications for emergency preparedness purposes, especially considering diet changes, improved biokinetics for cow and the potential for health impacts on the public. The tracer field studies represent a unique opportunity internationally, and follow-up studies will continue to evaluate the impact of stable I levels, as well as dynamic transfer to improve short term dosimetry, both for humans and for reference wildlife organisms.

References: Haug, A., *et al.* // Acta Agri. Scan. Sci.A, 2012, 62.3. 127-134.

Figure 16: Hans-Christian Teien spraying crops with I-131 at the Apelsvoll field site.

Photo: Deborah H. Oughton

Research Area 3 - Biological Responses

The aim of RA3 is to generate new knowledge related to biological responses in organisms exposed to radiation that have implications for risk assessment and radioprotection of humans and the environment, to reduce the existing uncertainties. In this respect a major data-gap exists on effects following exposure of low doses and low dose rates of ionizing radiation to both humans and wildlife. Such effects cover apical endpoints like reproduction, cancer, embryonal development, behavior and cander. The key research questions for are:

- Why are some organisms and life-stages more sensitive to stressors than others?
- How does the presence of other stressors, such as UV radiation, metals, changing temperature regimes etc., modify biological responses in organisms exposed to ionizing radiation?
- What mechanisms underpin the observed effects such as oxidative stress, genotoxicity, transcription and epigenetic regulation?

RA3 is divided into three interlinked umbrella projects: UMB3A - Mechanisms determining species radiosensitivity; UMB3B - Combined toxicity and cumulative risk assessment; and UMB3C - Transgenerational hereditary, reproductive and epigenetic effects.

<u>Umbrella 3A: Radiosensitivity (D.A Brede, NMBU/IMV):</u> Research is focused on chronic low to medium dose rate gamma radiation from the NMBU Co-60 source. The main hypothesis is that an organism's capacity to mitigate oxidative stress and thus maintain essential enzyme functions determines its ability to repair damage inflicted on essential macromolecules such as DNA. The indirect effects of ionizing radiation, particularly the formation of free radicals (ROS and RNS), can in turn damage cell components and cause perturbation in signaling systems and metabolism. It is further hypothesized that stem cells comprise the organismal function most susceptible to damage by radiation, and that 'late effects' such as developmental malformations, or reproductive defects, originate from damage to stem cell populations.

<u>Umbrella 3B: Combined Toxicity and Cumulative Risk (K.E. Tollefsen NIVA, T. Christensen NRPA):</u> The aim is to conceptually and experimentally characterize the impact of radiation in combination with other stressors (metals, organic chemicals, UV) under different environmental conditions, and to assess the cumulative risk. The main objectives are to:

1) establish a thoroughly evaluated set of prediction models for combined effects and cumulative risk assessment (CRA) of multiple stressors ranging from the mode of action (MoA) to the adverse outcome;
2) apply these models to relevant stressors, exposure scenarios, effect endpoints and species to characterize the impact of multiple stressors having similar and dissimilar MoAs;
3) assess and reduce uncertainty CRA of relevance for the RA4 approaches.

<u>Umbrella 3C: Transgenerational and Reproduction Effects (P. Aleström, NMBU/Vet, A-K Olsen, NIPH):</u> The focus of this area is reproduction, genotoxic effects and the underpinning explanatory mechanisms involving transcriptomic and epigenetic regulation. By following the offspring of exposed parents (mice and zebrafish), it is possible to test the hypothesis that radiation exposures during gametogenesis can cause developmental and irradiation specific effects in offspring, and to link these to changes in gene expression and epigenetic landscape patterns. Previous results obtained for selenium deficient male mice exposed to gamma demonstrated reproduction failure when low antioxidant status is combined with stressors.

Major Achievements 2013-2016

<u>Radiosensitivity.</u> A Biological Effects Toolbox has been produced, spanning twelve model organisms. The strategy is to develop a common set of tools

in order to conduct a systematic comparison of biological effects of gamma radiation on model species, and to identify the cellular processes and underlying mechanisms that contribute to radiosensitivity. Experiments have been carried out on various life stages of salmon, zebrafish and daphnia, as well as plants, nematodes, earthworms and cell cultures (Song *et al.*, 2014; Gomes *et al.*, 2017; Graupner *et al.*, 2016). Differences in radiosensitivity among species are not well understood at the cellular and molecular level, although factors like cell growth rate, DNA repair capacity, and life stage are known contributors. Evidence indicates that oxidative stress is an important modulator of toxic effect from chronic low dose rate radiation, and has been studied in CERAD through comparison of responses in different organisms, as well as in reporter organisms (nematodes).

<u>Biological Response and Hereditary Effects:</u> Different mouse models have been exposed to gamma radiation: a DNA repair deficient model, two models prone to develop blood cancer (acute myeloid cancer) and gastrointestinal cancer (colon cancer), and a model prone to develop Parkinson disease. Effects have been observed on functional endpoints such as reproduction, cancer and behavior. Underpinning molecular changes such as genotoxic, mutagenic and genetic effects (Graupner *et al.*, 2014; 2015; 2016), changes in epigenetic regulation or the transcriptome of germline and somatic cells have been identified. Zebrafish have been exposed during embryogenesis and gametogenesis. Results show effects on hatching, embryonic malformation, DNA damage, oxidative stress, transcriptomics and epigenomics (WGBS DNA methylation, ChIP-seq histone PTM and RNA-seq noncoding RNA), and a dose-response effect on gene expression was seen (Kamstra *et al.*, 2015). Studies with early life-stage and juvenile salmonids showed tissue and transcriptional changes relevant for a number of toxic MoA (e.g., Song *et al.*, 2014). Experiments with *Daphnia magna* revealed that ionizing radiation caused ROS formation, lipid peroxidation, DNA damage, and transcriptional changes associated with known and novel toxicity pathways. Growth, development, photosynthesis and pigmentation was also affected in terrestrial and aquatic plants and algae (Gomes *et al.*, 2017). Transgenerational studies demonstrate a wide spectrum of effects, including F2 and F3 effects on DNA methylation.

<u>Combined Toxicity and Multiple Stressors.</u> In the environment, a series of stressors can affect organisms. Radionuclides may have two MoAs: radiological toxicity and chemical toxicity. A suite of bioassays ranging from cell-based assays (zebrafish cell line ZF4, human cell line TK-6, salmonid primary hepatocytes) to whole organisms (algae, nematodes, crustaceans, fish, small aquatic plants, earthworms) has been identified as suitable for combined toxicity assessments. Twenty stressors (including ionising radiation, UVA, UVB, metals and organic chemicals) out of approximately one hundred assessed have been identified as significant on the basis of their MoA and environmental relevance. The role of an antioxidant (i.e. suboptimal selenium levels) on gamma exposed male mice demonstrated aggravated effects of gamma if the Se status was poor (Graupner *et al.*, 2015, 2016). Experimental studies focusing on MoA assessment, behavioral and adverse effect endpoints in selected models (Scots Pine, *L. minor*, *C. reinhardtii*, zebrafish, salmon, zooplankton, human and fish cells) were used to decipher the combined effects of binary mixtures of selected multiple stressors such as ionizing radiation, UV and radionuclides (Song *et al.*, 2016, Jensen *et al.*, 2016). Finally, recommendations on how to address combined toxicity and cumulative risk has been proposed (Beyer *et al.*, 2016) and implemented in CRA of radionuclides, metals and organic compounds under different ecologically-relevant exposure scenarios.

PhD and PostDoc positions: *PhD - S. Hurem (NMBU/Vet), D. Blagojevic (NMBU/IPV), E. Maremonti (NMBU/IMV), H. Dahl (NIPH), L. Xie (NIVA), J. Kamstra (NMBU/Vet), L. Martin (NMBU/Vet); PostDoc L. Lindemann (NMBU/Vet), T. Gomes (NIVA), A. Graupner (NIPH).*

Research Highlights – Biological Responses

TOXICITY ASSESSMENT OF IONIZING RADIATION IN *DAPHNIA MAGNA*

T. Gomes, Y. Song (NIVA), L. Xie, K.E. Tollefsen (NIVA, NMBU/IMV), D. A. Brede, Y. A. Kassaye, O.C. Lind, H.C. Teien, B. Salbu (NMBU/IMV), K. Gutzkow (NIPH)

Objectives: In order to provide relevant data for comparison of cross-species sensitivity to ionizing (gamma, γ) radiation and multiple stressors in the freshwater crustacean *Daphnia magna*, a combination of molecular, cellular and functional responses was assessed to characterize the toxicity to this cladoceran branchiopod. The data generated was used to identify key factors that drive species sensitivity to the different stressors and identify molecular targets and toxicity pathways relevant to adverse effects.

Methods: *D. magna* was exposed to γ-radiation (0.41–106 mGy/h) and exposure (reactive oxygen species (ROS) formation), early gene and functional (gene expression, lipid peroxidation (LPO), DNA damage) and adverse effects (growth, reproduction, survival) were determined by a suite of effects and response analysis.

Results: Oxidative stress in the form of ROS, LPO and DNA damage was detected in *D. magna* after 24 hrs and 48 hrs exposure, especially at higher γ dose rates (10.7, 42.9 and 106 mGy/h). Gene expression patterns showed dose-dependent transcriptional alterations in *D. magna* after 24h exposure, with differentially expressed genes identified at both low (0.41 mGy/h) and high (42.9 and 106 mGy/h) dose rates. Further analysis of these responding genes showed several associated with significant pathways as DNA repair, cellular response to stress, signal transduction and cell cycle (Fig. 17). Future studies with *D. magna* aim to assess chronic and transgenerational effects of ionizing radiation.

Conclusion: Exposure to γ-radiation resulted in a dose-dependent increase in ROS in irradiated daphnia that led to oxidative damage in the form of LPO and DNA damage (>10.7 mGy/h). At the molecular level, antioxidant defenses and DNA repair systems were triggered to counteract ROS formation and overcome oxidative stress, especially at the highest dose rate tested (106 mGy/h). Other underlying mechanisms were also identified at the gene expression level, thus providing a better understanding of the toxic effects of γ-radiation in *D. magna*. Results suggest a causal correlation between oxidative stress responses (ROS, LPO and DNA damage) and molecular alterations in *D. magna* in response to γ-radiation. Overall, results showed that oxidative stress is one of the most significant MoAs of γ-radiation in *D. magna* after short-term exposure, and can be used to assess impacts of low dose radiation effects in the environment and support identification of radiation sensitivity across species and taxa.

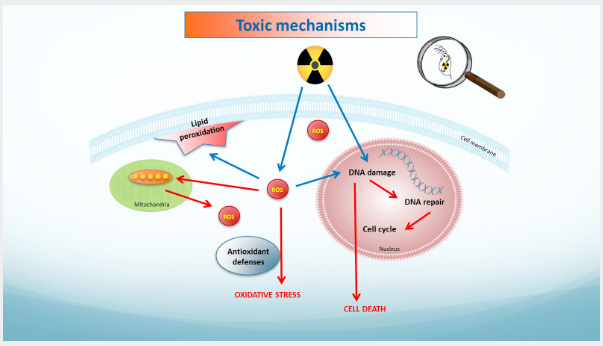

***Figure 17:** Putative toxic mechanisms of γ-radiation in the crustacean Daphnia magna after 24 hrs exposure.*

CERAD BIOLOGICAL EFFECTS TOOLBOX

D.A. Brede (NMBU/IMV) + multiple RA3 members (NMBU, NIVA, NIPH, NMBU/Vet, NRPA)

Objective: The overarching goal of this project was to construct a framework for systematic investigation of harmful effects of ionising radiation in selected model organisms. This included the construction of a toolbox for assessment of toxicological effects and mode of action (MoA) at the molecular level with construction of adverse outcome pathways (AOP) for the individual species.

Method: Selected model species representing plants, invertebrates, fish and mamals have been exposed to chronic low/medium dose rate gamma radiation at the Figaro facility, NMBU. Biological effects were measured using a standard set of endpoints including mortality, growth/development, reproduction, genotoxicity and ROS/oxidative stress. Effect endpoints were selected to address impact on ecological function of the model species, and to identify molecular responses to unveil harmful effects and protective response mechanisms. Toxicological effects and AOP analysis were conducted for the individual species.

Results: Twelve model species have been analysed and biological effects of gamma radiation been documented (Table 1 and Fig. 18). AOP models have been completed for four species. This includes the identification of sensitive lifestages/cellular targets, thus demonstrating the power of this approach.

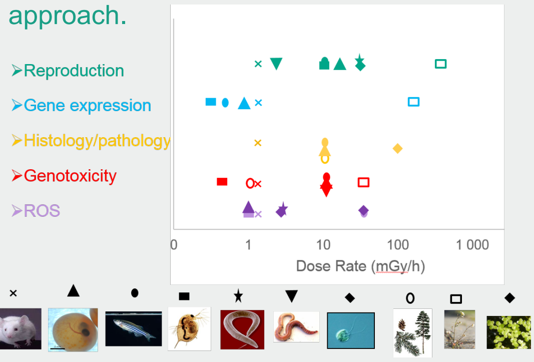

Figure 18: Identified LOEDR from chronic exposure to gamma radiation.

Conclusion: The toolbox framework is designed to serve as a template for comparative studies of all types of ionizing radiation including radionuclides. By means of bioinformatics and statistics an inter species comparison of molecular effects using EC10 will be conducted to identify common denominators of damage or activation of defense mechanisms, which could lead to identification of new radiosensitivity determinants, biomarkers of exposure or adverse outcome.

Organism	Mortality	Growth/ Development	Histology/ Pathology	Reproduction	Genotoxicity DNA-Damage & Apoptosis	ROS/ Oxidative stress	Gene expression	Epigenetics	U3A Radiosensitivity Dose rate Range (mGy/h)	U3B Combined effects and cumulative risk	U3C Transgenerational, reproductive and epigenetic effects
Salmon	√	√	√	√	√	√	√	√	0.4-40	γ/U/Cd	ChpL
Zebrafish	√	√	√	√	√	√	√	√	0.4-40	γ /UV	F0-F3
Mice	√	√	√	√	√	√	√	√	0.2-100	γ /Se/As	F0-F3
Daphnia	√	√		√	√	√	√	√	0.4-100	γ /UV/U	DNAme
C. elegans	√	√	√	√		√			0.4-100	γ /U/Cd/As	
Earthworm	√	√	√	√	√			√	0.4-40		F0-F3
Norway spruce	√	√	√		√	√	√		1-540		
Scots pine	√	√	√		√	√	√		1-540		
Arabidopsis	√	√	√	√	√	√	√		1-540		
L. minor		√	√	√		√			10-100	γ /UV/As, Co, Zn, Mo, Cd, Cu, bifenox	
C. reinhartii		√				√	√		0.4-1600	γ /UV	
S. costatum		√				√			20-100	γ /UV	

Table 1: The CERAD Biological Effects Toolbox.

CHRONIC LOW DOSE RATE GAMMA IRRADIATION AND SUBOPTIMAL SELENIUM STATUS IS REPROTOXIC IN MALE MICE

A.-K. Olsen, A. Graupner, H. Dahl, J. Andersen, B. Lindeman, T. Hofer, G. Brunborg, C. Instanes and D.M. Eide (NIPH), R.W. Doughty (Oslo University Hospital), D.A. Brede, D. Oughton, B. Salbu (NMBU/IMV)

Objectives: Germ cells are known to be sensitive to radiation at high acute doses, but little is known about effects induced by chronic low dose rate (LDR) exposure. Moreover, suboptimal antioxidant status of exposed animals due to Se-deficient feed may aggravate effects of radiation. Human blood levels of Se are also declining in Norway and other parts of the world due to intake of foodstuffs low in Se. Our hypotheses were: 1) Chronic continuous exposure to low dose rate γ radiation of spermatogonial stem cells hampers reproduction; 2) Low Se level in mice deficient in DNA repair of oxidative DNA damage aggravate reproduction.

Methods: Male mice were exposed to γ radiation (1.4 mGy/h) for 45 days resulting in males carrying sperm originating from exposed stem cell spermatogonia, that were mated with naïve females until day 90, and propagated further to F2. Se-depletion was obtained by 2-generation feeding of mice with low Se forage. An array of methods was used to assess effects: fertility measurements (fertility, fecundity, litter sizes, cannibalism, time-to-pregnancy), testis weights and pathology, testicular sperm head counts, testicular DNA damage and packing (Comet analyses and vas deferens sperm-chromatin structure analyses (SCSA)) and epididymal sperm fluid protein carbonylations.

Results: Se-deficiency induced through 2-generation depletion of Se led to sterility. F0 males with spermatozoa originating from stem cells exposed to chronic γ radiation showed reduced reproductive capacity. Changes were observed in testis weights, testis pathology (reduced seminiferous tubule diameters and tubular epithelium heights), testicular sperm head counts, testicular DNA damage (strand breaks and oxidized DNA bases) levels, SCSA (Fig. 19) and epididymal sperm fluid protein carbonylation. Se-deficient mice exposed to gamma irradiation showed higher DNA damage levels and more pronounced pathological changes in the testis compared to Se-deficient alone. Fertility was normal in male F1-offspring.

Conclusion: Chronic low dose rate γ radiation of male mice is reprotoxic, leading to reduced fertility, impaired sperm production and to sperm with changed DNA damage levels and DNA packaging. Combined with suboptimal Se status the effects are aggravated.

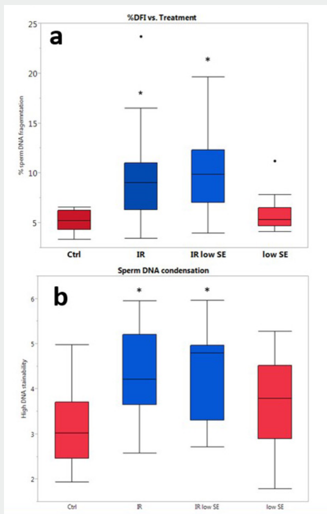

***Figure 19:** Epididymal sperm chromatin structure analyses (SCSA). Vas deferens sperm collected at irradiation stop (day 45). SCSA show sperm chromatin integrity in mice dependent on treatment. Effect of irradiation for 45 days (Ctrl vs gamma irradiation) and selenium (selenium deficient (low Se)), or both. Plot a) Relative fraction (%) of sperm with high DNA fragmentation (i.e. cells with increased level of single-stranded DNA) and plot b) Relative fraction (%) of cells with high DNA stainability (i.e. considered to be immature sperm cells with an incomplete chromatin condensation). Compared with Ctrl p<0.05 is considered statistically significant, and is marked with asterix*

References: Graupner, A. *et al.* // Mutagenesis. 2015, 30(2):217-25.

GAMMA RADIATION EFFECTS IN ATLANTIC SALMON (*SALMO SALAR*) DEVELOPING EMBRYOS

H.C. Teien, D.A. Brede, B.O. Rosseland, B. Salbu, Y.A. Kassaye, Z. Keke, A. Karlson, F. Grammes, Y.S. Torgersen (NMBU/IMV), T. Haugen (NMBU/INA), J. Kamstra (NMBU/Vet)

Objectives: To study gamma radiation effects in Atlantic salmon (*Salmo salar L.*) embryos exposed from fertilization of the egg to hatching, and to identify molecular mechanisms related to adverse outcome of chronic radiation during embryogenesis.

Methods: The toxicity of gamma radiation towards Atlantic salmon embryos was studied in two exposure experiments using the Co-60 source at Figaro, NMBU. Dry stripped eggs from three different females were dry fertilized with sperm from one male, and placed with US EPA very soft water (5.9±0.3 °C and pH 6.7±0.4) in three parallel exposure tanks. Each exposure unit received water from a reservoir in a recycling system (Fig. 20). Eggs were exposed for 92 days, from the time of fertilization until hatching, and transferred to no exposure conditions to follow long-term effects on developing Alevin during 6 months. The exposure protocol was based on the standardized OECD guidelines 210 (OECD 2013). Nominal gamma dose rates were 0.4 to 40mGy/h.

Results demonstrated dose-dependent responses at both the molecular and at the individual level. At 30 and 40 mGy/h gamma irradiation caused deformities in all embryos (6.0-58 Gy total dose). Necrosis, reduced growth, hemorrhages, eye deformities, pigmentation scattering, resulting in delayed development and reduced survival before hatching (Fig. 21).

At 20 mGy/h delayed hatching and development of the yolk sack fry were observed as well as reduced survival from hatching to swim-up, while at 10 mGy/h or lower, no deformities or effects on hatching were observed and the alevin showed normal development.

Toxic mechanisms in exposed embryos were explored by combining RNA-seq gene expression profiling, metabolomics profiling, histopathology, DNA-damage, ROS-defense enzyme activity. Results revealed oxidative stress and DNA damage at 1 mGy/h and 10 mGy/h. Gamma radiation induced changes in gene expression, metabolites and enzyme activities linked to adverse outcomes at the individual level, such as tissue damage, deformities and mortality (Fig. 22).

Conclusions: The findings highlight that dose rates between 20 – 40 mGy/h are critical for embryonal development in Atlantic salmon, during both 9 and 90 days of exposure. Future work will focus on identification of effects at gamma dose rates of ≤10 mGy/h.

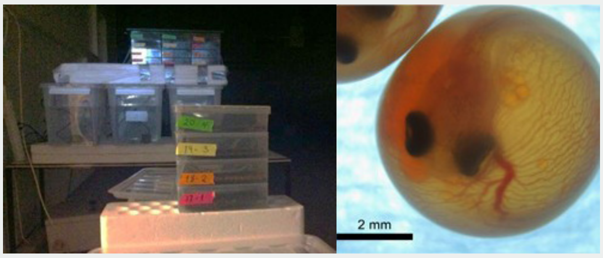

Figure 20: *Experimental set up.*

Figure 21: *Developmental effects at alevin stage of chronic radiation control (top) and 30 mGy/h exposed (under).*

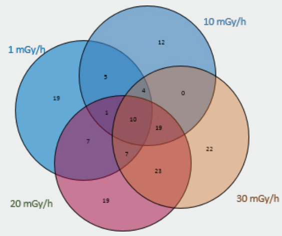

Figure 22: *Venn diagram of metabolite profile analysis of gamma radiation exposed alevins.*

A TRANSGENERATIONAL STUDY OF ZEBRAFISH EXPOSED DURING GAMETOGENESIS AT 10 AND 40 mGy/hr (~6 AND 26 Gy)

P. Aleström, V. Berg, C. Fernandez, S. Hurem, J. Kamstra, S. Mutoloki, L. Lindeman, J.L. Lyche, L.M. Martin (NMBU/Vet), D.A. Brede, O.C. Lind, Y.A. Kassaye, D.H. Oughton, B. Salbu, H.C. Teien (NMBU/IMV), T. Christensen, E. Lindbo Hansen (NRPA), T. Gomes, K.E. Tollefsen (NIVA), K.B. Gutzkow, A.-K. Olsen (NIPH), C. Mothersill (McMaster University, Canada), H. Aanes (NMBU/Vet, Patogen Analyse AS)

Hypotheses: Sub-chronic gamma radiation exposures during gametogenesis damages reproductive organs and performance and cause developmental and irradiation specific effects in F1 offspring. Phenotypic effects in F1 progeny are accompanied by changes in gene expression and epigenetic landscape patterns: DNA methylation, histone post-translational modifications (PTMs) and noncoding RNA profiles (Fig. 23).

Methods: Adult fish were exposed to 10 and 40 mGy/h external γ-radiation for 27 days. Endpoints assessed cover: macro/microscopic observations, fluorometric (ROS), colorimetric (LPO), Comet assay, histopathology. Transcriptomics by mRNA sequencing, methylomics by whole genome (WGBS) and amplicon bisulfite sequencing (BisPCR2), short non-coding RNA (sncRNA) sequencing and locus specific histone modifications (chromatin immunoprecipitation PCR, ChIP-PCR).

Results: Irradiated parents exhibit no effects on testes, but ovaries show a large number of previtellogenic follicles (Fig. 24). This is accompanied by lower embryo production. These embryos show early hatching, as well as increased mortality and increased deformities (changes in eye morphology) as also observed for salmon embryos. ROS formation increased in F1 embryos 1 month post-parental irradiation and decreased 1 year after parental irradiation. Lipid peroxidation and DNA damage increased 1 year after parental irradiation. mRNA-seq revealed that 2455 genes were differentially expressed (DEGs). WGBS analysis counted 7906 differentially methylated regions (DMRs). IPA analysis showed major overlap of enriched pathways between gene expression and DNA methylation. BisPCR2 DNA methylation analysis demonstrated persistent transgenerational effects (F1, F2 and F3) at specific loci (Fig. 25). sncRNA-seq showed an enriched number of reads in F1, indicating a general increase in miRNAs (Fig. 26). Pairwise comparison analysis of revealed 23 DE miRNAs in F1. Functional significance of the observed changes in the context of DEGs versus DMRs will be further explored. In addition to miRNA, piRNA and tRNA halves showed a global enrichment in expression as compared to non-exposed samples.

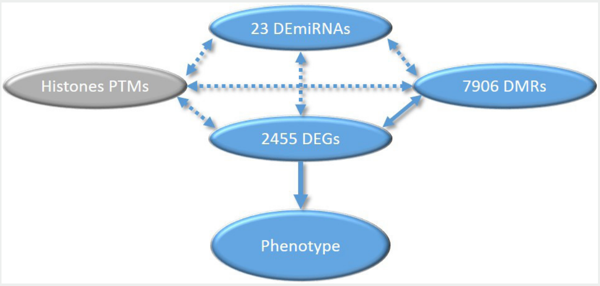

***Figure 23:** Proposed association of observed phenotypes to gene expression, and its relation to epigenetic alterations. Genome-wide omics sequencing analyses (blue) and in pipeline (grey). Associations that are established (solid line) and in pipeline (dashed line).*

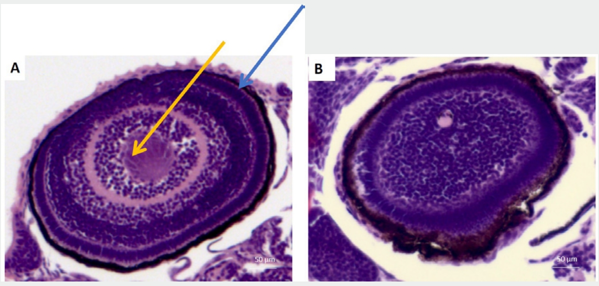

***Figure 24:** Phenotypic effect of gamma exposure (10 mGy/h) during parental gametogenesis. A. Control embryo with normal eye morphology (3 dpf) with clear lens (yellow arrow), clearly defined layers of cells, surrounded by the retinal layer (blue arrow). B. F1 offspring from Irradiated parental line. Presence of cells in the lens and poor differentiation of the cells outside the lens.*

ChIP-PCR analyses of zebrafish F1 embryos revealed changes relative to controls in histone PTMs at several selected loci. Histone H3 lysines displayed hypermethylation (K4) and hyperacetylation (K9) around transcriptional start sites of hnf4a, cebpa, vegfab and gmnn. From an evolutionary point of view, comparable changes on histone PTMs were observed in zebrafish and salmon with gamma radiation induced higher enrichment of H3K4me3 in the house keeping gene beta actin.

Conclusion: Gametogenesis is a sensitive developmental timeframe for radiation induced adverse effects. Parental radiological stress (increased ROS, LPO, DNA damage) can be transmitted to progeny. Embryos from exposed parents exhibit a generational effect on DNA methylation, miRNA expression and histone PTMs and first indications of a relation between these marks and differentially expressed genes that are linked to observed demographic endpoints. Further analysis will focus on possible correlations between different types of epigenetic signatures, differential gene expression and observed functional phenotypes.

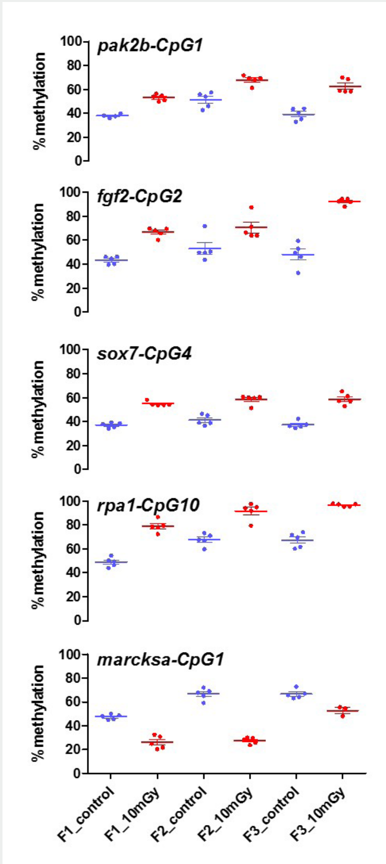

Figure 25: *Methylation analysis at specific loci shows a persistant change in embryos of three generations, derived from a radiation exposed (10 mGy/h) ancestral line. Embryos derived from controls (blue) and exposed ancestors (red).*

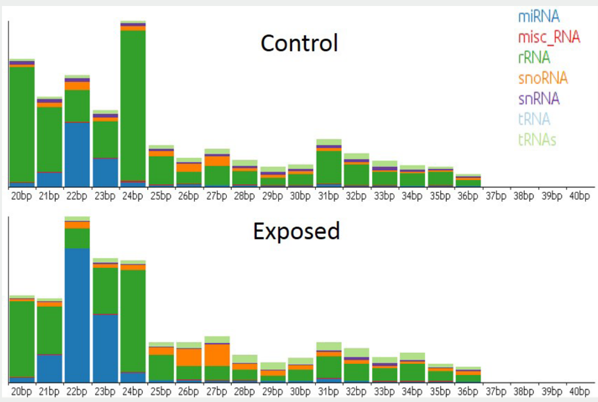

Figure 26: *A distribution analysis of sequence length of small non-coding RNAs, indicating an increase in miRNA expression (22 nt, dark blue) in exposed samples.*

References:

Aanes, H. *et al.* Subm.

Hurem, S. *et al.* Subm. PLoS ONE.

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COMBINED EFFECTS OF GAMMA RADIATION AND URANIUM ON ATLANTIC SALMON: MECHANISTIC UNDERSTANDING

Y. Song (NIVA, NMBU/IMV), B. Salbu, H.C. Teien, O.C. Lind, B.O. Rosseland (NMBU/IMV), Ø. Evensen (NMBU/Vet), K.E. Tollefsen (NIVA, NMBU/IMV)

Objectives: Characterize and compare the modes of toxic action (MoAs) of sublethal exposure levels of γ-radiation and depleted uranium (DU), individually and in combination, in juvenile Atlantic salmon.

Methods: Juvenile salmon were exposed to 70 mGy external γ-radiation delivered over the first 5 hrs of a 48 hr period (14 mGy/h), 0.25 mg/L DU continuously for 48 hrs and a combination of the two stressors (Fig.27). Stress responses were characterized using a suite of methods including microarray gene expression analysis, quantitative real-time RT-PCR assay, plasma glucose measurement and histopathology. The concentrations and bioaccumulation of DU in salmon after single and combined exposure were also determined.

Results: Results from the transcriptomic analysis showed that differentially expressed genes (DEGs) involved in a number of toxicity pathways were common between γ-radiation, DU and the combination. These DEGs were associated with several known MoAs of γ-radiation and DU, such as induction of oxidative stress, DNA damage, perturbation of mitochondrial oxidative phosphorylation, thus confirming the earlier findings from our research group. However, there were also a considerable number of DEGs that were stressor- specific, but may likely be grouped into common higher functional categories such as immune responses, cellular stress and injury, metabolic disorder and programmed cell death.

Conclusion: γ-radiation and DU may affect several common targets, however, the toxic mechanisms affecting these targets may be dissimilar between the single stressors as well as their combination. The results have supplied substantial mechanistically-based knowledge for better understanding the multiple stressor effects of γ-radiation and DU for future assessment of multiple stressor effects.

References: Song, Y. *et al.* // Sci. Total. Environ. 2016, 562, 270-9.

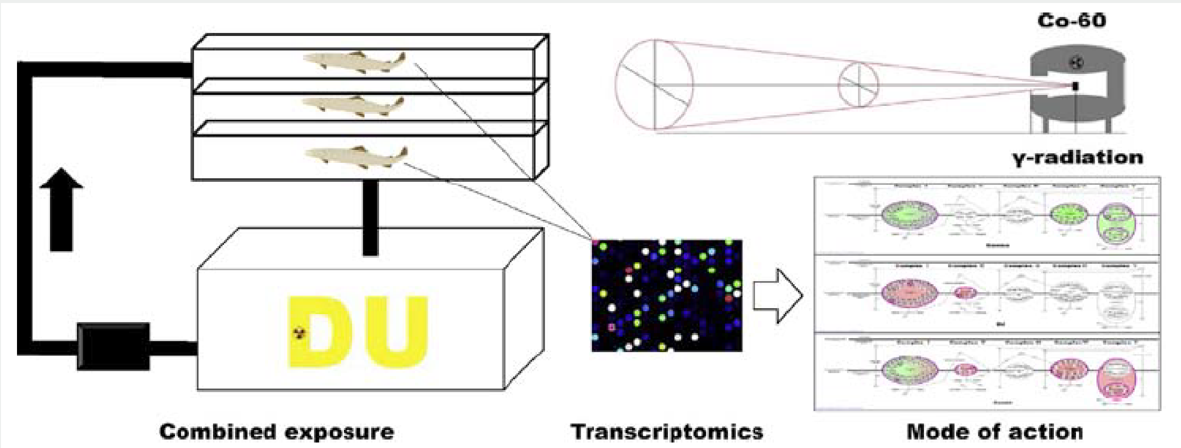

Figure 27: *Experimental setup and workflow of the studies with γ-radiation and depleted uranium (DU) (from Song et al., 2016).*

COMPARATIVE CROSS-SPECIES SENSITIVITY TO GAMMA RADIATION AND EFFECTS OF COMBINED GAMMA–UV-B EXPOSURE IN TERRESTRIAL PLANTS

D. Blagojevic, Y.K. Lee , J.E. Olsen (NMBU/IPV) L. Xie (NIVA), D.A. Brede, O.C. Lind, B. Salbu (NMBU/IMV), E.L. Hansen (NRPA), L. Nybakken, K.A. Solhaug (NMBU/INA)

Objectives: To compare cross-species sensitivity to gamma radiation and assess effects of combined gamma-UV-B exposure in terrestrial plants. We aim also to shed light on the background for differential sensitivity towards gamma.

Methods: Seedlings of Scots pine, Norway spruce and *A. thaliana* were exposed to gamma radiation (0.1-540 mGy/h for 6 (all species) or 15 days (A. thaliana). At termination of exposure, genotoxicity (Comet assay). ROS and phenotypic effects were assessed and after effects of gamma on subsequent development, histology, genotoxicity, and expression of selected genes were studied. Effects of combined gamma-UV-B (0.4 $W.m^{-2}$; photosynthetic active radiation 300 $\mu mol.m^{-2}.s^{-1}$) were studied in Scots pine for ≤100 mGy/h gamma.

Results: Consistent with increasing genotoxicity and ROS production, the size of Scots pine and Norway spruce seedlings decreased with increasing gamma dose rate. In *A. thaliana*, no such effect on shoot growth was observed in spite of increasing genotoxicity. During subsequent growing, shoot and root growth were negatively affected in the conifers (Fig. 28) with increasingly disorganized shoot and root apical meristems with increasing dose rate above 10 mGy/h, demonstrating adversely affected cell division pattern. In surviving conifer plants, genotoxicity persisted after termination of gamma-exposure. Despite persistent genotoxicity also in *A. thaliana*, most growth parametes were not affected, except delayed floral bud formation at dose rates ≥400 mGy/h (Fig. 1). Gamma-UV-B-co-exposure of Scots pine reduced seedling size further in a dose-rate-dependent manner with an additive genotoxic effect at 100 mGy/h, but not at lower dose rates.

Conclusions: Both Scots pine and Norway spruce seedlings show high sensitivity to gamma as compared to the highly resistant *A. thaliana*. The results on persistent genotoxicity in response to gamma radiation is consistent with higher tolerance to genotoxicity in *A. thaliana* than in Scots pine and Norway spruce.

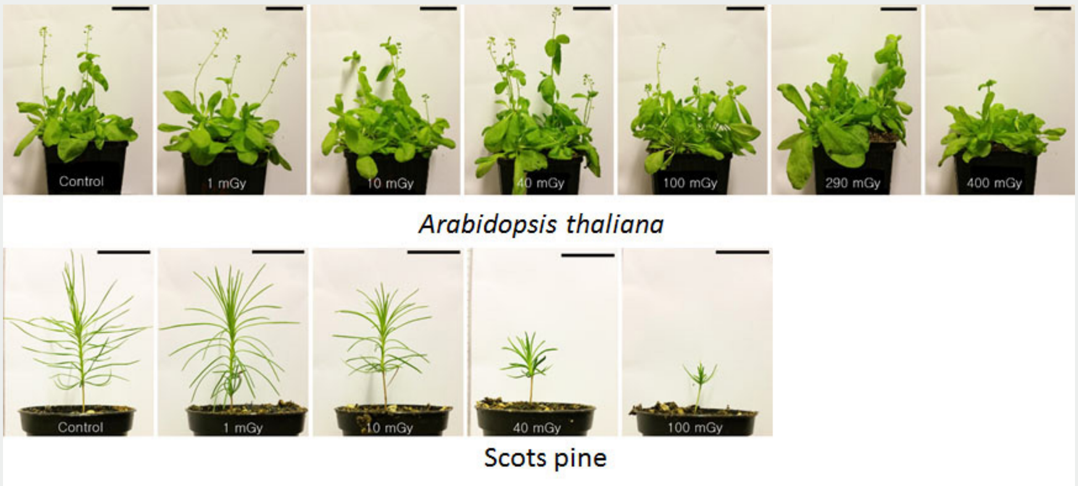

Figure 28: *Plant phenotype 44 days after termination of gamma exposure. From left: 0, 1, 10, 40, 100, 290, 400 mGy/h. Bars = 3 cm*

SENSITIVITY OF *CHLAMYDOMONAS REINHARDTII* TO GAMMA RADIATION

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Objectives: Evaluate the impact of gamma (γ) radiation in the freshwater algae *Chlamydomonas reinhardtii* by following alterations in photosynthetic activity and intracellular production of ROS.

Methods: *C. reinhardtii* was exposed to γ-radiation at 13 dose rates (0.49 to 1677 mGy/h) for 6 hrs and photosynthetic parameters such as maximum quantum efficiency of photosystem II, efficiency of the oxygen-evolving complex, effective quantum efficiency of photosystem II, non-photochemical quenching, coefficients of photochemical and non-photochemical quenching and photosynthetic electron transport rate) determined and linked to ROS formation (light and dark conditions).

Results: Results obtained for *C. reinhardtii* revealed that short-term exposure to γ-radiation led to an impairment in the photosynthetic activity, especially at the higher dose rates tested (235 – 1677 mGy/h). Gamma radiation affected photosystem II photochemistry through the activation of non-photochemical processes to counteract and protect the photosystem from ROS formation and consequent oxidative damage. Modifications of photosystem II energy transfer associated with electron transport were also detected at higher dose rates (943 – 1677 mGy/h). γ-radiation also induced a dose-dependent ROS production in *C. reinhardtii* that seemed to be influenced not only by photosynthesis but also by other mechanisms (light independent), such as modulation in the antioxidant defense system and perturbations in the mitochondria.

Conclusion: The decrease in the photosynthetic efficiency observed in *C. reinhardtii* in response to γ-radiation seems to be connected to ROS formation and can potentially lead to oxidative stress and cellular damage in chloroplasts. This work is the first insight into the mechanisms involved in γ-radiation toxicity on *C. reinhardtii* photosynthetic activity and ROS formation and will serve as a basis for future studies using multiple stressors (Fig. 29).

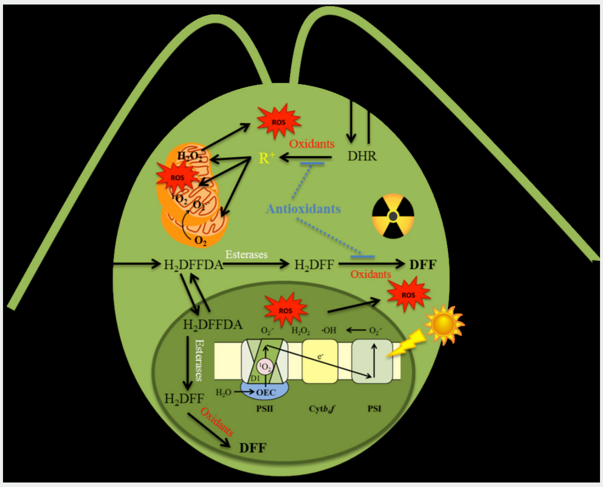

Figure 29: *Mechanisms involved in γ-radiation effects in the photosynthetic activity and ROS formation in the algae Chlamydomonas reinhardtii (Gomes et al., 2017).*

References: Gomes, T. *et al.* // Aquatic Toxicology. 2017 183: 1-10.

GAMMA RADIATION AT A HUMAN RELEVANT LOW DOSE RATE IS GENOTOXIC IN MICE

A. Graupner, D.M. Eide, C. Instanes, J.M. Andersen, D.A. Brede, S.D. Dertinger, O.C. Lind, A. Brandt Kjelsen, H. Bjerke, B. Salbu, D.H. Oughton, G. Brunborg, and A.K. Olsen (NMBU/NIPH/NRPA)

Objectives: There is substantial knowledge regarding genotoxicity and cancer after acute high dose rate radiation, but a lack of data on chronic low dose rate (LDR) radiation, despite its clear relevance for humans in non-medical exposure scenarios. CERAD has facilitated investigations of such effects due to a combination of its unique exposure facilities with scientific expertise encompassing dosimetry, animal experiments and biological effect measurements. Our hypothesis was that chronic continuous exposure to LDR γ-radiation is genotoxic, and that selenium deficiency or DNA repair deficiency of oxidised DNA would aggravate the genotoxic response.

Methods: Male mice were exposed to LDR γ-radiation (1.4 mGy/h) for 45 days. We applied stand-alone yet complementary assays covering three classes of genotoxic effects. These include a flow cytometry based micronucleus assay measuring chromosomal damage, a flow cytometry based DNA mutation assay measuring phenotypic mutations (Pig-a gene mutation of red blood cells, immature reticulocytes (RET) or mature erythrocytes (RBC)) and DNA lesions levels (single strand breaks/alkali labile sites and oxidized DNA) measured by the comet assay.

Results: The chronic LDR gamma exposure produced genotoxic effects in blood cells. Significantly increased levels of chromosomal damage (micronucleus, Fig. 30), phenotypic mutations (Pig-a gene mutation of RBCCD24−) and DNA lesions (single strand breaks/alkali labile sites) were observed in blood cells of irradiated animals, covering all three classes of genotoxic effects.

Conclusion: Chronic LDR γ-radiation is indeed genotoxic in an exposure scenario realistic for humans, supporting the hypothesis that even LDR γ-radiation may contribute to the induction of cancer. Selenium deficiency or impaired repair of oxidized DNA did not significantly contribute to the genotoxicity observed.

References: Graupner, A. *et al.* // Sci Rep. 2016, 6: 32977.

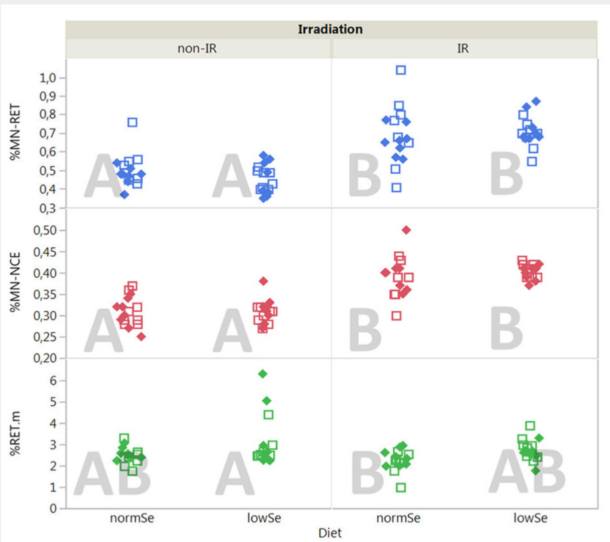

Figure 30: Micronucleus assay in red blood cells. Upper panel: Mean % micronucleated blood reticulocytes (% MN-RET). Middle panel: Mean % micronucleated normochromic erythrocytes (% MN-NCE). Lower panel: % reticulocytes (% RET) of unexposed (non-IR) and chronic LDR irradiated (IR) mice given two different diets (normal Se (normSe) and low Se (lowSe)). Solid diamonds (Ogg1+/−) and hollow squares (Ogg1−/−) represent individuals (8 mice per group). Dissimilar letters indicate significant difference between groups (Tukey's HSD).

CHARACTERIZATION OF THE TOXICITY OF UV AND GAMMA RADIATION TO *LEMNA MINOR*

L. Xie, K.E. Tollefsen (NIVA, NMBU/IMV), K.A. Solhaug (NMBU/INA), O.C. Lind, D.A. Brede, B. Salbu (NMBU/IMV), B. Johnsen (NRPA)

Objectives: This project aims to assess the toxicity of gamma radiation (γ) and ultraviolet radiation (UV) singly and in combination in the aquatic plant *Lemna minor*.

Methods: Exposures with UVB (0.37 W/m2) alone and in combination with gamma radiation (10, 20 and 40 mGy/h) were conducted with *L. minor* to characterize the effects on growth, photosystem II (PSII) activity, production of reactive oxygen species (ROS), lipid peroxidation (LPO), frond pigmentation (Chlorophyll a, Chlorophyll b and carotenoids), uncoupling of oxidative phosphorylation (OXPHOS) and frond malformations. A 7-d recovery study without stressors was conducted at the finalization of the 7 d exposure.

Results: Single γ exposure caused growth inhibition, morphological changes (colony formation), PSII inhibition, increase in carotenoids, uncoupling of OXPHOS, ROS induction and increase in LPO (40 mGy/h), whereas no changes were observed in Chlorophyll a and b at any dose rate. UV exposure led to ROS formation and PSII inhibition, whereas no significant effects were observed in terms of growth, morphological changes, PSII activity, pigment levels, OXPHOS and LPO. The combined exposure to the 2 stressors led to enhanced growth inhibition, morphological changes, carotenoid reduction, PSII inhibition, and OXPHOS uncoupling. No enhancement of ROS formation, LPO, Chlorophyll a and b were identified after co-exposures to the 2 stressors. Antagonistic interactions between the stressors were identified when assessing uncoupling of OXPHOS and carotenoid levels. After 7 d recovery, growth rate (γ, γ+UV), ROS (UV), PSII increase (γ+UV) were still affected, whereas OXPHOS, LPO, carotenoids and chlorophyll a and b had returned to normal values.

Conclusion: γ-radiation can lead to growth reduction and photosynthesis activity decrease, potentially due to uncoupling of OXPHOS and ATP production, increase in oxidative stress (ROS) and damage (LPO) in mitochondria and chloroplasts (Fig. 31). UV trigger some of the same toxicity pathways, albeit being less effective at the doses tested. Co-exposure to the 2 stressors both potentiate and antagonise the effects, and data suggests that some of these effects were due to interactions opposed to simple additivity. Effects observed were predominantly reversible, albeit some irreversible effects were observed both for exposure to the single stressors and combination of these. This work provides a better understanding of the effects of UV and γ-radiation singly and in combination, and has led to the detection of susceptible molecular targets and pathways and development of novel lab- and field-based bioassays. The data generated will facilitate improved linkage between molecular and cellular responses and adverse effects (outcomes) relevant for individual and population assessment and evaluate a suite of methods and endpoints for future studies with other aquatic species.

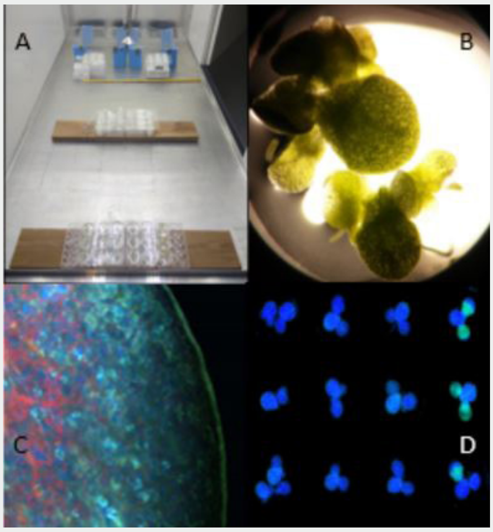

Figure 31: *Exposure in climate chamber(A), L. minor morphological change (B) and ROS formation in fronds (C) and Chlorophyll fluorescence reduction (D) after 7-d exposure to UV and γ-radiation.*

Research Area 4 - Risk Assessment and Ecosystem Approach

The aim of CERAD is to reduce the overall uncertainties in impact and risk assessments and thus increase the protection of man and the environment from harmful effects of ionising radiation, alone and in combination with other stressors. Key issues include how uncertainty is addressed in predictive modelling and risk assessment, and its implications for risk management, decision-making, and risk communication. By interfacing models, linking sources and associated releases via ecosystems to impact and risks, and implementing research from RA1-RA4, the uncertainties associated with model predictions should be improved. Secondly, there is an increasing focus on the effects and risk of low radiation doses at the community or ecosystem level, moving beyond single species exposure and impact assessment. Field studies of the impacts of radionuclides have attracted much attention and controversy in radioecology in recent years, not least due to purported effects at doses much lower than those seen in the laboratory (Strand *et al.*, 2014; Brechignac *et al.*, 2016). Finally, there is an increasing recognition that radiation protection should address socioeconomic impacts (IAEA, 2015).

RA4 is divided into three related umbrella projects: UMB4A Laboratory and field studies in an **ecosystem approach**; UMB4B **Potential Nuclear Events** – assessing impact and risk from specific sources; and UMB4C **Societal impacts** associated with socioeconomics, risk communication, risk perception and stakeholder dialogue.

<u>Umbrella 4A: Ecosystem Approach (A. Jaworska, NRPA):</u> The main aim is to evaluate the consequences of ionizing radiation and radioactive contamination on non-human biota on a higher level of organization, i.e. how do effects of radiation manifest themselves at the community/ecosystem level. The knowledge of radiation effects in radioecology today is mainly based on direct effects on single species in the laboratory or field. The key challenge is to translate this knowledge to cover multiple species ecosystems together with the abiotic part of the environment. Our overarching hypothesis is that ecosystem interactions and processes (e.g. food chain interactions, competition between and within species, changes in biodiversity) can result in indirect effects from exposure to ionizing radiation.

<u>Umbrella 4B: Potential Nuclear Events - impact and risk assessment (O.C. Lind, NMBU/IMV):</u> The main aim is to evaluate and improve impact and risk assessment tools for establishing a scientifically based set of decision criteria. Impact and risk assessments rely on compiling relevant information of the source term and deposition, ecosystem transfer, biological uptake and effect to determine if exposure scenarios encountered under normal conditions or emergency situations (incidents/accidents/malevolent acts) represent a risk to humans and wildlife. By sensitivity analysis, factors contributing the most to the overall uncertainties can be disclosed, thus setting the priorities for the research in RA1-RA3.

<u>Umbrella 4C: Societal Impacts (A. Liland, NRPA):</u> The overarching aim of UMB4C is to evaluate the broader consequences of radiation events and show that effects go beyond the direct effects of radiation contamination, and incorporate a range of economic, societal, and ethical impacts. Evaluation of these aspects requires multidisciplinary approaches between natural and social scientists to understand and present the total societal challenges. It is hypothesized that economic and societal impacts are, in turn, influenced by the way the risks are perceived and communicated. Stakeholder dialogue is adopted as a particularly important method of risk communication, as it can facilitate multidisciplinary assessment of risks. While sensitivity analysis carried out in UMB4B provides information on which factors contribute the most to the overall uncertainties, cost-benefit analysis would inform what mitigating effort would be needed to counteract the foreseeing impact and risks.

Major Achievements 2013-2016

Ecosystem Approach: CERAD's ecosystem approach research was initiated in 2015 and has important links to the International Union of Radioecology (IUR), including a task group for reviewing experimental ecosystem approaches (e.g., micro- and mesocosm studies). CERAD also co-organised the Miami Ecosystem Approach Consensus Workshop with IUR (Brechignac *et al.*, 2016). An aquatic microcosm experiment was performed in 2016 and an extensive number of endpoints has been measured after extended low dose gamma radiation exposure. The soil - plant microcosm experiments are closely linked to fieldwork in Fen, where plant studies have been performed, including plant diversity mapping along a gradient of gamma radiation and soil fauna assessment. As part of the field studies in Chernobyl and Fukushima, sampling and mapping earthworm species diversity has also been carried out to assess whether changes to community structures could be documented.

Potential Nuclear Events: The Western Norway case study, which covers the continuum from a source and release scenario to impact to man and the environments, is a cross-cutting - Flagship - activity that involves all CERAD partners and RAs. The success of coupling of various models has been demonstrated, linking the source and release scenario to impacts (i.e., atmospheric dispersion, aquatic/marine/terrestrial deposition and ecosystem transfer, uptake and potential effect in biota and man, as well as socioeconomic impacts). Models have been adapted to Norwegian conditions to predict the total impact of radioactive releases affecting Norwegian territories (e.g. Brown *et al.*, 2016a). Key factors contributing to major uncertainties in each model have been identified and quantified and the need for model improvement defined. Several of the models have also been applied to assess potential impact in Norway from potential accidents in sunken Russian submarines K-27 at Novaya Zemlya (Bartnicki *et al.*, 2016; Brown *et al.*, 2016b; Hosseini *et al.*, 2016a), and K-59 north of Murmansk (Gwynn *et al.*, 2014).

Risk assessment: A CRA framework addressing the overall risk of NORM and chemical stressors has recently been introduced and demonstrated in several cases studies as described in RA3 (U3C). Further development of a dynamic ERICA risk assessment tool, utilized for assessing impact of the Fukushima accident, is also expected from RA2 (Brown *et al.*, 2016a), and should also be applied for a variety of scenarios.

Societal Impacts: Two local stakeholder dialogue workshops related to the Western Norway scenario were arranged and suggested that collaborative deliberation contributes to increased learning, networking, and problem solving compared to pure information provision (Liland *et al.*, in press). Socioeconomic analysis were undertaken for two case studies: valuing lost recreational value from restricting fishing in the Western Norway scenario and the willingness-to-pay for radon risk reducing measures. These studies point to further applications using the extended expected utility and economics of information frameworks. The multidisciplinary competence within UMB4C has also supported a number of international studies and reviews of societal and ethical aspects of radiation protection and radioecology (Liland, 2015, Oughton, 2016). Risk communication and risk perception have been addressed in media analyses and highlighted unjustified bias in media presentation of radiation risks (Tomkiv *et al.*, 2016).

PhD and PostDoc positions: *PhD Y. Tomkiv (NMBU/IMV), A. Liland (NRPA), K J. Aurland-Bredesen (NMBU/HH)*

Research Highlights – Risk Assessment

EFFECTS OF GAMMA RADIATION ON ECOLOGICAL PROCESSES AND RESPONSES IN FRESHWATER MICROCOSMS

T.H. Hevrøy, L.K. Jensen, E.L. Hansen (NRPA), A.L. Golz, C. Bradshaw (Stockholm University), L. Xie (NIVA), L. Rossbach, D.H. Oughton (NMBU/ IMV)

Objective: To investigate effects of ionizing radiation on a model aquatic microcosm, including indirect effects caused by ecological interactions.

Methods: The aquatic microcosms were exposed to a gradient of gamma radiation with 4 decreasing dose rates (20, 8, 2, 0.8 mGy/h), a control and a positive control (8.8 and 44.3 µgCd/L). The experiment ran for 22 days. The cosms were assembled using artificial freshwater, sediment, phytoplankton (*Raphidocelis subcapitata* and *Eustigmatos sp.*), zooplankton (*Daphnia magna*), three plants (*Lemna minor*, *Lysimachia nummularia* and *Egeria densa*), one gastropod (*Lymnaea peregra*) and litter bags composed of leaves from 4 Nordic tree species (Fig. 32). Several structural and functional endpoints were measured. We sampled throughout the experiment for respiration, primary production, growth rates and water chemistry (C,N, P and major elements). On the last day of the experiment a wide range of endpoints assessing indirect and direct effects were measured and samples of all ecosystem components were taken for analysis of C, N and P content.

Results so far: The positive controls demonstrated that the microcosms were sensitive enough to respond to an external stressor. At both Cd concentrations, all *Daphnia magna* and *Lymnaea peregra* individuals died within 24 hrs and phytoplankton was reduced to a very low abundance. ROS production in *L. minor* increased with radiation dose, and growth rates (number of fronds) were suppressed in the radiation exposed groups. Several photosynthetic parameters of *L. minor*, as well as the other two aquatic plants, were negatively affected by radiation in a dose-dependent manner. Primary production decreased at all dose rates and the control during the first week and remained low for the duration of the experiment. Differences between treatments varied during the course of the experiment. This was probably due to the different timing in fluctuations in *D. magna* populations between treatments, in combination with potential direct effects to the phytoplankton. These temporal variations and treatment differences were also seen in measurements of whole ecosystem production and respiration. *Lymnaea peregra* produced fewer eggs at higher dose rates. Leaf litter degradation was slower in all radiation treatments compared to the controls, which would be expected to lead to differences in the release of particulate and dissolved nutrients into the sediment and the water column, with potential knock-on effects for the biota.

Conclusion: We demonstrated that these aquatic model ecosystems are suitable and practical for assessing direct and indirect ecosystem effects of ionising radiation. Radiation directly and potentially indirectly affected a range of different ecosystem components and processes.

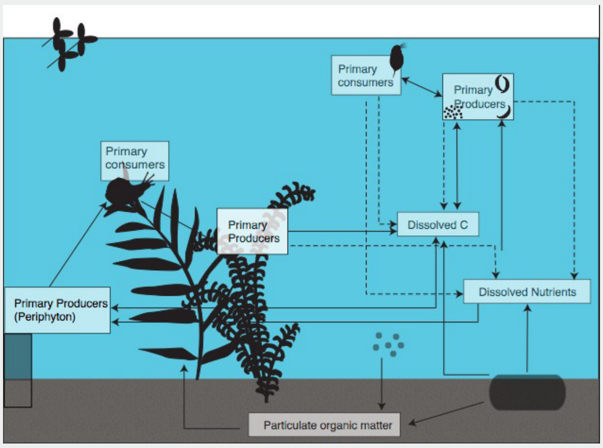

Figure 32: *Schematic illustration of the various components and species within our microcosms, and how they interact with another.*

SOCIOECONOMIC ASPECTS AND RISK COMMUNICATION

D.H. Oughton, Y. Tomkiv (NMBU/IMV), A. Liland (NRPA)

Objectives: The overarching premise is that the consequences of radiation events go beyond the direct effects of radiation, and incorporate a range of economic, societal, and ethical impacts. It is also hypothesized that these impacts are, in turn, influenced by the way risks are perceived and communicated.

Risk Communication: Communication of radiological risks during an emergency is a challenging task. As part of the EU NERIS and PREPARE projects, studies have been carried out on the role of traditional and social media in communication after the Fukushima accident. Analysis of newspaper coverage from six European countries showed that information about radiological risks was not always understandable and meaningful for the reader, and a number of mistakes were found (Tomkiv *et al.*, 2016). Results of a Twitter study highlighted the dissemination potential this social media has and its importance ad a dissemination channel. These and other results served in development of recommendations on how to communicate with traditional and social media in the radiological emergency (Perko *et al.*, 2016). Two stakeholder dialogue meetings were organized within the Western Norway project in January and March 2015 to address social, economic, environmental, ethical and risk communication aspects of the Sellafield-scenario. The stakeholder meetings demonstrated the value of cross-sectorial, cross-topical discussions on the consequences of a radiological accident for research and emergency preparedness. They also contributed to improved knowledge and engagement at the local level, and supported in finding solutions to problems (Liland *et al.*, in press).

Socioeconomic Impacts: CERAD researchers have contributed to the analysis of the societal and ethical impacts of the Fukushima accident in a number of forums, including IAEA, ICRP and NEA (see separate section on societal impact for more information). They have participated in ICRP stakeholder dialogues in Fukushima, and have contributed to international recommendations for health surveillance of affected populations as part of the EU SHAMISEN, including ethical challenges from thyroid screening (Oughton, 2016; Liland, 2015, Buessler *et al.*, 2016). Socioeconomic analysis has been undertaken for valuing lost recreational value from restricting fishing in the Western Norway scenario.

Conclusions: The importance of risk communication and the socioeconomic impacts of nuclear events is increasingly recognized internationally, and the fact that CERAD has included this as part of its research portfolio is a good illustration of the innovative and holistic approach of CERAD.

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ICRP Fukushima dialogues
Photo: Yevgeniya Tomkiv

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Norwegian Centre of Excellence

REDUCING THE UNCERTAINTIES IN RISK ASSESSMENT MODEL PREDICTIONS

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Objectives: The Western Norway sub-project within CERAD CoE is an integrating project involving all the research groups and covering all aspects of risk assessment from sources and releases via air transport and deposition, via ecosystem transfer, exposure and biological effects of radionuclides to consequences of health, environment, society, economy and ethics. It considers a potential atmospheric release from waste tanks at Sellafield and deposition in Rogaland, Western Norway. The goal is to reduce the overall uncertainties in the assessment. The hypothesis is that improvement of key factors contributing to uncertainties in each model would greatly improve the predictions in risk assessment. Sensitivity analysis of models serve as input to ongoing and upcoming focused research aiming to reduce the uncertainties.

Methods: Develop protocols to link up to 8 different models in a chain (Fig. 33). The parameters associated with the largest uncertainties were to be identified and the uncertainty factors to be quantified. Implementation of the results of focused CERAD research into the various models to reduce uncertainties and improve model predictions. To obtain site-specific information on bioproduction, industries and sensitive activities such as tourism, regional and local authorities were involved through separate meetings, fieldwork/visits and stakeholder seminars in Rogaland.

Results: The models were successfully coupled and the results showed increased contamination levels in all ecosystems and related organisms, including humans. The key factors contributing to uncertainty for each model were identified. The need for regional and site-specific data was emphasized. The key model improvements so far are summarized in Table 2.

Table 2: *Key improvements obtained for each model to reduce uncertainties.*

Model	Key improvements performed to reduce uncertainties
Atmospheric modelling (SNAP)	Increased grid resolution, particle size and density taken into account, how to use meteorological uncertainty in decision making assessed
Agricultural transfer model (AgriCP)	Updated with regional values for leaf area indices, production yields, harvest dates, animal feeding regimes and human dietary habits
Transfer from pasture to milk and meat (STRATOS)	Fieldwork performed in Rogaland, analyses ongoing to determine site-specific transfer
Exposure of wildlife (ERICA Tool)	Updated transfer data, new extrapolation methods
Catchment transport (INCA-RAD)	5 particle sizes included in the model
Estuary: new model under development by coupling INCA-RAD and the NRPA box model	Particles, colloids and low molecular fractions included as well as dynamic Kd's and CFs
Marine model (ROMS/TRACMASS)	Increased grid resolution, tidal transport investigated, dynamic sedimentation, resuspension and phase transfer processes included

Conclusion: In order to reduce the overall uncertainties it is crucial to replace constants with dynamic functions, and to obtain site-specific information through fieldwork, laboratory experiments and stakeholder involvement.

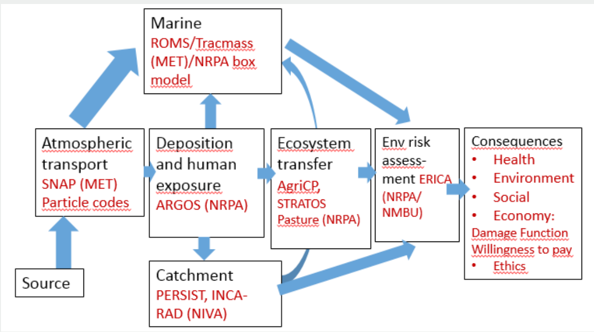


Figure 33: *Risk assessment models coupled in sequence with the key factors to be addressed in order to reduce uncertainties in risk assessment.*

International Collaboration

CERAD has continued and expanded its bilateral and international collaboration, as these activities have a major influence on scientific research priorities. This work contributes to a better understanding of radioecological processes, radioprotection of humans and underpins the improvement of extant assessment models, source term concepts, and the development of new dynamic transfer models, which results in reduced uncertainties related to risks of radioactive contamination in affected areas, for instance in the Arctic. CERAD participates actively in the intergovernmental Arctic Council; CERAD's involvement in the Arctic Monitoring and Assessment Programme (AMAP) provides reliable scientific information and assessments related to Arctic environmental threats and supports Arctic governments in remedial and preventive actions relating to contaminants and climate change. CERAD participates in several Nordic Nuclear Safety Research (NKS)-projects strengthening the competence within radioecology, environmental protection, emergency preparedness and analytical methods.

CERAD participates actively in several international bodies, such as The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Atomic Energy Agency (IAEA), International Union of Radioecology (IUR), and International Commission on Radiological Protection (ICRP). CERAD scientists have been involved in follow-up assessments of the consequences of the Fukushima accident, resulting in three White papers, the latest being UNSCEAR (2016). An in depth review of environmental impacts from the Fukushima accident by the CERAD Deputy director contributes to the new IAEA Coordinated Research Project on Environmental Behaviour and Potential Biological Impact of Radioactive Particles (2015-2018), the Director of CERAD acting as chair. CERAD members are involved in other IAEA activities; revision of technical safety guides, and coordinated work on the societal impacts of Fukushima for the IAEA Comprehensive Report. CERAD collaborates with the IUR in developing an Ecosystem Based Approach for radioecology, organising a Consensus symposium in Florida in 2015. CERAD experts are members of two ICRP committees and participated in three co-expertise dialogues in Fukushima and one final international workshop on the ICRP dialog initiative. CERAD's Research director is a member of UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology. CERAD has cooperated with the intergovernmental OECD-Nuclear Energy Agency (NEA), in facilitating cooperation among countries with respect to advanced nuclear technology infrastructures, and the OECD NEA: Expert group on Management of Radioactive Waste After a Nuclear Power Plant Accident, both chaired by the CERAD Deputy director.

CERAD is prominent within EU radioecology and radiobiology research, through the European Radioecology Alliance (ALLIANCE) platform, European Platform on preparedness for nuclear and radiological emergency response and recovery (NERIS), Multidisciplinary European Low Dose Initiative (MELODI) and European Radiation Dosimetry Group (EURADOS) and via participation in a series of EU projects. CERAD is a partner in the EJP CONCERT project and partners in the EU projects TERRITORIES and CONFIDENCE 2017. Due to close international cooperation CERAD has performed a series of fieldwork or expeditions to accident sites, nuclear test sites, and NORM sites in other countries (Japan, Ukraine etc) since 2013, and got access to unique experimental facilities (e.g., synchrotrons in France, Germany, Australia, AMS in Spain, Australia), models, and archive samples (radioactive particles from previous accidents). Thus, many published articles (see Publication list) include co-authorship with international scientists.

CERAD/NMBU also hosts the only European MSc in radioecology, and collaborating international scientists contribute with lecturing and supervision. Furthermore, collaboration agreements (MoU) with universities abroad (e.g., Ukraine and Japan) will strengthen the international dimension, and includes both science and education.

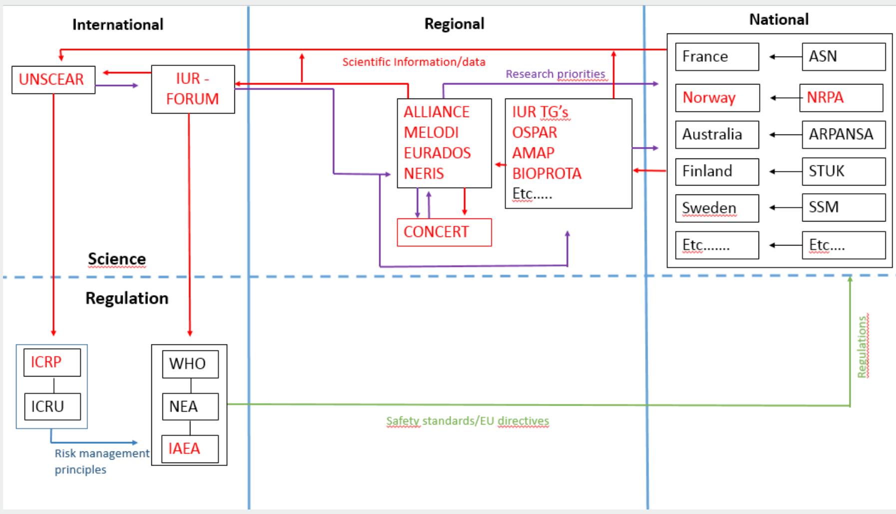
National, Bilateral and International Collaboration

In Detail

During 2016, CERAD has maintained and expanded its national, bilateral and international collaboration. National collaboration within the Fram Center, Trømsø, where NMBU, NRPA and NIVA are members has continued. This resulted in a FRAM funded project where NORM and metals in connection with mining activity are studied. Norwegian-Russian collaboration remains an important focus for several CERAD partners, an important conduit being the Nuclear Action Plan within which nuclear safety initiatives have contributed to reduce the risk of nuclear accidents and radioactive contamination in Northwest Russia. Bilateral collaboration in regulatory support and research based projects at both Andreeva Bay on the Kola Peninsula and the Mayak Production Association in the Urals have addressed themes as diverse as internal human dosimetry and radiological impacts on freshwater ecosystems, the fruitful working arrangement continuing as evidenced by recent achievements. An EU-funded project concerning the preparation and feasibility testing of an action plan on the safe and secure management/disposal of dumped and sunken radioactive objects in the Arctic continues with active CERAD member participation.

Regional Arctic cooperation, in addition to AMAP activities under the Artic Council, includes the Emergency Prevention, Preparedness and Response Working Group (EPPR) which CERAD/NRPA participates in and contributes to. The EPPR addresses various aspects related to the prevention of, preparedness for and response to environmental emergencies in the Arctic. International collaboration during 2016 has included the CERAD international network (SAC), participation within relevant EU projects, access to various experimental platforms as well as collaboration with and representation on international bodies such as UNSCEAR, IAEA, OECD/NEA, ICRP and the International Union of Radioecology (IUR). Different roles and interactions between the international bodies is shown below.

The contribution of scientific research to the development of effective regulation and its subsequent implementation is achieved via a number of conduits and interfaces. This information flow is conducted in a feedback loop whereby national entities and regional and international scientific groupings supply high quality information and data to expert international bodies. These subsequently distil this input and contribute to the efforts of organisations that produce recommendations and guidelines underpinning national and international regulations. Effective feedback loops ensure that the generation of information in the first stages is oriented towards



Key international organizations (in red: CERAD contributions) and their interactions with focus on the relationship between regulations and science.

addressing the needs of subsequent components in the process. Through effective streamlining of the efforts of national and regional components of the system and the maintenance of feedback systems, national capacities can contribute in a synergistic and flexible manner to the production of regulations that are fit for purpose and adequately address the requirements of national regulators. CERAD features prominently on a European level with connections to the European Radioecology Alliance that has been established between the radiation protection organizations in Europe to pool knowledge and research efforts and to train new experts/young scientists in the field of radioecology. Indeed, NMBU hosts the only MSc in Radioecology in Europe, and collaborations (MoU) with several universities (e.g., France, Russia, Spain, Ukraine, Japan) include education and research. Within radioecology, CERAD is partner in the EU COMET and COMET/RATE projects, and has also been partner in projects associated with radiochemistry (CINCH-II), radiobiology (DoReMi) and emergency preparedness (PREPARE). CERAD members also collaborate within the Open Project for the European Radiation Research Area (OPERRA), are members of the NERIS European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery, and are partners in the European Joint Programming CONCERT, as well as CONFIDENCE "COping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCiEs" and TERRITORIES "To Enhance unceRtainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations". CERAD is also involved in CONCERT E&T Experimental Radioecology-course and Assessing Risk to Humans and Environment (course) and CONCERTs Infrastructure platform (Gamma source at NMBU).

Experts from CERAD have been involved, under the auspices of UNSCEAR, in follow up work in determining the consequences of the Fukushima Dai-ichi nuclear power plant accident. UNSCEAR undertook an initial comprehensive assessment that ended in 2013 (UNSCEAR, 2014) and considered it necessary to monitor the robustness of the original conclusions and recommendations in the light of new information from subsequent years. This analysis have led to an in depth review of environmental impacts following the Fukushima accident as presented by Strand *et al.* (2017). More recently, CERAD has been involved in a new working group aimed at assessing and reviewing literature from the last decade pertaining to radon and the associated risk of lung cancer, in order to produce a follow-up report to UNSCEAR's last radon publication from 2006. Similarly, CERAD has been invited to contribute to the 2nd Handbook of Plutonium, 50 years after the first edition, published by American Nuclear Society. The CERAD MG is also members of two ICRP committees, and the CERAD Research director chairs the ICRP task group on ethics. CERAD members have also participated in three ICRP co-expertise dialogues in Fukushima and one final international workshop on the ICRP dialog initiative. CERAD works also works together with the IUR towards the development of an Ecosystem Based Approach in radioecological assessment. In this regard, a workshop was held in Florida in November 2015 in order to discuss issues related to assessment of radiation impacts in the environment and to establish consensus where possible. CERAD is also heavily involved in the new IAEA Coordinated Research Project on Environmental Behaviour and Potential Biological Impact of Radioactive Particles (2013-2016), where the Director of CERAD acts as chair. CERAD members are also involved in other IAEA activities such as revision of technical safety guides and co-ordinating work on the societal consequences of Fukushima for the IAEA Comprehensive Report.

CERAD/NMBU has been involved in NATO Science for Peace and Security programs for many years. As a follow up, CERAD is currently involved in projects related to Central Asia. CERAD/NRPA has also worked in collaboration with the Nuclear Energy Agency (NEA), an intergovernmental agency facilitating cooperation among countries with advanced nuclear technology infrastructures. This led to the following report: OECD NEA: Expert group on Management of Radioactive Waste After a Nuclear Power Plant Accident - chairperson of the group CERAD/NRPA.

Positions and Awards

CERAD MG and lead scientists are active players on the international arena, being members of a series important international scientific and policymaking organisations in the field, in addition to those directly linked to the Arctic (e.g., Arctic Monitoring and Assessment Programme (AMAP), Arctic Council: Emergency Prevention, Preparedness and Response Working Group and the Norwegian – Russian Expert Group on radioactivity in the Northern areas).

Board and committee memberships

• ICRP (International Committee for Radiation Protection), CERAD Deputy Director Per Strand is member of Committee 5: Protection of the Environment, and CERAD Research Director Deborah H. Oughton is member of Committee 4: Application of the Commission's Recommendations. Several of the partner scientists are members of ICRP Task groups (Task Group No 74, 76, 94, 98).

• OECD/NEA Expert Group on Fukushima Waste Management and Decommissioning, CERAD Deputy Director Per Strand chaired the group. Additional CERAD scientists are members of OECD/NEA: Working Parties.

• UNSCEAR's assessment of the Fukushima nuclear accident (Effect in the environment), CERAD Deputy Director Per Strand was Lead Expert. Additional CERAD scientists contributed to the UNSCEAR Impact of the Fukushima Nuclear Accident on Marine Biota.

• UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), CERAD Research Director Deborah H. Oughton is member - nominated by KD.

• IAEA: Coordinated Research Project (CRP) Environmental Behaviour and Potential Biological Impact of Radioactive Particles, CERAD Director Brit Salbu act as chair.

IAEA: Regulatory Supervision of Legacy Sites (RSLS) –initiated by Malgorzata Sneve (NRPA).
IAEA: The Co-ordination Group for Uranium Legacy Sites (CGULS), members Malgorzata Sneve (NRPA), Brit Salbu (NMBU).
IAEA: Fukushima Comprehensive Report, CERAD Research Director Deborah Oughton co-ordinated section on societal impact and revitalisation.
IAEA: MODARIA II (Modelling and Data for Impact Assessments) – Justin Brown (NRPA).
IAEA: BIOPROTA – Justin Brown (NRPA).

• ALLIANCE: The European Alliance of Radioecology, CERAD Deputy Director Per Strand is Vice President from 2012, CERAD Director Brit Salbu is member of Board.

• NERIS: The European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery, CERAD Research Director Deborah Oughton is member of Board.

The Chernobyl 30 year memorial medal was awarded CERAD Director Brit Salbu

Deputy Director Per Strand is elected President of IUR 2016
Photo: Quentin Mennecart

Honours and awards

• IUR: International Union of Radioecolog, CERAD Deputy Director Per Strand, elected President 2016, Council Board: Deborah Oughton (NMBU). CERAD scientists are in lead of Task Groups.

• The IUR 4th V. I. Vernadsky prize was awarded CERAD Director Brit Salbu in 2014.

• The Chernobyl 30 year memorial medal was awarded CERAD Director Brit Salbu, 26 April 2016.

• CERAD Director Professor Brit Salbu was also appointed Honorary Professor at National University of Environment and Life Sciences, Kiev, Ukraine, 1 September 2016.

• The professors Salbu and Oughton are elected members of the Norwegian Academy of Science and Letters.

Picture top: *V. I. Vernadsky prize.*

Picture left: *V. I. Vernadsky prize was awarded CERAD Director Brit Salbu in 2014.*

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Experimental Facilities, Models and Tools

A clear Vision for the Scientific Output from CERAD CoE is to provide:

- Novelties: major progress at the interface between disciplines
- New concepts: integrated concept for man and the environment, integrated concept for contaminants, integrated concept ionizing and UV radiation, and explore an effect unit non-human organisms
- Cutting edge: combination of advanced tools from other disciplines
- Dynamic models: time and climate depended variables

To meet the scientific requirements, the CERAD CoE has the possibility to perform cutting edge research due to access to unique experimental facilities, models and tools, both within CERAD and in collaboration with partner institutions and also internationally. Below the experimental facilities, models and tools are listed in short.

IN SITU SPECIATION AND FRACTIONATION TECHNIQUES

In situ fractionation systems such as chromatography-hollow fibre and tangential flow systems are available at NMBU Isotope Laboratory, and these are used in field expeditions all over the world where CERAD/NMBU is involved in aquatic research projects.

PARTICLE ARCHIVE

At the Isotope laboratory, NMBU, CERAD has a unique particle archive containing micrometer to millimetre sized radioactive particles released from different sources, varying with respect to composition, particle size, crystalline structure and oxidation states. The well characterized anthropogenic and naturally occurring particles originate from different historical sources and release scenarios such as nuclear weapon tests, conventional detonation of nuclear weapons, reactor accidents, accidental and routine releases from nuclear reprocessing facilities, different NORM sites, the use of depleted uranium and particles associated with dumped waste.

RADIONUCLIDE AND ELEMENT DETERMINATION

At NMBU Isotope Laboratory and NRPA instrumentations and methods for determination of both gamma- beta- and alpha emitting radionuclides are available. At NMBU, three Agilent 8800 Triple Quadrupole ICP-MS (ICP-QQQ-MS) are utilized for the determination of long-lived radionuclides, including isotope ratios, and a large range of other elements in the periodic table.

A new Bruker M4 Tornado micro-XRF was installed at NMBU in November 2016.

ACCESS TO ACCELERATOR MASS SPECTROMETRY (AMS)

At very low concentration levels, the AMS facilities at Australian National University, Canberra, Australia and Centro Nacional Acceleradores, University of Seville, Spain are utilized.
The cooperation with Australian National University and University of Seville allows access to Accelerator Mass Spectrometry (AMS) for determination of very low level elements, long-lived radionuclides and isotope/atom ratios.

IN LAB SPECIATION TECHNIQUES

A FIFFF-ICP-MS (flow field flow fractionation) system is utilized for further spesiation work at the laboratory together with a HPLC-ICP-MS system.
FIFFF, being a proper separation method, coupled to multi detection equipment such as ICP-MS is one of the most useful tool for identifying metal-organic compounds at the nm scale, and to follow changes in the metal speciation (molecular mass) due to transformation processes also occurring in the environment.

HPLC-ICP-MS is being used to discover biomolecules, metabolites and proteins, involved in the metabolism of selenium and iodine and to understand their interrelashionship (Fig. 34).

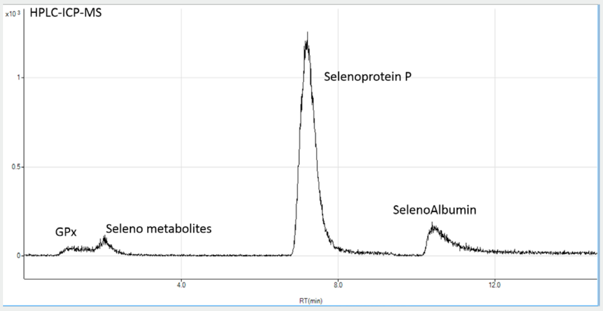

Figure 34: *Chromatographic separation of selenium biomolecules by means of affinity chromatography using ICP-QQQ-MS as specific detector of Se-78.*

CERAD ACTS AS NODE TO THE IMAGE CENTRE AT NMBU

The Imaging Centre Campus Ås is aiming at a state-of-the-art status within microscopy (ESEM-EDX, TEM, confocal laser SEM, light microscopy, live cell imaging and spectroscopy (x-ray, RAMAN micro imaging etc). Within the roadmap, CERAD acts as an important node with respect to competence and instrumentation (stereo microscope with micromanipulation, micro-XRF).

ACCESS TP EXTERNAL PLATFORMS -SYNCHROTRON X-RAY RADIATION FACILITIES

Based on many years of close collaboration with scientists nationally and internationally CERAD/NMBU has access to and has utilized ESEM-EDX, TEM, TOF-SIMS, nano-CT, synchrotron radiation nano-and microscopic techniques. These SR techniques (i.e., 2D/3D XRF – elemental distributions, XRD - structure, XANES – oxidation state) utilized for particle research at facilities such as PETRA, Germany, ESRF, France have been developed by NMBU, University Antwerp and the beamline scientists. In addition, access to synchrotron microscopic techniques is also obtained in Australia (ANSTO).

THE BIOLOGICAL EFFECTS TOOLBOX

The CERAD consortium has established a toolbox for systematic interspecies comparison of harmful effects of chronic exposure to radioactivity as part of Research Area 3. The toolbox has been designed to serve as a framework for investigation of radiosenisitivity, and combined stressor scenarios including radionuclides, toxic metals and UV.
The aim is to investigate the apparent differences in radiosensitivity and to identify mechanisms at the molecular level that determine susceptibility to chronic low/medium dose rate gamma radiation alone, and in combination with other stressors.

The toolbox focuses on selected model species including mammals, fish, invertebrates and plants (Table 3). The toolbox includes standardized experimental designs and protocols with a common set of biological effects endpoints. To ensure comparable exposure scenarios, standardized dosimetry and a core set of dose rates are employed for all model species. Additional dose rates are customized for each model species to establish a dose-response.

CERAD MODEL ORGANISMS

The CERAD model organism test panel have been selected to address both radioecology and human health research. The models were chosen based on relevance to the Nordic environment, their presence in historical nuclear release sites like Chernobyl and Fukushima, and ICRP, or OECD recommendations for Radioecology and toxicity research. To address human health and risk aspects, both different mice models (cancer, DNA repair deficiency and Parkinson), human cell lines and zebrafish are employed. With respect to radioecology, the models include both terrestrial and aquatic ecosystems species, and represent multiple trophic levels from primary producers to top predators, as well as test organisms at different life history stages. These species also represent a wide range in terms of sensitivity towards ionizing radiation and other environmental stressors.

Table 3: CERAD toolbox organisms

ORGANISM		REPRODUCTION	ECOSYSTEM FUNTION	TROPHIC LEVEL		PHYLUM
Mus musculus (Mice)		FEMALE/ MALE SEXUAL REPRODUCTION	PRIMARY CONSUMER/PREY	OMNIVORE	TERRESTRIAL	MAMMALIA
Caernorabditis. elegans		HERMAPHRODITE/ MALE SEXUAL REPRODUCTION	SOIL NUTRIENT CYCLING	BACTIVOROUS NEMATODE		NEMATODA
Eisenia fetida (Earthworm)		HERMAPHRODITE/ SEXUAL REPRODUCTION	SOIL NUTRIENT CYCLING	DECOMPOSER		ANNELIDS
Picea abies (Norway spruce)		SEXUAL, CROSS-POLLINATION	CONIFEROUS EVERGREEN TREE	PHOTO-SYNTHESIS		PINOPHYTA
Pinus sylvestris (Scots pine)		SEXUAL, CROSS-POLLINATION	CONIFEROUS EVERGREEN TREE			PINOPHYTA
Arabidopsis thaliana		SEXUAL, SELF-POLLINATING	PIONEER ANNUAL PLANT			ANGIOSPERMS
Salmo salar L. (Atlantic salmon)		FEMALE/ MALE SEXUAL REPRODUCTION	ANADROMOUS MIGRATORY FISH	PREDATOR	AQUATIC	TELEOSTI
Danio rerio (Zebrafish)		FEMALE/ MALE SEXUAL REPRODUCTION	TROPICAL FRESH WATER FISH	PREDATOR		TELEOSTI
Daphnia magna		PARTHENOGENESIS OR SEXUAL	FRESH WATER FILTER FEEDER	PRIMARY-PREDATOR		ARTHROPODA
Lemna minor (Duck weed)		VEGETATIVE OR FLOWERING	FRESH WATER PLANT	PHOTO-SYNTHESIS		ANGIOSPERMS
Chlamydomonas reinhardtii		MATING/BINARY FISSION	FRESH WATER UNICELLULAR ALGAE			CHLOROPHYTA
Skeletonema. costatum		MATING/BINARY FISSION	SEA WATER DIATOMIC ALGAE			BACILLARIOPHYTA

FISH EXPERIMENTAL FACILITIES - TRANSFER AND EFFECTS EXPERIMENTS ON FISH - BOTH FRESHWATER AND MARINE FISH SPECIES.

At NMBU, the new Fish laboratory facilities are located in the newly buildt Centre for animal research at Ås. This comprises a specifically designed Isotope laboratory for using radionuclides in experiments with aquatic organisms including fish. The laboratory includes a temperature controlled room with logging system for water variables; pH, temperature and oxygen. The facility is so far limited to batch/flow through experiments, but with large flexibility to use different fish speciesand different types of freshwaters (both naturally and synthetic).

Facilities to perform experiments of different life stages of fish are available, e.g., the early life stages releated to the period from fertilisation of egg until hatching and swim up stage, start feeding, juvenile and adult fish.

Experimental facilities and availability of a large range of marine species to perform exposure studies with radionuclides are available at NIVA Solbergstrand marine research station. Thus, the combination of experiments on different fish species, at different life stages in different types of water with the use of advanced analytical techniques will allow different controlled tests to obtain information on the bioavailability, uptake and toxic effects of different radionuclides and to evaluate the sensitivity of different fish species as well as , the sensitivity of different life stages.

ZEBRAFISH PLATFORM – TRANSFER AND EFFECT STUDIES ON ZEBRAFISH

The Norwegian Zebrafish Platform (http://zebrafish.no) was established at NMBU/NVH in 2007 as a FUGE Technology Platform (RCN #183344) and consists of a medium size zebrafish facility (AZLab) with a capacity of 10,000 fish, having a high operational quality standard with accreditation from AAALAC. The Platform coordinates the Zebrafish Network Norway (ZNN) and has organized an annual international ZNN Conference combined with a PhD course. The AZLab has participated for several years in a research program focused on microgravity effects on biological functions. The Zebrafish Platform organized the European Zebrafish Meeting 2015 with about 800 participants (www.zebrafish2015.org). The CERAD zebrafish research focuses on sensitive life stages, as well as transgenerational effects and epigentics in organisms exposed to gamma radiation at NMBU.

MOUSE PLATFORM –TRANSFER AND EFFECT STUDIES ON MICE

NIPH comprises an animal facility which has been extensively used for in vivo investigations of responses to chemicals and X-ray radiation in mice and other rodents for many years. The conjunction of the animal facility at NIPH with the gamma irradiation facility at CERAD/NMBU enables studies of biological effects of low to medium dose rate/low doses of gamma radiation, alone, or in combination with other stressors. Mice from the NIPH-facility have been transported to the CERAD/NMBU gamma radiation facility for exposure, after which mice have been terminated. Biological material have been prepared for endpoint analyses at the gamma facility, or the mice have returned to NIPH for endpoint analyses. The basic infrastructure including lab benches, refrigerators, freezers, centrifuges etc are available at CERAD/NMBU.

GREENHOUSES/PLANT UPTAKE AND EFFECT EXPERIMENTS (PHYTOTRON)

At the Centre for Plant Research in Controlled Climate (SKP) at NMBU, the greenhouse compartment includes an isotope laboratory and growth chambers are available on a rental basis. This enables plant experiments under controlled conditions. The CERAD-funded prototype climate chamber to be utilized for the combined UV and gamma exposure (at Figaro) has been constructed by SKP, and mixed exposure experiments are ongoing.

THE NMBU LOW-MEDIUM DOSE GAMMA RADIATION EXPOSURE FACILITY (FIGARO)

The NMBU constructed gamma irradiation source at Aas is the only one of its kind and provides a continuous dose rate field from 3 Gy/hr down to 400 µGy/hr, and allows simultaneous chronic exposure of samples over the whole dose-rate field. The CERAD/NMBU facility opened in 2003, was upgraded in 2012, supported by the EU DoReMi project. The facility is utilized for a series of chronic exposure experiments (including combined gamma/alpha and multiple stressor studies) on various test organisms.

CLIMATE CHAMBERS FOR COMBINED UV AND GAMMMA EXPOSURE

Two climate chambers have been constructed where organisms can be exposed to gamma radiation in combination with realistic levels of UVR, under controlled light, temperature and humidity conditions. The chambers containing test organisms can be split into test and control compartments. Dimmers with timer functions enable manual adjustment of the irradiance levels, and on/off operation for simulated lighting conditions. A regulator with diurnal cycling functions ensures control of humidity and temperature. The spacious compartments enable installation of moderate size, portable lamp units used at the partner laboratories for non-gamma stressor studies and optimization of experiment protocols before deployment at the gamma facility.

IN SITU GAMMA AND UV MEASUREMENT STATIONS

NRPA in cooperation with the Norwegian Environment Agency/NILU is responsible for nine monitoring stations in Norway. Monitoring data of both gamma radiation and UV is available on-line, real time. Based on almost 20 years of monitoring data and a widely used radiative transfer model, NRPA in cooperation with met.no is currently exploring the possibilities of predicting surface UV for locations of interest for CERAD. Variables like snow-cover, altitude, time of day, thickness of the ozone layer etc. will be included as input variables in the models.

OTHER UV-A AND UV-B EXPOSURE

UV-A and UV-B are examined separately and in combination at the NRPA UV lab, at NMBU, at NIVA and in the phytotron at NMBU/Ås. Furthermore, optical radiometers for the monitoring of source stability and total exposure are available at NRPA and at NMBU. These can be used in laboratory experiments. Other monitoring setup for field use will be explored.

DISPERSION AND TRANSFER MODELS

Advanced air/marine transport models and real time/historic/future prognostic meteorological data are further developed by MET and NRPA. Ecosystem transport models (NIVA, NRPA), advanced models on dosimetry (NRPA), as well as human food chain and wild life food chain models (NRPA) are also utilized at CERAD.
All models will be further developed as process understanding and parameterizations improve and more site specific data become available. In addition, models will be linked to represent the chain between source and release conditions to impact and risk. Furthermore, sensitivity analysis will be applied to identify factors contributing the most to the overall unceratinties. Mechanistic models related to high and low LET radiation will be combined with UV, to evaluate biological effects for exposed organisms (NRPA).

RISK ASSESSMENT MODELS

Models for impact and risk assessment including the ERICA assessment tool and Cummulative Risk Assessment (CRA), are available to predict the hazard and risk of single stressors and combinations of these (multiple stressors).
All models will be further developed as process understanding and parameterizations improve with more site specific data. Effort to link the hazard and risk assessment models to existing dispersion and transfer models is ongoing to assess both processes and impact of low dose radiation and multiple stressors.

ECONOMIC MODELLING

The economic modelling under CERAD covers three main parts linked to Case studies (Potential nuclear events):

1) Scenario specific assessment of economic consequences for agriculture due to potential accidental release and radioactive contamination.
2) Scenario specific assessment of economic consequences for recreational fisheries due to potential radioactive contamination.
3) Economic assessment of catastrophic risks utilizing an extended expected utility framework.

Field Studies and Expeditions

Every year several expeditions and fieldwork campaigns have been performed within CERAD. Since the start of CERAD, fieldwork or expeditions to sites contaminated by accidental release of radionuclides, nuclear test sites, naturally occurring radioactivity (NORM) sites and sites included in case studies have been performed. The CERAD fieldwork provide input to all CERAD research areas (RA), as investigations carried out relate to the speciation of radionuclides (RA1), mobility and transfer in the environment and bioavailability towards aquatic and terrestrial organisms (RA2) and also possible effects in the studied organisms from both radionuclides and other stressors (RA3). Thus, most results feed into the environmental risk assessment performed in RA4. Below is presented a summary list of fieldwork and expeditions performed during the first 4 years of CERAD:

Fieldwork concerning contamination at nuclear test sites:

- In 2014, CERAD visited the Semipalatinsk Test site, north-eastern Kazakhstan, where a total of 456 nuclear weapon tests were conducted in the period from 1949 to 1989. The collected samples have been transported to Norway.

Fieldwork concerning accidental release of radionuclides to the environment, representing different source terms:

- Nuclear accident: The Chernobyl exclusion zone, Ukraine, has been visited several times (in 2013, 2014 and in 2016). In May 2016 a comprehensive fieldwork was performed where samples from both aquatic and terrestial environment were taken. The fieldwork was performed in collaboraration with our Ukrainian partners at UIAR. The site was also revisited several times to do in-field experiments.
- Nuclear accident: A large fieldwork campaign was also performed in the Fukushima exclusion zone in September 2016, where CERAD was one of the first international organizations to attain samples from the exclusion zone. Samples were taken from both aquatic and terrestrial environment, and the results will be compared with those derived from studies within the Chernobyl excusion zone.
- Nuclear accident: In 2015, a site visit at Chalk River, Ontario, Canada was performed. Several accidental and routine discharges have occurred at the Atomic Energy Canada Limiteds nuclear facility at Chalk River.
- Conventional explosion of atomic bomb: Fieldwork visits to Palomaris, Spain, were performed in both 2014 and 2015 looking into several sites in and around the village contaminated by plutonium and uranium containing particles originating from the explosive fire involving thermonuclear devices as a result of the nuclear weapons accident in 1966.
- Nuclear weapon production and reprosessing: Mayak PA area in Chelyabinsk, Ural, Russia, was visited in 2014. This site has been contaminated by several sources back from the 1950ies, and several expeditions have taken place since mid 1990ies..
- Dumped radioactive material: In 2014, CERAD was part of a large expedition in the Barents Sea for sampling of marine samples to investigate possible leakage from the Russian nuclear submarine K-159.

Fieldworks concerning naturally occurring radioactive material (NORM):

- Thorium site: The Thorium (Th) rich FEN area in Ulefoss, Norway, is an excellent site for studying transfer of Th and other metals transfer in the terrestial environment. Several fieldworks have been performed, the latest in 2016.
- NORM and metals: The Hadeland alum shale areas, with elevated levels of uranium (U) and other stressors (As, Cd, etc) arising from road and tunnel construction were visited several times for sampling of waters, soil/sediments and biota in collaboration with the NORWAT project.
- Uranium sites: Bleikvassli and Orrefjell, Norway, are other U-elevated sites where sampling has been performed several times as part of projects funded by the FRAM center in collaboration with CERAD.

- NORM and metals: Runoff of NORM and metals from roadconstruction deposits of sulfur bearing gneiss in Lillesand, Norway, results in estuarine mixing zone processes and effects in organisms in the receiving fjord system. The fieldwork in 2016 included exposure of caged fish and blue mussels in a gradient from the outlet runoff across the coastal mixings zone and into the fjord.
- Among international NORM sites, CERAD have been collected samples in 1) Uzbekistan where local U rich fertilizer is used and NORM is transfered into food, 2) Komi, Russia, a site contaminated from radium production in the 1950ies, 3) Poland to investigate NORM and other elements in an area contaminate by coal mining and production. In addition, a site visit was performed to mining sites in Sudbury, Canada, with elevated U and metal concentrations.

Fieldworks concerning the CERAD case study "Western Norway":

- Fieldwork have been performed in Vikedal, a potential affected western Norway county from a hypothetical accident at Sellafield, UK (Umbrella 8, RA4 case study). The work includes investigation of the transfer of stable analogues in aquatic and terrestrial ecosystems, to identify long-term effects, and to identify key factors contributing to the overall unvcertainties in the assessments.

Collaborative fieldstudy in Fukushima, Japan.
Photo: Brit Salbu

Research Education and Training

An essential ingredient in CERAD is researcher training and education (MSc, PhD, PostDoc) to provide an attractive research environment, and to produce candidates that are internationally competitive within radioecology and ecotoxicology. All courses are given in English and most courses are run intensively to make access possible for students from all over Europe.

To do this we are dependent on interactions with the wider radioecology community, through outreach to students, teachers, employers and employees, and other stakeholders outside our networks. Since radioecology is a multidisciplinary science, students in radioecology have a wide range of future carrier opportunities.

The PhD education at NMBU and collaborating universities are programmes given to provide the European nuclear stakeholders their future workforce. Of particular concern to the stakeholders (EU Commission, authorities, industry and professionals) are the significant and persistent needs for post-graduates with skills in radiochemistry, radioecology, radioecotoxicity, environmental modelling, radiation protection including radiobiology and dosimetry. The PhD students can take several courses at NMBU to fulfil the theoretical part of their work (see table 4).

So far five CERAD associated PhDs students have already defended their work (two in 2014, one in 2015, two in 2016), 15 students are currently working associated to CERAD and 2 positions are to be filled (Fig 35). Two totally new PhD positions will also be announced in 2017 along with new PostDoc positions. Thus, a total of 22 PhDs in 2016 and 24 PhD will be associated with CERAD in 2017. We can therfore expect that these students will finish their work and do their dissertations within the upcoming CERAD period. Until 2016, seven PostDoc's have been working within CERAD, all heavily involved in the research in the different research areas.

The following five PhD students (3 male and 2 female) have successfully defended their work:

- Mrdakovic Popic, J. (2014) "Environmental Impact of Radionuclides and Trace Elements in the Thorium Rich Fen Area in Norway" PhD Thesis, NMBU, (female).
- Song, Y. (2014) "Transcriptional responses in Atrlantic salmon (Salmo salar) following single and combined exposure to depleted uranium and gamma radiation" PhD Thesis, NMBU (male).
- Graupner, A. (2015) "Genotoxic Effects of Continous Chronic Low Dose Rate Gamma irradiation and Selenium Deficiency" PhD Thesis, UiO (female).
- Alvarenga Castellanos, E. H. (2016) "Applicability of Natural Porous Materials and Lime with Conditioning and Sorption Properties for Wastewater Treatment" PhD Thesis, NMBU (male).
- Strømme, C. B. (2016) "Phenology, growth and metabolism of two northern deciduous tree species in relation to temperature and light conditions" PhD thesis, NMBU (male).

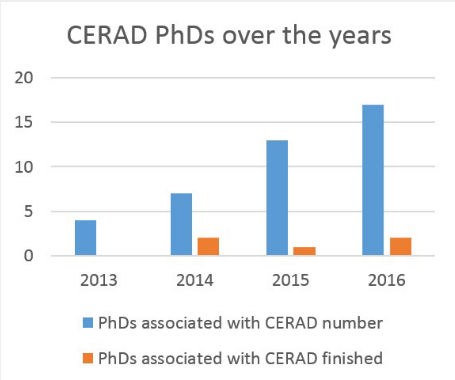

Figure 35: *The number of PhD students associated with CERAD per year.*

CERAD-NMBU also host The Radioecology Research School together with Stockholm University. The research school is an international networking forum aimed primarily at PhD students in radioecology and other relevant nuclear sciences. Most European PhD students are expected to take some accredited courses as part of their PhD training. These courses are often relevant and attractive for PostDoc and professional training as well. The PhD course in Environmental Radiobiology (MINA 410) is a 5 ECTS course, and is part of the international Radioecology Research School (Table 4) open to both PhD students and PostDocs.

INTERNATIONAL COOPERATION

During the first year of CERAD, Memorandum of Understanding (MoU) have been signed between NMBU and several universities and research institutes, covering both research and education:

- Moscow State University, Russia.
- National University of Life and Environmental Sciences of Ukraine, Ukraine.
- University of Fukushima, Japan.
- Tomsk Polytechnical University, Russia.
- University of Seville, Spain.
- CIEMAT, Spain.

A Cotutelle agreement has been signed with the University of Seville (UoS), Spain, giving credits to both NMBU and UoS for common PhD students. Letter of intent (LoI) and ERASMUS+ Inter-institutional agreement 2014-21 has been signed with: Czech Technical University (Czech Republic), Chalmers University of Technology (Sweden), University of Helsinki (Finland), Loughborough University (UK), University of Leeds (UK), University of Oslo (Norway).

Through projects funded by the Norwegian Centre for International Cooperation in Education (SiU), bilateral cooparation projects Norway – Russia and Norway – Ukraine have been established. These projects have given common courses and travel fee for students and lecturers.

Within the Radioecology Exchange webpage (http://www.radioecology-exchange.org/), CERAD has developed an education and training platform (Fig. 36), linking education in different nuclear disiplines.

CERAD is also one of the founding members of the The European Network on Nuclear and Radiochemistry (NRC) Education and Training, legally created in 2016: http://nrc-network.org/. The objective and functions of the European NRC Network are to cooperate and promote NRC education and training in Europe.

During 2013 – 2016, CERAD has arranged several international short courses, either at NMBU or at other host institutions, open to MSc, PhD, PostDocs and professionals:

1) Our “Experimental Radioecology course”, which is part of our MSc program in Radioecology (10 ECTS), has been held every year open to international students co-funded with EC projects CINCH-II, STAR and COMET.
2) Field course “Fieldcourse on Chernobyl fallout in the environment” at Ukrainian Institute of Agricultural Radiology (UIAR), Ukraine, September 2016. The course was organized by UIAR and NMBU/CERAD in cooperation with the EU project COMET.
3) Field course “Course on naturally occuring radioactive material (norm) in the environment” at Silesian Centre for Environmental Radioactivity, Poland, September 2015. The course was organised by Silesian Centre for Environmental Radioactivity and NMBU/CERAD in cooperation with the EU project COMET.
4) Radiochemistry course “Second Spring school on Radiochemical Analysis”, at Lomonosov Moscow State University, Russia, April 2015. The course was organised as part of a SiU project collaboration Norway – Russia.
5) Radiochemistry course “First Spring school on Radiochemical Analysis – heavy nuclide separation”, at Lomonosov Moscow State University, Russia, April 2014. The course was organised as part of a SiU project collaboration Norway – Russia.

In 2016, CERAD-NMBU was awarded two EU CONCERT projects to provide two of our courses internationally: 1) The KJM351 “Experimental Radioecology” course to be given in January 2017, and the 2) KJM360 “Environmental Risk Assessment” course to be given in June 2017.

During 2016, a new course within CERAD was admitted into the NMBU course portifolio: FMI 320 “Effect and biomarker methods in (eco)toxicology” utilising expert teachers from the CERAD national and international network.

EUROPEAN MSC PROGRAM IN RADIOECOLOGY

The only MSc in Radioecology in Europe has been established at NMBU. Students from within Europe and outside have attended individual course modules or the whole MSc program. Expert teachers are also from collaborating institutions from different countries in Europe and in North America. The EU supported MSc in Radioecology is unique in Europe, forming a useful recruitment base for PhD education.

In short, the EU MSc in Radioecology is a tailored two year, Bologna accredited (120 ECTS) MSc programme consisting of obligatory and voluntary stand-alone course modules, with expert teachers from national and international institutions. At present the MSc is hosted at the NMBU. But, as for any EU MSc, students are free to obtain credits by taking ECTS accredited courses at other institutions and at collaborating universities. The list of NMBU courses available are presented in Table 4.

The courses are implemented in large European projects due to the fact that NMBU holds the only EU MSc in Radioecology. The main courses within CERAD are listed in the table below. Already today some courses in the MSc in Radioecology are linked to other EU education and training initiatives such as COMET (Radioecology), CINCH-II (Nuclear chemistry) and DoReMi (Radiobiology). Attending the courses included in these platforms can further expand the list of possible courses the students can attend as part of their degree. This enables a more cost effective use of the resources already invested in on-going courses and facilities in Europe.

As stated earlier, a new course within CERAD was admitted into the NMBU course portifolio: FMI 320 "Effect and biomarker methods in (eco)toxicology". This course will be run for the first time in August 2017 with invited lecturers from the whole CERAD national and international network.

Every year CERAD also has a series of MSc students working on their MSc research projects associated to CERAD projects.

Through projects funded by Norwegian Centre for International Cooperation in Education (SiU), bilateral cooparation projects Norway – Russia and Norway – Ukraine have been established. These projects have given common courses, travel fee for students and lecturers and stipend to MSc students from Russia or Ukaine following the European MSc programme at NMBU.

LINK TO OTHER E&T PLATFORMS

CERAD-NMBU courses are presented at NMBU websites for education programmes and courses and on the CERAD website (https://www.nmbu.no/en/services/centers/cerad). The MSc programme and courses are also linked to several EU projects and platforms:

Radioecology exchange:
http://www.radioecology-exchange.org/

CINCH Nuclear chemistry:
https://nucwik.wikispaces.com/

DoReMi training & education:
http://www.doremi-noe.net/training_and_education.html

Within the Radioecology Exchange webpage, CERAD/NMBU has developed an education and training platform (Fig. 36), linking education in different nuclear disiplines. The Radioecology Education and Training Platform is a website focal point for students and professionals interested in radioecology. The platform presents an overview of education and training course modules within radioecology/environmental radioactivity presently offered by the COMET consortium and will be followed up by the Radioecology Alliance.

This platform holds a lot of different courses within radioecology and ecotoxicology ranging from MSc and PhD courses to workshops and professional development. The Education and Training platform is also responsible for running the Radioecology PhD network. The Radioecology E&T platform also provides links to other E&T platforms (within Radiochemistry, Radiobiology and Radiation Protection). This is an important outreach mechanism for the Radioecology E&T platform, as – for example – many of the basic course modules within radioecology are also relevant for other nuclear science students, and vice versa.

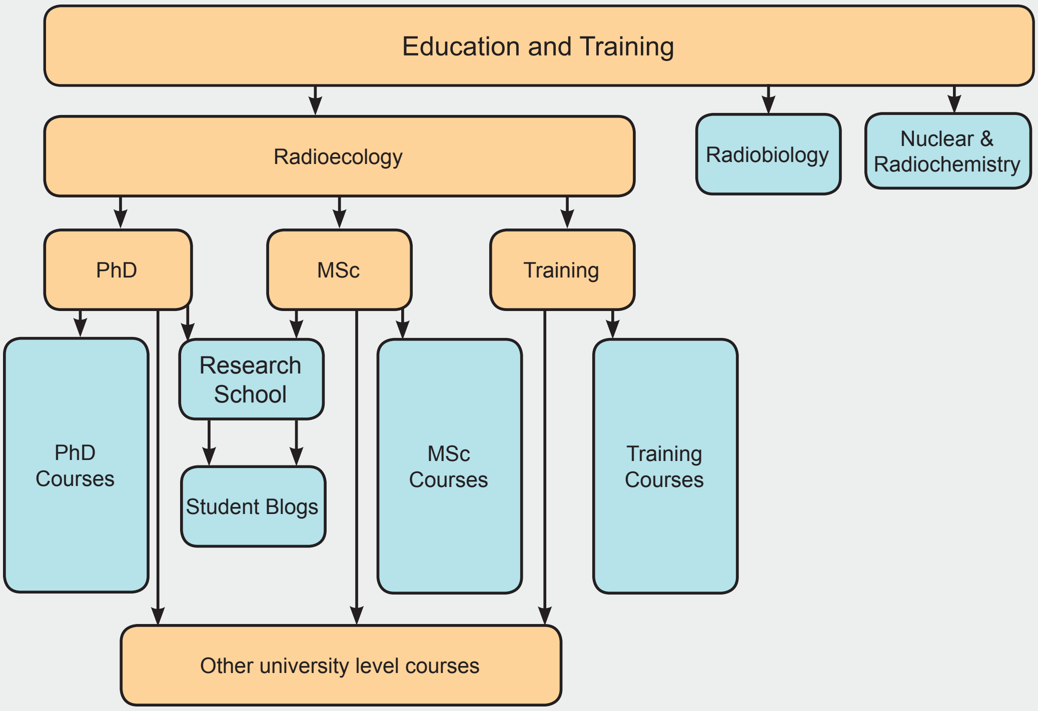

Figure 36: *The Radioecology Exchange Education and training platform*

Table 4: CERAD COURSES AVAILABLE WITHIN THE FIELDS OF RADIOCHEMISTRY / ENVIRONMENTAL RADIOACTIVITY / ECOTOXICOLOGY

Course code	Title	ECTS	Course Syllabus In Short	Course Responsible
KJM350	Radiation and Radiochemistry	10	http://www.nmbu.no/search/courses/kjm350	Lindis Skipperud
KJM352	Radiation and Radiation Protection	5	http://www.nmbu.no/search/courses/kjm352	Lindis Skipperud
KJM351	Experimental Radioecology	10	http://www.nmbu.no/search/courses/kjm351	Ole Christian Lind
KJM353	Radioecology	5	http://www.nmbu.no/search/courses/kjm353	Ole Christian Lind
MINA310	Project Management and Research Methods	10	http://www.nmbu.no/search/courses/mina310	Lindis Skipperud
KJM360	Assessing Risk to Man and Environment	10	http://www.nmbu.no/search/courses/kjm360	Deborah H. Oughton / Per Strand
MINA410	Environmental Radiobiology	5	http://www.nmbu.no/search/courses/mina410	Deborah H. Oughton
FMI309	Ecotoxicology	10	http://www.nmbu.no/search/courses/fmi309	Hans Christian Teien
FMI310	Environmental Pollutants and Ecotoxicology	15	http://www.nmbu.no/search/courses/fmi310	Hans Christian Teien
FMI320	Effect and biomarker methods in (eco)toxicology	5	New course 2017	Knut Erik Tollefsen

CERAD Funding and Expenditures 2016

The account reflects a high level of activity in CERAD for 2016.

The project financing constitutes of funding from the Research Council of Norway (RCN) and of a substantial In kind contribution from all CERAD institutions. In addition, several ongoing RCN (EU) funded projects at NMBU/Isotope Laboratory are included as a financial source for CERAD.

The turnover for CERAD in the fourth operational year is MNOK 52.8.

The RCN direct contribution, the core funding, in 2016 was MNOK 16 (30 %). Other cash contributors (MNOK 2.25) are the Norwegian University of Life Sciences (NMBU) and The Norwegian Radiation Protection Authority (NRPA). Other In kind contributions from partner institutions, mainly personnel, amounted to MNOK 27 (51%).

On the expenditure side, salaries amounted to MNOK 36 (68%) the sum includes overhead covering indirect costs.

Other running expenses amounted to MNOK 16.6 (32 %).

CERADs financial situation provides a solid foundation for stable and flexible project management and long term research in the years ahead.

Participants at the «Consensus Symposium on the ecological effects of radiation on population and ecosystems» organized by IUR and NRPA/CERAD, Miami, USA

Photo: IUR

CERAD Economy 2016

(NOK 1.000)	Accounts 2016	%
Revenues		
RCN funding	16 000	30,3 %
NMBU funding	1 250	2,4 %
NRPA	1 000	1,9 %
Other RCN projects	5 474	10,4 %
International funds/public funds	1 874	3,5 %
Partners (in kind)	27 014	51,2 %
Unused funds from previous years	199	
Total funding	**52 811**	

Expenditures		
Salaries	35 915	68,1 %
FoU	0	0,0 %
Equipment	0	0,0 %
Seminars etc.	246	0,5 %
Other operational costs	16 600	31,5%
Total expenditures	**52 761**	
Unused Funds 2016	**50**	

Specification of partners in kind contributions:		
NMBU	17 953	66,5 %
NRPA	4 016	14,9 %
NIPH	1 627	6,0 %
NIVA	2 275	8,4 %
Met	1 143	4,2 %
Total	**27 014**	

Annual CERAD Conference 2016

The annual CERAD conference was held at the Norwegian Academy of Science and Letters in Oslo, Norway, the 8th - 9th of February 2016. The conference attracted 75 of CERAD's scientists, the Board, the international Scientific Advisory Committee (SAC) and the Relevant Advisory Committee (RAC).

The aim of this conference was to present the focused research areas of CERAD, including the Umbrella research areas/priorities within CERAD, and the ongoing and planned scientific work including results so far. The detailed programme can be found in Appendix. The presentations fuelled constructive discussions on priorities and the way forward. All enjoyed HYBRIS, the CERAD Houseband concert prior to dinner.

Participants at the CERAD conference, Norwegian Academy of Science, February 2016
Photo: Ole Christian Lind

Dissemination and Communication

From 2013 to 2016, CERAD CoE has published a total of 117 publications in international journals with referee, with an increasing number each year (Fig. 37). Seven publications (5 articles, 2 book chapters) are currently "in press" and six articles was submitted late 2016. Six monographs have been published over the years, in the form of books and PhD theses. Every year the CERAD scientists have been active in presenting their research results at international conferences, workshops and seminars, amounting to more than 270 oral and poster presentations during the first four years of CERAD. In this annual report, only the publications and dissemination for 2016 are presented. Scientific work has also been disseminated through reports and through popular media, if possible. Earlier publications (2013 – 2015) can be found in CERAD Annual reports or on the CERAD webpage: http://cerad.nmbu.no.

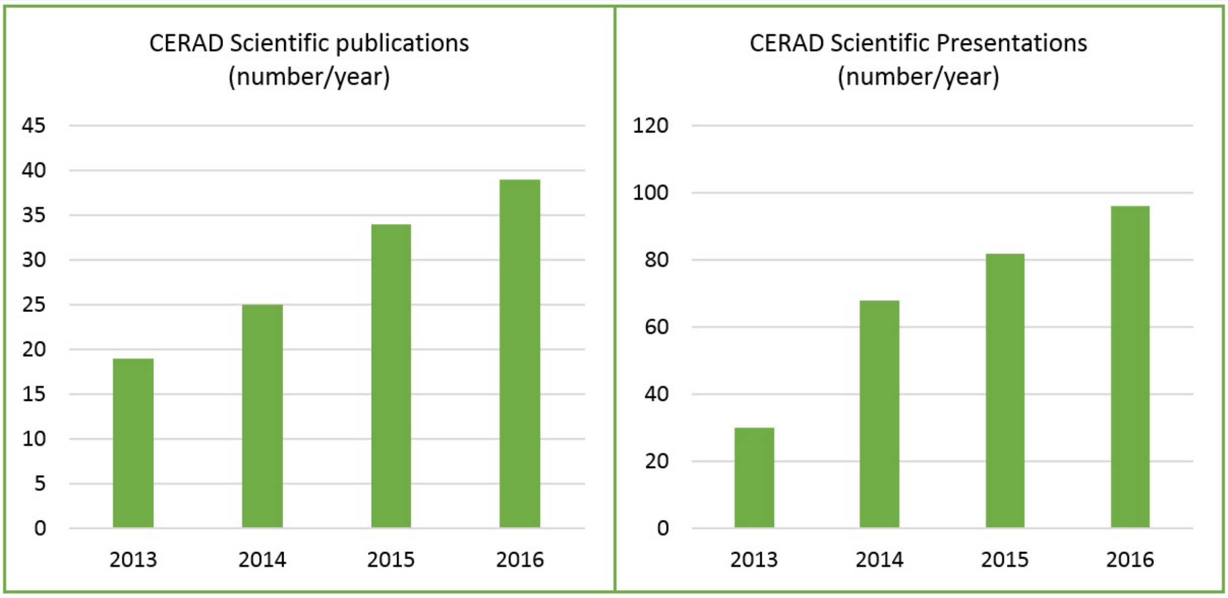

Figure 37: The number of publications in international journals with referee (left) and the number of scientific oral- or poster presentations (right).

A communication strategy for the CERAD CoE has been developed in early 2016. Its aim is to make research effort and the educational opportunities within CERAD visible in the society, and to encourage CERAD's scientists in active participation in the public debate on relevant topics. CERAD Blog was also launched in 2016. Blog entries include interviews with key scientists and research highlights in the popular-science format. Several scientists have participated in a popular-science writing course for media and several more will receive an opportunity to do so in the years to come. CERAD is actively using social media (Facebook, Twitter) to communicate news updates and announcements.

The communication strategy concerns internal communication within the centre as well. CERAD Intranet pages are continuously developed to support effective information sharing between the partners and increase the partners' feeling of ownership in CERAD.

Societal Impact

As detailed in the International Collaboration section, CERAD's research is of importance for a large number of national and international policy makers. CERAD members have participated in, and CERAD research has been used to support, many high level reports, white papers and policy documents. These include Three White papers for The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and numerous Reports from International Atomic Energy Agency (IAEA), International Union of Radioecology (IUR), International Commission on Radiological Protection (ICRP), and the Arctic Monitoring and Assessment Programme (AMAP). Further details can be found in the International Sections as well as the Publication lists.

Work carried on Fukushima by CERAD for UNSECAR and IAEA has attracted a high degree of international attention, not only because of the scientific relevance, but also due to the considerable societal consequences of the accident and the controversy surrounding the potential impacts, both to humans and the environment. CERAD coordinated work on stakeholder involvement and the societal impact of Fukushima for the IAEA Fukushima Report. In addition to producing a number of scientific articles on the social and ethical implications of nuclear accidents, CERAD (NRPA/NMBU) has participated in a series of co-expertise stakeholder dialogues organised by the ICRP, The Nippon Foundation and Hiroshima/Nagasaki University. These involved participation of a wide-range of stakeholders (international and Japanese authorities and scientists) including members of the affected population in Fukushima, thus having a direct influence on both policymaking and society. As part of the EU SHAMISEN project, CERAD has contributed to new recommendations for health surveillance of affected populations after a nuclear accident, including an assessment of ethical challenges from thyroid screening. Following up on controversy surrounding the ecological impacts on Fukushima, the Consensus Symposium organised by IUR and CERAD in Miami 2015 produced a statement document on the *Ecological Effects of Radiation on Populations and Ecosystems*, signed by 30 scientists from research disciplines, spanning radioecology, ecology, ecotoxicology and genetics.

CERAD has cooperated with the intergovernmental OECD-Nuclear Energy Agency (NEA), in facilitating cooperation among countries with respect to advanced nuclear technology infrastructures, and the OECD NEA: Expert group on Management of Radioactive Waste After a Nuclear Power Plant Accident, both chaired by the CERAD Deputy director.

UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology is currently preparing a Declaration on Water and Ocean Ethics in collaboration with the Intergovernmental Oceanographic Commission (IOC). The Research director is a member of the Commission (nominated by the Norwegian Ministry of Education and Research), and has fronted both CERAD's and Norwegian research and policy interests feature (e.g, radioactive waste discharges, oil industries, OSPAR).

CERAD has arranged two Stakeholder conferences in Rogaland connected to the Western Norway Scenario -a hypothetical nuclear accident in Sellafield and deposition at the western Norway - with the intention of exchanging knowledge on the potential impacts, and increasing collaboration between national and local authorities. These attracted a wide range of stakeholders including central and regional authorities, local representatives, industry and NGOs, thus facilitating dissemination of CERAD's research as well as facilitating an increased understanding of the technical, organisational and socioeconomic challenges of radiation risks. As part of this work, socioeconomic analysis has been undertaken for valuing lost recreational value from restricting fishing.

Norwegian University of Life Sciences

Norwegian Centre of Excellence

CERAD members participate in most of the EC H2020 EURATOM programme boards, and as such have been instrumental in formulating topics and text for the recent EU CONCERT calls. This has included an increased focus on risk communication, risk perception and societal aspects of radiological protection within EU research, which is fully in line with CERADs multidisciplinary approach and inclusion of research on social and ethical aspects in addition to its strong natural science foundation (see pages 48 for further information on CONCERT).

Participants at the Western Norway stakeholder seminar
Photo: Astrid Liland

Publication List

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Wærsted, F.M., and Skipperud, L., Leaching Of Radioactive And Toxic Metals From Alum Shale Under Different Redox Conditions. 6th Norwegian Environmental Toxicology Symposium (NETS2016). Oslo, Norway, October 2016, Oslo, Norway.

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Xie, L., *et al.* Multiple stressor effects of ionizing radiation and non-ionising radiation in duckweed (Lemna minor). 6th Norwegian Environmental Toxicology Symposium (NETS2016), October 2016, Oslo, Norway.

Ytre-Eide, M., and Album, A., UV-model for Norway, 8th EUROSKIN workshop/NOFFOF/CERAD symposium, November 2016, Bergen, Norway.

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CERAD IN THE MEDIA

8th EUROSKIN workshop/NOFFOF/CERAD symposium in Bergen, Norway, 3-4 November: https://www.nrk.no/hordaland/vil-byggja-_skuggebygg_-for-a-hindra-hudkreft-1.13209993

Estuarine field experiment in Lillesand to study effects of metals included U in runoff from road construction deposits of sulfur bearing Gneiss in Lillesand area entering into coastal water. https://tv.nrk.no/serie/distriktsnyheter-soerlandet/DKSL99051316/13-05-2016#t=5m55s

Unique field cage experiment with clean fish into contaminated Lake Glubokoye, contaminated fish into clean water. Collaboration CERAD and ChEZ http://dazv.gov.ua/novini-ta-media/vsi-novyny/provedennya-naukovikh-doslidzhen-u-zoni-vidchuzhennya-2.html

På radioaktiv leting etter jod i melkekua. Forskning.no, 23.03.2016 http://forskning.no/mat-og-helse-landbruk/2016/03/pa-radioaktiv-leting-etter-jod-i-melkekua

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Sebrafisk. Dagbladet, 14.05.2016, page 24-27, 29-30

Æresdoktorat til norsk pioner innen radioaktiv forskning. Forskning.no, 13.09.2016

Omorgansiering uten mål og mening. Klassekampen, 11.05.2016

CERAD Scientific Personnel 2016

Professors, scientists and academic personnel	Academic Grade	Employed
Brit Salbu, Professor	Dr.philos	NMBU
Lindis Skipperud, Professor	Dr.scient	NMBU
Ole Christian Lind, Associate Professor	PhD	NMBU
Anicke Brandt-Kjelsen, Scientist	PhD	NMBU
Deborah H. Oughton, Professor	PhD	NMBU/CERAD
Bjørn Olav Rosseland, Professor	Dr.philos	NMBU
Eirik Romstad, Associate Professor	PhD	NMBU/HH
Ståle Navrud, Professor	Dr.scient	NMBU/HH
Knut Einar Rosendal, Professor	PhD	NMBU/HH
Olvar Bergland, Associate Professor	PhD	NMBU/HH
Jorun Olsen, Professor	Dr.scient	NMBU/IPV
Sissel Torre, Associate Professor	Dr.scient	NMBU/IPV
Hans Christian Teien, Scientist	Dr.philos	NMBU/CERAD
Dag Brede, Scientist	PhD	NMBU/CERAD
Per Strand, Director	Dr.philos	NRPA
Unn Hilde Refseth, Director	Dr.scient	NRPA
Åste Søvik, Head of Section	PhD	NRPA
Justin Brown, Senior Scientist	PhD	NRPA
Alicia Jaworska, Senior Scientist	PhD	NRPA
Terje Christensen, Senior Scientist	PhD	NRPA/CERAD
Håvard Thørring, Scientist	Cand.scient	NRPA
Martin Album Ytre-Eide, Scientist	Cand.scient	NRPA
Mikhail Iosjpe, Senior Scientist	PhD	NRPA
Lavrans Skuterud, Senior Scientist	PhD	NRPA
Tanya Helena Hevrøy, Scientist	PhD	NRPA
Bjørn Johnsen, Scientist	Siv.ing	NRPA
Hans Bjerke, Senior Adviser	Cand.real	NRPA
Per Otto Hetland, Scientist	Cand.scient	NRPA
Hallvard Haanes, Scientist	PhD	NRPA
Runhild Gjelsvik, Scientist	Cand.scient	NRPA
Louise Kiel Jensen, Scientist	PhD	NRPA
Ali Hosseini, Senior Scientist	Cand.scient	NRPA
Lill Tove Nilsen, Senior Scientist	PhD	NRPA

Jan Erik Dyve, Senior Adviser	Cand.scient	NRPA
Anne Liv Rudjord, Head of Section	Cand.real	NRPA
Malgorzata Sneve, Director	MSc	NRPA
Hilde Skjerdal, Adviser	MSc	NRPA
Torbjørn Gäfvert, Senior Adviser	PhD	NRPA
William Standring, Senior Scientist	PhD	NRPA
Knut Asbjørn Solhaug, Professor	Dr.scient	NMBU/INA
Line Nybakken, Associate Professor	Dr.scient	NMBU/INA
YeonKyeong Lee, Scientist	PhD	NMBU/INA
Øystein Hov, Director	Dr.philos	MET
Jerzy Bartnicki, Senior Scientist	PhD	MET
Pål Erik Isachsen, Senior Scientist	Dr.scient	MET
Heiko Klein, Senior Scientist	PhD	MET
Øyvind Sætra, Senior Scientist	PhD	MET
Harald Schyberg, Assistant Director	Cand.scient	MET
Knut Erik Tollefsen, Senior Scientist II/Prof II	Dr.scient	NIVA
Karina Petersen	Dr.scient	NIVA
Yan Lin	MSc	NIVA
You Song	PhD	NIVA
Jens Thaulow	PhD	NIVA
Ailbhe Macken	PhD	NIVA
Ana Catarina Almeida	PhD	NIVA
David Eidsvoll	MSc	NIVA
Lie Xie	MSc	NIVA
Peter Aleström, Professor	Fil.dr.	NMBU/Vet
Jan Erik Paulsen, Professor	Dr.med.vet	NMBU/Vet
Ian Mayer, Professor	Dr.scient	NMBU/Vet
Jan L. Lyche, Professor	Dr.med.vet	NMBU/Vet
Ann-Karin Olsen, Senior Scientist	Dr.philos	NIPH
Gunnar Brunborg, Senior Scientist	Dr.philos	NIPH
Christine Instanes, Senior Scientist, Head of Department	Dr.philos	NIPH
Nur Duale, Senior Scientist	Dr.philos	NIPH
Kristine Bjerve Gutzkow, Senior Scientist	Dr.philos	NIPH
Oddvar Myhre, Scientist	Dr.scient	NIPH
Dag Marcus Eide, Senior Scientist	Dr.vet	NIPH
Birgitte Lindeman, Senior Scientist	Dr.philos	NIPH

CERAD PhD and PostDoc Personnel 2016

PhD students		
Astrid Liland	Cand.scient	NRPA/CERAD
Christian B. Strømme	MSc	NMBU/IPV
Dajana Blagojevic	MSc	NMBU/IPV
Erica Maremonti	MSc	NMBU/IMV
Frøydis Meen Wærsted	MSc	NMBU/IMV
Hildegunn Dahl	MSc	NIPH/CERAD
Jorke Kamstra	MSc	NMBU/Vet
Jose Antonio	MSc	CERAD/RATE
Kine J. A. Bredesen	MSc	NMBU/HH
Leonardo M. Martin	MSc	NMBU/Vet
Emilio A. Castellanos	MSc	NIBIO
Lie Xie	MSc	NIVA/CERAD
Lisa Rossbach	MSc	NanoCharm
Magne Simonsen	MSc	NMBU/MET
Merethe Kleiven	MSc	NMBU/IMV
Selma Hurem	DVM	NMBU/Vet
Yevgeniya Tomkiv	MSc	NMBU/IMV

PostDoc		
Anne Graupner	PhD	NIPH/CERAD
Cato C. Szacinski Wendel	PhD	NMBU
Elisabeth Lindbo Hansen	PhD	NRPA
Leif Lindeman	PhD	NMBU/Vet
Pablo Lebed	PhD	NMBU/IMV
Sachin Nehete	PhD	NMBU/CERAD
Tânia Gomes	PhD	NIVA/CERAD

CERAD Technical and Administrative Personnel 2016

Technical/Administrative		
Alexander Carl Friedrich Buerg	PhD	MET
Anja Nieuwenhuis	Head Administration	NMBU/CERAD
Anne Marie Frøvig	Cand.polit	NRPA
Håvard Alsaker Futsæter	Senior engineer	MET
Jill Andersen	Chief engineer	NIPH
Karl Andreas Jensen	Senior engineer	NMBU
Yetneberk A. Kassaye	Chief engineer	NMBU/CERAD

Kim Jensen	Engineer	MET
Lene Valle	MSc	NMBU/CERAD
Marit Nandrup Pettersen	Chief Engineer	NMBU/CERAD
Mirian Wangen	Higher Executive Officer	NMBU
Ståle Mygland	MSc	NIVA
Øyvind Enger	MSc	NMBU

CERAD visiting scientists 2016

International guest scientists		
Scientist II Simone Cagno	PhD	Belgium
Jacub Jaroszewicz	MSc	Poland

International scientific network - SAC		
Dr David Clarke		USA
Prof. Valeriy Kashparov	NMBU Prof.II	Ukraine
Prof. Koen Janssens		Begium
Prof. Peter Stegnar		Slovenia
Prof. Carmel Mothersill		Canada
Prof. Colin Seymour		Canada
Prof. Tom Hinton	NMBU Prof.II	France/Japan
Dr Clare Bradshaw		Sweden
Dr Marcel Jansen		Ireland
Prof. Janet Bornman		Australia

Appendix: CERAD Meetings and Workshops 2016

CERAD CONFERENCE 8TH – 9TH FEBRUARY 2016

The Norwegian Academy of Science and Letters
Drammensveien 78, 0271 OSLO

Theme
Reducing overal uncertainties in environmental impact and risk assessments
Future research priorities

Monday February 8.

Coffee 09:30 – 10:00

10:00 – 11:00 Welcome, CERAD Director Brit Salbu
- Opening of the CERAD Conference, Rektor NMBU Mari Sundli Tveit
- CERAD Highlights, CERAD team

Session 1: Sources, deposition, exposure characterization — Chair: Halvor Hektoen

11:00 – 11:15 Nuclear events, particle sources and effects
- Overview: Umbrella 8 and 1 priorities, Ole Christian Lind

11:15 – 13:00 Panel discussion
- Intro: From nuclear sources to impact and risk – Key knowledge gaps to be covered, Dr Ted Lazo, OECD/NEA
- Intro: Reactor accidents – lessons learned from the Chernobyl accident, Professor Valeriy Kashparov, NUBiP, Ukraine
- Intro: Norm sources, Professor Peter Stegnar, Jožef Stefan Institute, Slovenia

Panel: T. Lazo, V. Kashparov, P. Stegnar, O.C. Lind, J. Bartnicki

13:00 – 14:30 Lunch

Session 2: Biological effects — Chair: Lindis Skipperud

14:30 – 15:30 Radiosensitivity, MixTox and Transgenerational effects
- Overview Umbrella 3, 4, and 5 priorities: Dag A Brede, Knut Erik Tollefsen and Anka Olsen, Salmon and Zebrafish experiments, Hans Christian Teien,Peter Aleström

15:30 – 17:30 Panel discussion
- Intro: Challenges in radiobiology of relevance for radioecology, Professor Sisko Salomaa, STUK, Finland
- Intro: Challenges in ecotoxicology of relevance for assessing radiation effects, Professor Juliette Legler, Brunel University, UK

Panel: S. Salomaa, J. Legler, C. Mothersill, C. Seymour, D. Brede, K.E. Tollefsen, A. Olsen

17:30– 18:00 Coffee

18:00 – 19:00 Concert – CERAD house orchestra

19:00 Dinner

Tuesday February 9.

Coffee: 08:30 – 09:00

Session 3: Ecosystem transfer, gamma + UV exposure **Chair: Per Strand**

09:00 – 10:00 Ecosystem transfer/approach and integrating gamma with UV

- Overview Umbrella 2, 6 and 7 priorities, Justin Brown, Alicja Jaworska and Terje Christensen

10:00 – 10:40 Panel discussion

- Intro: Challenges related to ecosystem transfer, Professor Kathryn Higley, Oregon State Univerrsity Corrvallis, USA
- Intro: How to integrate effects from ionizing radiation and UV, Professor Janet Bornman, Curtin University, Australia

10:40 – 11:00 Coffee

11:00 – 12:00 Panel: K. Higley, C. Bradshaw, J. Bornman, H.C. Teien, A. Jaworska, T. Christensen, J. Olsen

12:00 – 13:00 Lunch

Session 4 Overall research priorities **Chair: Deborah H. Oughton**

13:00 – 14:30 Panel discussion: Input to revised SRA

- Intro: IUR research priorities within,radioecology, Dr., François Bréchignac, IRSN, France

Panel: F. Bréchignac, T. Lazo, V. Kazparov, S. Salomaa, K. Higley, P. Strand

14:30 – 15:00 Way forward and Closing

Mid term evaluation, LivFuruberg, Adviser, Research Council of Norway

Closing, CERAD Director Brit Salbu

COMET WP5 WORKSHOP 15TH - 17TH JUNE, 2016

Sevilla, Spain

"Models fit for purpose"

Wednesday June 15.

14:00 – 14:15 Brit Salbu
Welcome and scope of the workshop

Purpose: Why do we need radioecology models? Chair: Brit Salbu

14:15 – 14:35 Jordi Vives i Batlle
Models: What are they for?

14:35 – 14:55 Martin Steiner
What should an ideal radioecological model look like?

14:55 – 15:15 Igor Linkov
Top-down and Bottom-up Approaches for Integrating Judgment in Environmental Models: Methodology and Case Studies

15:15 – 15:45 Coffee and tea

15:45 – 17:00 Group work
Purpose of radioecology models

17:00 – 17:30 Group work reports and discussion

Thursday June 16.

Interaction between modellers and experimentalists Chair: Marie Simon Cornu

09:00 – 09:30 Rafael G-Tenorio
The need of interaction between modellers and experimentalists – from the experimentalists' point of view

09:30 – 10:00 **Juan Carlos Mora Cañadas**
The need of interaction between modellers and experimentalists – from the modellers' point of view

10:00 – 10:30 Coffee and tea

10:30 – 11:30 Group work
Interaction modellers – experimentalists: Defining each other's requirements

11:30 – 12:00 Group work reports and discussion

12:00 – 14:00 Lunch

Fit: How should an ideal radiological model look like? Chair: Jordi Vives i Batlle

14:00 – 14:20 Martin Steiner
Are probabilistic models always the better choice? or: Deterministic vs. probabilistic models: Are probabilistic models always the better choice?

14:20 – 14:40 Céline Duffa / Marie Simon Cornu
Which models should be used to support a technical crisis centre

14:40 – 15:00 Marc-André Gonze
Fit-for-purpose spatial modelling of environmental systems

15:00 – 15:20 Juan Carlos Mora Cañadas
Understanding uncertainties in models

15:20 – 15:50 Coffee and tea

15:50 – 17:00 Group work
Fit for purpose

17:00 – 17:30 Group work reports and discussion

Social GET-TOGETHER in the evening, sponsored by Center for Environmental Radioactivity CERAD, Norway

Friday June 17.

Needs: Model/data requirements Chair: Juan Carlos Mora Cañadas

09:00 – 09:20 Philippe Ciffroy
Stakeholder's experience in assessing exposure to chemicals, the case of MERLIN-EXPO

09:20 – 09:40 Russell Walke
So you want to build a model: platforms and implementation

09:40 – 10:00 Jorge Molinero
Innovative approaches to modelling the transport of contaminants in groundwaters

10:00 – 10:20 Coffee and tea

10:20 – 10:40 Brit Salbu
Uncertainties in source term and dynamic transfer of radionuclides

10:40 – 11:00 Wolfgang Raskob
Model validation – how do we do this?

11:00 – 12:00 Discussions

12:00 – 14:00 Lunch

Model-specific session – parallel sessions

Fit for purpose models and data for the atmospheric environment

Fit for purpose models and data for the transfer to humans

14:00 – 15:00

Introduction lectures

Jerzy Bartnicki (15 min)
Nuclear emergency dispersion modelling

Marie Simon Cornu (15 min)
Modelling transfer to humans - possibilities and uncertainties

Discussions

Debate between modellers and experimentalists on key input data/factors required for the models

Debate between modellers and experimentalists on key input data/factors required for the models

15:00 – 15:30 Coffee and tea

Introduction lectures

Fit for purpose models and data for the marine environment

Fit for purpose models and data for terrestrial forests

15:30 – 17:00

Introduction lectures

Raul Perianez (20 min)
Marine transport models - possibilities and uncertainties

Jordi Vives i Batlle (15 min)
Process and data identification in a radionuclide transfer model for pine forests

Philippe Calmon (15 min)
Data/model intercomparison with post-Fukushima measurements in forests.

17:00 – 17:30
Wrap-up session by Lindis Skipperud

17:30
Closing workshop

Norwegian University of Life Sciences

Norwegian Centre of Excellence

AGENDA - CERAD UMB5 EPIGENETICS MEETING 25TH AUG 2016

VENUE: NMBU Campus Adamstuen, Building 14, “BasAm Spiserom” 1st floor

12:00 – 12:30 CERAD Seminar Lunch

12:30 – 12:45 Opening by Deborah Oughton & Peter Aleström

12:45 – 14:30 Progress and plans epi-groups (10 min presentations + 5 min discussion) (Chair Peter)

12:45 – 13:00 Jens
- Characterising and quantifying epigenetic changes that have relevance for transgenerational effects in Daphnia magna

13:00 – 13:15 Ann-Karin Olsen
- Epigenetics in mice

13:15 – 13:30 Dag
- Differential gene expression in Salmon

13:30 – 13:45 Hans Christian
- Salmon

13:45 – 14:30 Jorke, Leif, Leonardo
- Generational effects on the epigenetic landscape following exposure to IR in Zebrafish

14:30 – 15:00 Break

15:00 – 16:00 Planning and collaborations (Chair Deborah)
- How can we effectively collaborate in order to reduce costs, etc savings.
- Plans for midterm review: How shall we publish cross species epigenetic results.
- Other things to discuss
- Conclusions

CERAD PhD / PostDoc Seminar 13TH – 14TH OCTOBER 2016

Vitenparken, Fredrik A. Dahlsvei 8, 1430 Ås

PROGRAM

THURSDAY 13TH OCTOBER

09:30 Coffee

10:00 Welcome Brit Salbu

10:15 – 10:45 Magne Simonsen (PhD)
«Marine transport modelling»

10:45 – 11:15 Pablo Lebed (PostDoc)
«Tracing Fe nanoparticles at field sites»

11:15 – 11:45 Yevgeniya Tomkiv (PhD)
«Radiation risks in mass media»

11:45 – 12:00 YeonKyeong Lee
«Knockin' on Imaging Centre's Door»

12:00 – 12:45 Lunch

12:45 – 13:15 Frøydis Meen Wærsted (PhD)
«Leaching of NORM and toxic metals from alum shale under different redox conditions»

13:15 – 14:45 Anne Graupner (PostDoc)
«Genotoxic and epigenetic effects of different low dose rates of gamma radiation different low dose rates of gamma radiation in combination with arsenic»

13:45 – 14:15 Erica Maremonti (PhD)
«Investigating oxidative stress and DNA damage in response to chronic gamma--radiation in the nematode Caenorhabditis elegans»

14:15 – 14:30 Break

14:30 – 15:00 Lisa Rossbach (PhD)
«The assessment of the toxic effects of nanoparticles on the terrestrial ecosystem»

15:00 – 15:30 Li Xie (PhD)
«Multiple stressor effects in aquatic organisms»

15:30 Summing-up first day Lindis Skipperud

FRIDAY 14TH OCTOBER

09:00 Coffee

09:30 – 10:00 Selma Hurem (PhD)
«Biological effects of gamma radiation in sensitive life stages of zebrafish»

10:00 – 10:30 Leonardo M. Martin (PhD)
«Non-coding RNA profiling during zebrafish embryogenesis in F1, F2 and F3 after gamma radiation exposure under gametogenesis of parental generation»

10:30 – 11:00 Leif Lindeman (PostDoc)
«Effects of low dose rates gamma irradiation on histone modifications during zebrafish embryogenesis»

11:00 – 11:30 Tania Gomez (PostDoc)
«Gamma radiation effects in the crustacean Daphnia magna»

11:30 – 12:30 Lunch

12:30 – 13:00 Elisabeth L.Hansen (PostDoc)
«STAR report on methods for wildlife dosimetry – an intro to computational dosimetry»

13:00 – 13:30 Dajana Blagojevic (PhD)
«Comparative toxicity assessment of ionizing radiation in Scots pine, Norway spruce and Arabidopsis thaliana»

13:30 – 14:00 Astrid Liland (PhD)
«Societal consequences of nuclear accidents»

14:00 – 14:15 Break

14:15 – 14:45 Kine J.A. Bredesen (PhD)
«Risk management when measures are correlated»

14:45 – 15:00 Jose Antonio Galván Moreno (PhD)
«Preliminary abiotic leaching studies on Pu /U particles»

15:00 Summing-up Brit Salbu

6th NORWEGIAN ENVIRONMENTAL TOXICOLOGY SYMPOSIUM (NETS2016, 25TH – 27TH OCTOBER)

Assessing and solving environmental challenges in a multiple stressor world

Knut Erik Tollefsen[1,2]
[1]Norwegian Institute for water Research (NIVA), [2]Norwegian University of Life Sciences (NMBU)

Aquatic and terrestrial organisms are exposed to a high number of stressors (multiple stressors) that originate from the production, use of anthropogenic chemicals, and exploitation of natural resources. Improving our knowledge of how different stressors act singly or in combinations to cause exposure, bioaccumulation, biomagnification, toxicity to organisms and impact the environment as a whole are key to protecting natural resources that Norway and other countries rely upon. The NETS meeting (www.niva.no/nets2016), organised in the Oslo Science Park, 25-27 October 2016 by NIVA, addressed this complex issue by establishing collaborative platforms and discussion arenas for science of high quality in several relevant topics for CERAD.

- Priority and emerging pollutants
- Nanoparticles and microplastics
- Ionizing and non-ionizing radiation
- From mechanisms to ecological relevance (populations)
- Monitoring, risk assessment and environmental management
- From urban development to sensitive environments
- Multiple stressors and environmental interactions

About 140 registered participants took part in this 3-day event, which started with an open seminar on Adverse Outcome Pathways (AOP) and a student pre-symposium on the 25th, followed by 2 days dedicated to scientific presentations, disseminations and networking. A total of 5 keynotes (Dan Villeneuve, Renee Bechmann, Veerle Jaspers, and Frederic Alonzo), one honorary lecture (Janniche Utne Skåre) along with 35 platform presentations and 62 posters, whereof CERAD research was disseminated by 7 platform and 18 poster presentations. The symposium was a huge success, with a new record in attendees and number of presentations.
The symposium provided an excellent platform for data sharing, scientific discussions and networking opportunities. It was covered by 12 media stories, and 22 manuscripts were submitted to a special issue of Journal of Toxicology and Environmental Health (JTEH) hosted by Prof. Sam Kacew (Editor-in-Chief) and Prof. Knut Erik Tollefsen (NIVA/NMBU) as co-editors. CERAD was one of NETS2016 sponsors.

Media coverage

http://www.niva.no/nets2016
http://www.niva.no/6th-nets
http://www.niva.no/en/6th-nets
https://www.nmbu.no/en/services/centers/cerad/news/node/29203
https://www.nmbu.no/en/services/centers/cerad/news/node/27416
https://www.mynewsdesk.com/no/niva/news/6th-norwegian-environmental-toxicology-symposium-215608
http://nsft.net/6th-norwegian-environmental-toxicology-symposium-nets
http://www.niva.no/en/lusemidler-kan-skade-krepsdyr)
http://www.alphagalileo.org/ViewItem.aspx?ItemId=171791&CultureCode=en
https://www.sciencedaily.com/releases/2017/01/170120085842.htm
https://phys.org/news/2017-01-anti-sea-lice-drugs-pose-hazard.html
http://uk.anygator.com/article/anti-sea-lice-drugs-may-pose-hazard-to-non-target-crustaceans__6127860

Norwegian University of Life Sciences

Norwegian Centre of Excellence

SHAMISEN Oslo meeting 1ST – 3RD DECEMBER 2016

Hotel Royal Christiania

PROGRAM

THURSDAY 1ST DECEMBER

08:30 – 09:30 Coffee, registration of the participants

9:00 – 10:30 **CCA3 – Ethical issues** & **Task A1.2**

10:30 – 11:00 Coffee break

11:00 – 13:00 **Task A3.1** & **Task A1.2 (cont)**

13:00 – 14:00 Lunch, registration of the participants

14:00 – 14:30 Introduction – organizational items D. Oughton
Presentation of ST3 draft recommendations/preliminary thoughts from subtask leaders

14:30 – 15:30 **Task A3.1 (cont)** & **A1.3** & **ST2**

15:30 – 16:00 Coffee break

16:00 – 17:30 **Possible ST1 other meetings** & **A3.5** & **ST2 (cont)**

18:00 Reception – Hotel Christiania (sponsored by CERAD)

FRIDAY 2ND DECEMBER

8:30 – 9:00 Coffee

9:00 – 9:15 Welcome **Brit Salbu/Per Strand (CERAD/NMBU)**
Plan for the Day **Deborah Oughton (CERAD/NMBU)**

9:15 – 11:00 Presentation of results from ST1: Lessons learned from dosimetric and health screening, evacuation and health surveillance

Chair: Elisabeth Cardis (ISGlobal), Gerry Thomas (Imperial Collage, UK)

A1.1 Critical review of recommendations on and experiences in dose assessment, evacuation, medical assessment of potentially exposed people, and dose reconstruction for intermediate to long term. Francesc Barquinero (UAB)

A1.2 Critical review of long-term medical surveillance programmes. Ausrele Kesminiene (IARC)

A1.3 Critical review of lessons learned from epidemiology on radiation risks from radiation accidents. Elisabeth Cardis (ISGlobal)

11:00 – 11:30 Coffee break

11:30 – 13:00 Presentation of results from ST2: Lessons learned from living conditions and health status of populations

Chair: Thierry Schnieder (CEPN), Koichi Tanigawa (FMU, Japan)

A2.1 Experiences with the Sámi population relating to Chernobyl fallout in Norway. Lavrans Skuterud (NRPA)

A2.2 Review of experiences after the Chernobyl accident in Belarus, Russia and Ukraine Pascal Crouail (CEPN)

A2.3 Review of current activities carried out after the Fukushima accident in Japan Thierry Schneider (CEPN)

13:00 – 14:00 Lunch

14:00 – 15:30 Presentation of initial thoughts from ST3: Preparedness and improvement of post-accident response and health follow-up

Chair: Deborah Oughton (NMBU), Johan Havenaar (Altrecht Institute of Mental Health Care)

A3.1 Recommendations for collection and communication of data on dose, in early, intermediate, and late post-accidental phases, and on medical assessment in the early emergency phase. Paola Fattibene (ISS)

A3.2 Recommendations for evacuation decisions. Koichi Tanigawa (FMU)

A3.3 Designing health surveillance programmes that respond to the concerns of the local population and improve their living conditions. Deborah Oughton (NMBU)

A3.4 Recommendations for improving professional support of affected populations. Rafael Vilasanjuan (ISGlobal)

A3.5 Recommendations for preparedness and post-accidental epidemiology. Dominique Laurier (IRSN)

15:30 – 16:00 Coffee break

16:00 – 16:45 Breakout/working group sessions
ST1/ST3 & **ST2/ST3**

16:45 – 17:30 CCA presentations: 1, 2 and 3

19:30 Dinner at Argent, Oslo Opera House (sponsored by NMBU and NRPA)

SATURDAY 3RD DECEMBER

9:00 – 10:30 Plenary reporting from breakout sessions
ST3 brainstorming (cont.)

10:30 – 13:00 Parallel sessions: ST3 discussion + CCA

13:00 Lunch

14:00 – 15:00 Plenary summary

CERAD Reproduction workshop, Thursday 8th of December

Institute of Public Health (FHI)

09.00 – 09.30 Welcome and coffee

09.30 – 09.50 Ann-Karin Olsen FHI
«Direct and transgenerational reproductive effects of one paternal chronic low dose rate gamma irradiation and selenium deficiency (SeIR-exp) in mice»

09.50 – 10.10 Ann-Karin Olsen FHI
«DNA methylation of repetitive elements and imprinted genes in sperm of paternally exposed mice from the SeIR-experiment»

10.10 – 10.30 Nur Duale FHI
«Transcriptome analyses in testis of directly exposed F0 male mice in the SeIR-experiment»

10.30 – 10.50 Dag M. Eide FHI
«Direct and transgenerational reproductive effects of paternal chronic exposures to low and medium dose rates gamma irradiation in two mouse strains»

10.50 – 11.10 Coffee break

11.10 – 11.40 Steven Verhaegen NMBU
«Hormones and Reproduction - In vitro Approaches»

11.40 – 12.00 Hans-Christian Teien NMBU
«Atlantic salmon - sensitive life stages and effects of gamma radiation»

12.00 – 12.20 Peter Aleström NMBU
«Fish and amphibian embryos as alternative models in toxicology and teratology»

12.20 – 12.40 Jan Lyche NMBU
«Zebrafish»

12.40 – 13.40 Lunch break

13.40 – 14.00 Deborah Oughton NMBU
«The worm's eye view of reproduction»

14.00 – 14.20 Tânya Gomes NIVA
«The secret life of Daphnia magna (cyclical parthenogenesis, asexual and sexual reproduction)»

14.20 – 14.40 Dag Brede NMBU
«C. elegans reproduction, story of the hermaphrodites and the odd male.»

14.40 – 15.00 Li Xie NIVA
«Reproduction in aquatic plants and algae»

15.00 – 15.20 Coffee break

15.20 – 16.00 Round table- open discussion

Winter at NMBU
Photo: Yevgeniya Tomkiv

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