Norwegian Centre of Excellence

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

2013 ANNUAL REPORT

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CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

CERAD CoE - In Short 2013

CERAD Partners	
NMBU = UMB+NVH	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
Scientific Articles	19
Books/Monograph	1
Technical/Scientific Reports	5
Presentations Internationally	28
Presentations Nationally	2
Popular science presentations	5

Funding 2013	Million NOK
RCN funding	12.0
In kind, personnel	18.9
In kind, other	2.0
Other research projects	4.1
Total	37.0

Human Resources - Part time Personnel	
Professors	13
Ass. Professors/Scientists	39
Technicians	5
Administration	2
Postdocs	4
PhD	5
MSc	4
Guest Researchers	10
Total	82

Forskningsrådet

Summary of marks

Criterion	Mark
Scientific merit	7
The project manager and project group	7
Feasibility	A
International cooperation	A
National cooperation	A
Value added generated by establishment of the centre	7
Dissemination and communication of results	A
Overall mark	7

CERAD CoE - In Short 2013

The CERAD CoE was established in 2013 to perform fundamental long term research to improve the ability to accurately assess the radiological risks from environmental radioactivity 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 needed for better management of those risks. The scope includes man-made and naturally occurring radionuclides that were released in the past, those presently released as well as those that potentially can be released in the future from the nuclear fuel cycle and non-nuclear industries.

Using an ecosystem based scientific approach, CERAD focuses on different source term and release scenarios, transfer of radionuclides in terrestrial and aquatic ecosystems, biological responses 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. The assessments can also be utilized to prioritize our focus on nuclear sources in proportion to the radiological threats that they pose. The strategic research agenda covers a broad scientific field, and the program is based on the interdisciplinary effort from scientists representing 5 Norwegian organisations (NMBU, NRPA, MET, NIPH, NIVA) and a network of international specialists.

CERAD Management Group (MG)

From left: Deputy Director Per Strand, Research Director Deborah H. Oughton, Education Director Lindis Skipperud, Centre Director Brit Salbu,

Photo: Gisle Bjørneby

COMMENTS FROM THE CENTER DIRECTOR BRIT SALBU

The Three Mile Island accident in USA (1979) demonstrated that low probability nuclear accidents occur, the Chernobyl accident (1986) showed that the consequences can be more severe than expected, the Fukushima accident (2011) illustrated that geohazards can be underestimated, and the World Trade Centre event (2001) clearly demonstrated that extremists have both the intention and capacity to harm. A paradigm shift has taken place whereby nuclear accidents now are considered to be more serious than earlier anticipated. The existing nuclear and radiological threats to Norway have also been recognized by the Norwegian government, based on a report from the Crisis Committee for Nuclear Preparedness[1]. The report highlighted risks from nuclear power fuel cycle installations and other major sources, as well as unintended and intended actions affecting Norwegian territories. Furthermore, naturally occurring radioactive materials (NORM) or those modified by human actions, including non-nuclear industries such as mining and oil/gas production, are of concern. NORM sources are generally the largest dose contributors to man, and external γ radiation in specific areas of Norway is among the highest in Europe. Following amendments to the Norwegian Pollution

Control Act (2011)[2], the term environmental contaminant includes not only metals and organic components, but also radioactive substances. Consequently, risk assessment and management of such materials represent a challenge, in Norway and abroad.

[1]Governmental document based on The Crisis Committee for Nuclear Preparedness "Nuclear Threats" report (2008) The Norwegian government, Oslo, Norway, 2010.
[2]Pollution Control Act (Forurensningsloven), 1981. LOV-1981-03-13-6. http://www.regjeringen.no/en/doc/Laws/Acts/Pollution-Control- 267 Act.html?id=171893

During the last decennium, several international organisations (EC, OECD, IUR) have recognized a decline in environmental radioactivity/radio-ecology research and educational capacity in Europe, despite the challenges associated with nuclear threats, the continuing legacy and new nuclear renaissance within Europe. To reverse this decline, the ALLIANCE (www.er-alliance.org) has been established to "enhance radioecological competences and experimental infra-structures in Europe, with an international perspective, and to address scientific and educational challenges related to the assessment of the impact of radioactive substances on humans and the environment." It has become clear that a systematic joint effort is needed to address research challenges associated with nuclear and radiological sources, potential releases and associated environmental/biological responses to varying levels of natural and man-made radiation. As tools and methods have improved, and our knowledge of how complex ecosystems function, a joint effort over time seems highly needed also in Norway, within the framework of a national/international CoE.

There were four key factors that motivated the application to establish CERAD CoE:

- *Manysources can contribute to releases of radioactivity in the future.* We are surrounded by a series of potentially releasing nuclear/radiological sources, including NORM. State-of-the- art "competence" must be in place to manage these risks.
- *"Competence must be available when needed.* Competence in radioecology was built in Norway and other countries during the nuclear weapons test period. Following the test ban, when global fallout decreased, the competence and recruitment within nuclear sciences declined. When the Chernobyl accident occurred, "competence" was not available when needed, and many decisions were made on poor

scientific grounds. The competence built post-Chernobyl is again declining in Europe, despite the continuing legacy and new nuclear renaissance challenges. The Fukushima accident also showed that competence was not in place, when needed. Thus, again, lessons had not been learned.

- *Science/New knowledge/Recruitment needed.* There are important gaps in knowledge that contribute to unacceptable uncertainties in impact and risk assessments. The challenges should stimulate basic science, being highly relevant to the several stakeholders.
- *Science must underpin the risk management to maintain public trust.* In this field of research, the distance between science, economy and politics is short. To maintain public trust and avoid unnecessary anxiety, decisions must be based on a solid scientific foundation. It is equally important to identify what is a hazard and what is not.

The CERAD programme is much more ambitious than anything hitherto attempted within environmental radioactivity in Norway. By joining forces, NMBU (UMB and NVH) and NRPA with the support from MET, NIPH and NIVA and the international network have got the opportunity to contribute to state-of-the-art science in a robust research environment, of relevance to the international community. Thus, a clear vision for 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

The CERAD objectives can only be achieved through integration of leading scientists, and the development and implementation of a Strategic Research Agenda, addressing key challenges within environmental radioactivity.

One year of the CERADs life has passed, and it is a privilege to be part of a growing research organization with a highly competent international network forming the Scientific Advisory Committee, and a series of stakeholders forming the Relevance Advisory Committee. It has been a pleasure to follow the development of the CERAD CoE research community, from a scattered crowd of 40 part time scientists representing different fields of science, different scientific culture, different expertise and priorities, via a brain storming period, workshops and project planning to the development of the Research Agenda with focused aims, hypotheses and eagerness to reach the essence of the objectives:*To significantly reduce the overall uncertainties in impact and risk assessments associated with radiation (ionizing + UV), also combined with other stressors*.

At the same time, collaboration with other organisations nationally and internationally has been initiated, broadening the research and providing access to internationally facilities and experimental sites. Therefore, I am looking forward to the progress with respect to scientific and conceptually output, to the development of the scientific organisation, and to the future role of CERAD internationally.

Center Director professor Brit Salbu

Photo Gisle Bjørneby

Comments from Ruth Haug, the Chair of the CERAD Board 2013

CERAD's first year of existence was a great beginning of what I expect will manifest itself to become a highly successful center of excellence with outstanding results. The first year can be described as busy in establishing efficient administrative and financial systems, developing a joint research strategy, organizing an international start-up conference and profiling the center internally and externally.

Team building among participatory institutions and within research groups, were an important part of the start-up phase. Different collaborative partners needed to come together and discuss roles, contributions, research focus and distribution of funds. Luckily, these processes went very well as all participants were highly committed to make CERAD a success.

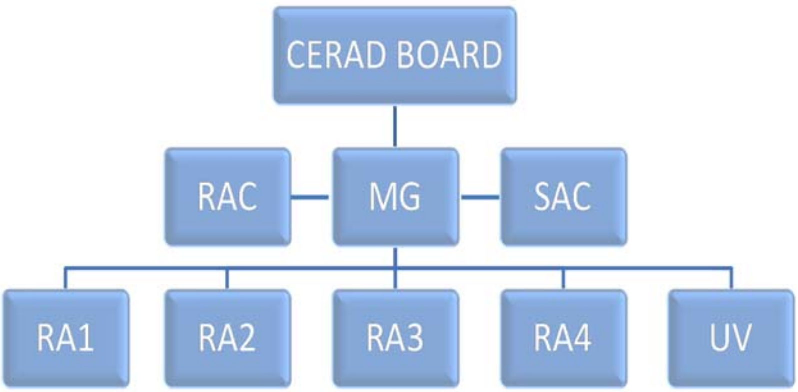
CERAD's academic focus, environmental radioactivity that will provide new scientific knowledge and tools for better protection of people and the environment from harmful effects of radiation is of high relevance both nationally and internationally.

CERAD's leadership has already experienced great interest from many actors not yet being partners to CERAD. The opportunities of further strengthening of CERAD in relation to possible new partnership, more grants, higher profiling and visibility, and increased internationalization appear to be many. CERAD is indeed a great asset for the new university, NMBU.

I would like to end by wishing my successor, Halvor Hektoen all the best luck as a new board chair of CERAD in 2014.

The chair of the CERAD board 2013, Pro-Rektor Professor Ruth Haug,

Photo Håkon Sparre



The UV group is referred to as RA5

ORGANISATION OF CERAD

THE CERAD BOARD HAD 9 MEMBERS IN 2013:
NMBU (UMB) Pro-rector of research (chair), IMV (IPM) department director, NRPA (director), representatives for the 4 contributing national institutions, CERAD center director and 1 representative from staff.
CERAD CENTRE MANAGEMENT GROUP MG:
CERAD Director B. Salbu, Professor, NMBU and Head Isotope Laboratory, Deputy Centre Director: P. Strand, Director for Environmental Radioactivity and Emergency Response, NRPA/Professor II, NMBU, Education Director: L. Skipperud, Professor, NMBU Research Director: D. H. Oughton, Professor, NMBU
RAC – RELEVANCE ADVISORY COMMITTEE:
The Norwegian Ministry of Health and Care Services The Ministry of Trade, Industry and Fisheries The Ministry of the Environment becomes the Ministry of Climate and Environment The Ministry of Foreign Affairs Norwegian Radiation Protection Authority
SAC – SCIENCE ADVISORY COMMITTEE: CERAD International Network
Dr. David Clarke Dr Valeriy Kashparov Professor Koen Janssens Professor Peter Stegnar Professor Carmel Mothersill Professor Colin Seymour Dr. Tom Hinton Dr. Clare Bradshaw Dr. Marcel Jansen Professor Janet Bornman

EXTENDED MANAGEMENT GROUP
MG + Research Area (RA) Leaders
RA1 O.C. Lind + J. Bartnici
RA2 J. Brown + HC Teien
RA3 A.K. Olsen + P Alestrøm
RA4 A Liland + KE Tollefsen
RA5 T. Christensen + J. Olsen
CERAD BOARD MEMBERS
Pro-rector Ruth Haug (NMBU), Chair
Director Ole Harbitz (NRPA), Deputy chair
Department Head Øystein Johnsen (NMBU/IPM)
Division Director Toril Attramadal (NIPH)
Pro-rector Halvor Hektoen (NVH)
Project Director Merete Johannessen Ulstein (NIVA)
Research Director Øystein Hov (NMI)
Senior Eng. Marit Nandrup Pettersen (NMBU)
Centre Director Brit Salbu (CERAD)
Kirsti Pettersen/Anja Nieuwenhuis/ (NMBU), Board Secretary
BOARD MEETING OBSERVERS:
Deputy Director Per Strand
Education Director Lindis Skipperud
Research Director Deborah H. Oughton

Photo Signe Dahl

CERAD Strategic Research Agenda

INTRODUCTION AND BACKGROUND

The CERAD Strategic Research Agenda (SRA) presents the five CERAD research areas (RA) and their main research questions, hypothesis and approaches to testing those hypotheses. In addition to focusing on the key challenges within individual research areas, the SRA also identifies integrated research areas, and forms the basis for decisions about needs and priorities for personnel, experiments, and equipment within CERAD. Following brain storming sessions and several workshops, the first outline of the SRA was completed in April 2013, with the involvement of over 40 scientists from all partner organisations, in addition to consultations with CERAD international partners. The SRA is a living document that will evolve and be updated as the work in CERAD progresses, and a revised draft was produced in December 2013. The next update will include a detailed roadmap for the planned activities during the next 5 – 10 years, is expected at the end of 2014.

DESCRIPTION AND EVOLUTION OF THE RESEARCH AREAS

The CERAD CoE is focused on four overarching Research Areas: RA1 Source Term and Release Scenarios; RA2 Ecosystem Transfer, RA3 Biological Effects and RA4 Risk Assessment. In addition, a transient research area focusing on UV exposure has been established to unite scientists working with UV exposure of man with scientists focusing on UV exposure of non-human organisms. When the UV research area has consolidated their joint scientific fundament, the group will merge into the other four research areas. This is expected to occur during the next 12 months period.

PRIORITISATION OF RESEARCH ACTIVITIES

The SRA has formed the basis for selection of research priorities and projects for 2013 and 2014. The main priority has been given to projects providing opportunities for collaboration between partners in order to stimulate integration across research areas (see below). For 2014, two additional criterias were funding of new positions (PhD, PostDocs) and the availability of co-funding from CERAD partners.

OTHER FUNDING CRITERIA INCLUDED:

- Relevance: Radiation ecology, risk evaluation, novelty, basic science, multidisciplinary, reduce overall uncertainties, relevance with respect to sources/threats of concern to Norway.
- Potential impact: Increased protection of man and the environment, accordance with societal needs, applicability to radiation protection, change in paradigm, education/ training/recruitment.
- Feasibility: Availability of expertise, access to relevant sites, samples, facilities infrastructures, experimental models.

INTEGRATION ACROSS RESEARCH AREAS

Collaboration across different research areas is an important mechanism for integration and collaboration, both scientifically and to build human competence and capacities.

Hence a number of joint projects have been presented in the SRA. Briefly, case study scenarios will act as a focus point for all RAs, impacting on the knowledge needed for fieldwork and laboratory model studies. Sensitivity analysis performed will highlight factors/variables/ processes contributing to the overall uncertainties risk assessment. Collaboration between release scenarios and ecosystem transfer will be particularly important with respect to the source-term, speciation and particle weathering impacts on transfer, including UV impacts on transfer. Ecosystem transfer will be linked to biological response with respect to the exposure of organisms, bioavailability and uptake, depuration and retention of radionuclides as well as stressors such as metals or defficiency of antioxidants like selenium. This will be important not only for the exposure and effect in non-human biota, but also exposure of humans through food-chain transfer. Impact and risk assessment will link to all other RAs both to guide selection of necessary research and to gather new results from their activities that will improve the analysis of risk, impact and benefit-cost. Use of different test organisms, biomarkers and toxicity endpoints in exposure and effect analysis, including the approach to multiple stressor, interspecies, and life-history trait impacts will improve our understanding of how single and multiple stressors affect organisms. The UV group will also collaborate with the source term group on the installation of UV sources, and calibration, dosimetry and monitoring.

OBJECTIVES AND KEY RESEARCH QUESTIONS

A brief summary of some of the overarching objectives and key research questions within the RAs is given below together with a table of ongoing projects. More detailed information on the ongoing projects and approaches to answering these questions can be found in the project reports in the Scientific Activities Section.

RA1 SOURCE TERMS AND RELEASE SCENARIOS: To characterize radionuclides released from different sources under different release scenarios with respect to physico-chemical forms, and to use such information to better determine the potential implication for air/water dispersal and further environmental transfer through development of integrated models.

Key research questions:

- How do release scenarios impact the release (source term); radionuclide and multiple stressor composition and speciation, in particular the nano- and micrometer sized particle characteristics,
- What is the relevance of particle releases to air/water transport, deposition and exposure models?
- What is the relevance of uneven particle exposure to dose estimates?

RA2 ECOSYSTEM TRANSFER: To specify how speciation, co-contaminants, climate conditions and biological factors influence radionuclide transfer through ecosystems in a Nordic context, and to replace equilibrium transfer constants with time and temperature dependent functions.

Key research questions:

- What are the key factors that influence, under boreal and sub-arctic climatic conditions, the mobility and speciation of radionuclides in soil, sediments and water?
- Which abiotic factors influence food chain transfer in Nordic environments?
- Which physiological parameters influence accumulation in different organisms?
- How do ecological factors, such as trophic interactions, influence the bioaccumulation of radionuclides?

RA3 BIOLOGICAL RESPONSES: To identify responses induced in biota exposed to medium to low radiation doses/dose rates, in combination with other stressors such as UV radiation, metals and antioxidant defficiency under varying temperature/climate conditions.

Key research questions:

- Are effects at high doses/dose rates relevant for low doses/dose rates? If yes – does this apply to both humans and non-human biota?
- Which biomarkers are most relevant for field investigations and chronic exposures?
- What are the implications of chronic multi-generational exposures for reproduction, hereditary and epigenetic effects?
- To what extent are the effects of ionising radiation (gamma, alpha) on living organisms modulated by exposure to other chemical stressors ?
- Why are some species, tissues and life stages more sensitive to ionising radiation than others?

RA4 IMPACT AND RISK ASSESSMENTS: To evaluate and improve impact, risk and benefit-cost assessments for establishing a scientifically based set of decision criteria for handling radiation and multi-stressors within an environmental and societal perspective.

Key research questions:

- Can harmonization and integration of risk assessment approaches improve the existing models?
- Can the risk of multiple stressors be predicted on basis of in-depth knowledge of the exposure and effect of single stressors to identify ecological relevant risk scenarios?
- How can benefit-cost analysis be used to illustrate the trade-off between environmental and public health risk and net benefits of mitigating measures and regulatory actions in a societal perspective?

RA5 UV GROUP To evaluate how UV and ionizing radiation interact in biological systems and the effects of tertiary stressors (e.g. biological processes, metals,) and climate change (e.g. temperature and acidification) on transfer and effects.

- To what degree do the damage and regulatory effects induced by UV in terrestrial and aquatic organisms depend on life cycle stages and environmental conditions?
- How does the production and composition of ROS species induced by UV, ionizing radiation and other stressors differ?
- Can the protective mechanisms induced by one stressor protect against effects of other stressors?

CERAD Kick off meeting

Photo Gisle Bjørneby

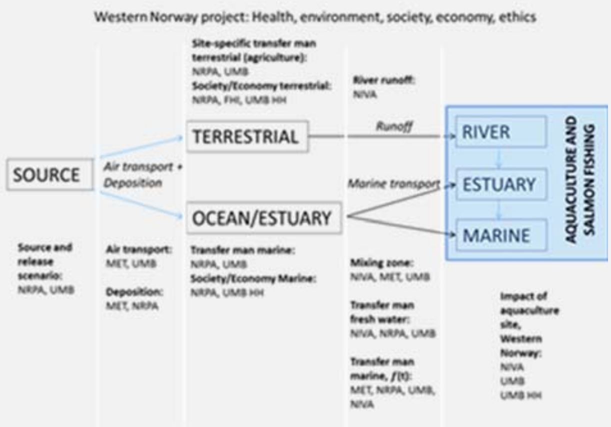
Research Activities 2013	Collaboration	NMBU	NMBU NVH	NRPA	NIVA	FHI	MET
Projects:	Project leader:			CERAD Participants			
Research Area 1							
U1-1 Virtuelt scenario	NMBU; OCL	x		x	x	x	x
U1-2 Source term, K-27	MET; JB	x		x			x
U12-1 TRAP	NRPA; JB	x		x			
Field work/samples available							
U12-2 KOMI NORM	NMBU; DO	x					
U12-3 Chernobyl	NMBU; LS	x		x			
U12-4 Fukushima	NMBU; DHO	x					
U12-5 Kara Sea	NMBU; OCL	x		x			
Research Area 2							
U2-1 Modell particle, Water-soil	NMBU; OCL	x		x			
U2-2 Modell particle, C-elegans	NMBU; DB	x					
U2-3 Modell exp, salmon + U	NMBU; HCT	x		x	x		
U2-4 Modell exp, algae + U	NIVA; ARU	x		x	x		
U4-1 ERICA Dynamics	NRPA; JB	x		x			
Research Area 3							
U3-1 Zebrafish + gamma	NVH; JL	x	x	x			
U3-2 Se Mice + Gamma genotox	FHI; AKO	x				x	
U3-3 Se Mice + Gamma mRNA	FHI; AKO	x				x	
U3-4 *C. elegans* mix tox	NMBU; DB	x					
U3-5 RBE-Zebrafish	NVH; JL	x	x	x			
Research Area 4							
U4-2 Sensitivity Analysis	NRPA; AL	x	x	x	x		x
U4-3 Workshops	NIVA; KET	x	x	x	x	x	
Research Area 5							
U5-1 UV + zebrafish	NVH; JL	x	x	x			
U5-2 UV + plants	IPM; JEO	x				x	
U5-3 Testing cell culture	NIVA; KPE			x	x		
U5-4 UV-antioksidant	NRPA; TC		x	x	x		
Equipment 2013	NMBU; OCL						
ICP-QQQ-MS		x					
U5-6 FIGARO upgrade		x					
U5-7 FFF auto sampler		x					
U5-8 UV installation		x		x			
U5-9 Exposure incubators					x		
U5-10 FIGARO control shielding		x					

Research Highlights

THE WESTERN NORWAY PROJECT

Ole Christian Lind, NMBU

The Western Norway sub-project is an integrating project involving all the CERAD research groups and covering all aspects of risk assessment from sources via transfer, exposure and biological effects of radionuclides to consequences on health, environment, society, economy and ethics. The overall goal is to reduce the uncertainties in the risk assessment work. Simulations of hypothetical nuclear accidents in the UK are used to identify knowledge gaps and perform sensitivity analyses using real-time meteorological data for atmospheric transport of radionuclides to the west coast of Norway, and subsequent deposition.



The Western Norway Project

Two different hypothetical accidents have been selected as source terms: 1) an accident with release of liquid radioactive waste from the Sellafield B215 High liquid waste facility, Cumbria, UK that has been subjected to reprocessing and storage (i.e. U and Pu have been removed and short-lived radionuclides have decayed), and 2) a nuclear reactor accident at Hartlepool nuclear power plant, County Durham, North East England with release of fresh fallout. As a worst case scenario, weather conditions unfavourable for Norway (i.e. wind to the East), have been selected. Various atmospheric dispersion model runs are in progress using the selected weather conditions and parameters from the selected source and release conditions. Results from atmospheric transport simulations using the SNAP model software will feed into the deposition modelling of the marine environment and the Vikedalselva catchment area (Rogaland, Norway) which has been selected as a detailed case study location in one of the most affected regions. Modelling of catchment runoff of radionuclides to the marine environment requires development of the INCA software and so far a transport prototype model for ^{137}Cs has been implemented. Transfer to man from aquatic and terrestrial food sources will be modelled using the AgriCP and Stratos software. A task group on modelling and uncertainty quantification hasinitiated sensitivity analyses based on source term 1. This scenario has been previously assessed (NRPA, 2009) and results from previous and current assessments will be compared. Work is in progress on coupling of the various models used by the different groups. The results will feed into all RAs and the integrated air/terrestrial/ estuary/marine model.

References: NRPA, Strålevernrapport 2009:6 and Strålevern,. See report 2010:13

Participants: J. Bartnicki, P.E Isachsen, H. Klein, M. Simonsen, Ø. Sætra (MET), R.M. Couture, Ø. Kaste,Y. Lin, J. Moe, K.E., Tollefsen (NIVA), J.E.Dyve, A Hosseini, M. Iosjpe, A.Liland. H. Thørring, M.A Ytre-Eide (NRPA), Ø. Bergland, S. Navrud, D.H.Oughton J.E. Paulsen, B.O. Rosseland, B. Salbu, Y. Tomkiv (NMBU).

Other Information: Magne Simonsen holds a CERAD PhD fellowship (2013-).

SPECIATION UPTAKE AND TOXICITY OF URANIUM IN ATLANTIC SALMON (*SALMO SALAR*)

Hans-Christian Teien, NMBU

Uranium is a naturally occurring radionuclide as well as a heavy metal that can be found in elevated concentrations (mg/L) in the aquatic environment and may pose a risk to aquatic organisms including fish. The biotic ligand model (BLM) is used to describe the speciation, bioavailability and toxicity of toxic metals and competing cations. At present there is no model for uranium in the Atlantic salmon (*Salmo salar*), and knowledge about the bioavailability and toxicity of U towards aquatic organisms is relatively limited.

A series of controlled exposure experiments were carried out wherein Atlantic Salmon juveniles (in total about 1000 fish) were exposed to commercially available depleted uranium (DU) in accordance with the OECD guidelines for acute toxicity tests. Speciation, gill accumulation and induced toxicity of U as a as a function of varying water concentrations of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}as well as U were studied. In addition to recording mortality, blood samples were collected and analysed for general stress parameters (plasma Cl and glucose).prior to fish dissection and collection of different tissues.

The observed dose-response demonstrated that varying concentrations of K^{+}, Na^{+} or Mg^{2+} had no apparent effect on induced toxicity in terms of 96 h LC_{50}-values. U toxicity was, however, strongly dependent on pH. Reducing pH from about 6.7 to 6.0 or 5.5 reduced the LC_{50}-value from 3.1 to 1.4 mg U/l. However, by increasing pH to 7.9, LC_{50}-values increased to 25 mg/L. Fractionation of the exposure waters, demonstrated that U was present as dissolved species less than 10 kDa in size, predominantly as anions, but about 30 % was present as U colloids (3-10 kDa). U accumulated in fish gills as a function of U concentration in the water. U accumulation at >50 µg U/g dry weight gill was correlated with ion regulation problems and stress response in fish, reflected by reduced plasma Cl concentration and increased blood glucose. Mortality was observed at concentration levels >300 µg/g gill dry weight. The concentration of U in gills was highly dependent upon pH in water and the U speciation. U did not only absorb to the external boundary of the fish gills, but it was also taken up and present in the core of the gill filament (See report O.C. Lind). Time dependent deposition, uptake and distribution of U in different fish tissues and rate of excretion were also studied.

Uranium toxicity studies

Participants; Y. Ayalew Kassaye, A. Brandt-Kjelsen, D.A. Brede, O.C Lind, L. Sørlie Heier, T. Hertel-Aas, B. Nkwell Sone, K.A. Jensen, M. Kleiven, D. H. Oughton, M. Nandrup Pettersen, S. Lohne, B. Salbu, L. Skipperud, Y. Tomkiv (NMBU) L. Kiel Jensen, G. Rudolfsen, H. Thørring (NRPA) and S. Lofts (NERC).

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SELENIUM AS ANTIOXIDANT

Brit.Salbu NMBU

Selenium (Se) is an essential element to all living organisms, a key component influencing major metabolic pathways such as antioxidant defence systems, reproduction and immune functions. Norway is a Se deficient country, and since the import of Se enriched wheat from USA and Canada ceased, the blood serum Se concentration in the population has declined about 30 % since mid 1990ies. The RCN supported project: "Anti-inflammatory and anti-carcinogenic effect of Se-enriched plant foods" was also supported by CERAD in 2013, and the upgrading of gamma facility supported by DoReMi/RCN. The overall objective was to optimise the bioavailability of Se-species in Se-enriched food plants, having optimal antioxidant effect, acting as a protective agent against oxidative stress, DNA damage and inflammatory diseases. Results showed that the spring wheat (*Triticum aestivum L*), bulb onion (*Ailluum cepa L*) and broccoli *(Brassica oleracea*) grown in the field could be enriched to various Se levels, by controlling the N/S ratio using inorganic selenate as fertiliser. In Se enriched wheat, Se was mainly transformed to SeMet, being more bioavailable than inorganic Se. Thus, Se enriched feed (0.04-1.20 Se mg/kg) containing highly bioavailable Se species (SeMet) was produced to perform biotest experiments (chicken, GMO mice).

The male chicken experiments showed that the Se and SeMet concentrations in muscle were significantly higher (factor 5) when chicken were fed Se-enriched wheat diet compared to a inorganic selenate diet. The use of Se enriched wheat as dietary sources to chickens significantly ($p<0.05$) increased the concentration of SeMet in liver and muscle of chickens, functioning as a reservoir for the bioactive SeCys.

The male GMO (Ogg1-/-, deficient in DNA repair) mice experiments showed that low Se diet, in contrast to high Se diet, resulted in genotoxic and reproduction effects, and sterility was observed in males born from mothers given low Se feed (See reports by A.K. Olsen). Gamma exposure of control mice (1.63 mGy/h, continuously for 45 days) indicated genotoxic effects, For mice with low Se diets, the exposure to chronic low dose oxidative stress by gamma irradiation aggravated these effects.

The female mice (Ogg1-/-) experiments showed that low Se diet and chemical stress (LPS) resulted in abnormal inflammatory responses, based on a series of biomarkers/endpoints (e.g., mRNA expression levels of selenoproteins, the inflammation-related gene TNFa, the protein of the NF-kB transcription factor signalling pathway-RELA-being vital in regulation of immune and inflammatory responses, cytokines).

Results show that Se-enriched wheat as flour or bran can serve as a valuable dietary Se source to human and animals. Thus, the link between low Se diets and reduced reproductive capacity should also be highly relevant to humans in Norway being a Se poor country.

Participants: NMBU, NIPH, UiO, Yara International ASA, with support from Nortura. **NMBU:** B. Salbu, E. Govasmark, A. Brandt-Kjeldsen (PhD, 2013), D.A. Brede, O.C. Lind, **NIPH:** A.K. Olsen, A. Graupner (PhD support), C. Instanes, J. Andersen, G. Brunborg, **UiO:** R. Blomhoff, H. Karlsen, I. Paur, S.K. Bøhn. A. Graupner is a PhD student partly financed by CERAD.

Left: Autoradiography (P- imaging) of ^{75}Se in spring wheat. Right: experimental mouse.

MICE MODEL STUDIES: CHRONIC CONTINUOUS LOW DOSE-RATE RADIATION IS MUTAGENIC

Ann-Karin Olsen, NIPH

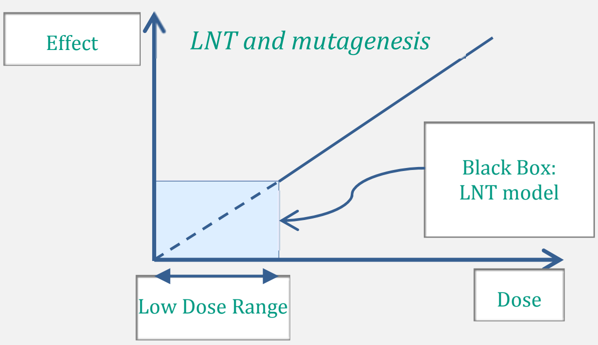
The central dogma in radiation protection is that one can extrapolate effects such as cancer occurring at high dose rate/high doses of ionizing radiation (IR), to low doses or low dose rates, in a linear fashion with the assumption that there is no threshold for effects (the LNT model). The shape of the dose curve in the low dose area is a matter of intense scientific discussion.

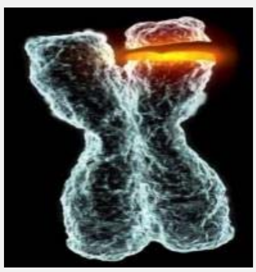
The Co-60 gamma facility at NMBU (FIGARO) is one of very few that allows continuous chronic low dose rate gamma irradiation. An extensive study was carried out in spring 2013 (See report B. Salbu). where one of the main goals was to elucidate whether exposure to continuous chronic low dose rate gamma radiation of mice would lead to negative biological effects such as genotoxicity and mutagenicity. It is already established that high dose rate/high dose IR is genotoxic, leading to gene mutations that predispose for cancer development. But less is known about the low dose rates/low doses that are the most relevant exposure scenarios in the environment and after accidents such as Chernobyl and Fukushima. The experiments showed that after exposing mice to chronic low dose rate gamma irradiation (1.63 mGy/h, continuously for 45 days), the mice acquired genotoxic changes, in the form of both altered DNA damage levels in blood cells, and more importantly - as statistically significant induction of two classes of mutations (point mutations and chromosomal mutations) in blood cells. This supports the hypothesis that genotoxic effects are indeed induced also at low dose rates of gamma irradiation in the intact animal.

Aiming at more detailed mechanistic information, we used a mouse model that has impaired repair of oxidative DNA damage (Ogg1-defective mice), such as that induced by gamma irradiation, and we deprived some of the mice from selenium that is essential for production of several antioxidant species. The results suggested that neither selenium deprivation nor DNA repair deficiency aggravated the mutagenic effects of gamma irradiation (See report AK Olsen). This novel insight from mouse experiments is related to central issues within the low dose area of radiation, and is directly relevant for humans. However, the question remains as to whether the magnitude and the character of the observed effects are similar to those inflicted by acute radiation. This is an essential issue for CERAD.

Participants: A. Graupner, J. Andersen, C. Instanes, H. Rasmussen, G. Brunborg, A.K Olsen (NIPH), O.C. Lind, DA. Brede, A. Brandt-Kjeldsen, B. Salbu, D.H. Oughton (NMBU), H.Bjerke (NRPA).

Other Information: Anne Graupner is a PhD student partly funded by CERAD. The work has been co-funded by RCN and the EU DoReMi project.





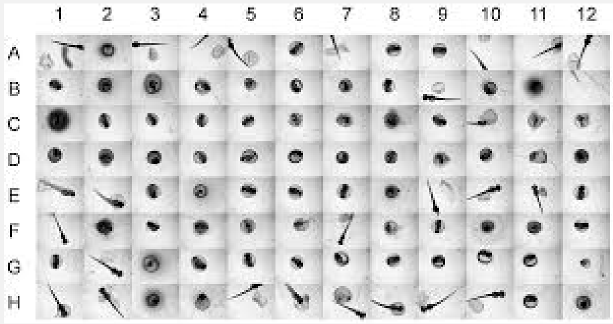
ZEBRAFISH MODEL: DOSE RESPONSE RELATIONSHIP BETWEEN GAMMA IRRADIATION AND ADVERSE EFFECTS DURING EARLY LIFESTAGES

Jan Ludvig Lyche, VetBio, NMBU

Different life stages of exposed organisms show different sensitivity to ionizing radiation. The aim of this dose response study was to assess relevant doses for a multigenerational experiment. Zebrafish embryos from wild type AB strain were exposed to different dose rates (0.5, 1, 5, 25, 40 mGy/h) of gamma irradiation between 2 hours to 5 days post fertilization (dpf), a total of 118 hours. Single embryos were placed in 96 well micro-plates. During the exposure period, samples for gene expression analysis were collected at 5 hours post fertilization (hpf). The number of dead embryos, malformations, and the hatching rate were observed at at 48 and 118 hpf.

Results showed that hatching rate and number of malformations were significantly different from controls in all exposure groups. The mortality rates were significantly different from control in all groups except for the lowest dose (0.5 mGy/h), suggesting that doses from 1 mGy/hour and higher during 5 days of exposure induce acute toxic effects in zebrafish during embryogenesis.

In order to study effects of the gamma irradiation on gene expression during a very early life stage, RNA was isolated from embryos exposed for 3.5 hours, between 2 and 5.5 hpf at the same doses. Genome-wide data-sets will be generated by RNA sequencing (RNA-seq) and analyzed using a bioinformatics pipeline available at Partner NMBU Vetbio (Aanes et al. 2011). As part of the long term



96 well micotiter-plate with single zebrafish in each well with stressor compounds added to system water in a final volume of (250µL).

perspective goal to compare gene expression data sets with epigenetic changes and to identify whether such changes are transferred to offspring generations, a method for global DNA methylation analysis using HPLC-MS has been established and work is in progress to establish a pipeline for Bisulphite (BIS)-seq and the bioinformatics tools to uncover changes of DNA methylation at the nucleotide level. Both methods will be fully applicable to any other species (animals and plants) used in the CERAD research program.

Participants: J.L. Lyche, H.C. Teien, O.C. Lind, D.A. Brede, T. Hertel-Aas, L. Sørlie Heier, V. Berg, S. Hurem, J. Kamstra, D.H. Oughton, B. Salbu, P. Alestrøm.

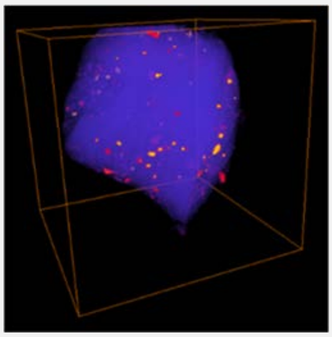
X-RAY ABSORPTION NANOTOMOGRAPHY COMBINED WITH CONFOCAL SR XRF UTILIZED WITHIN RADIOECOLOGY

Simone Cagno, NMBU

An important tool in radioecology is the solid state speciation of radionuclides in complex systems, such as organisms, or heterogeneous rocks or sediments. For this study selected particles, rock fragments and segments of earthworms as well as fish eggs were subjected to nano/micro-CT at the Technical University of Warsaw. Moreover, the same samples were analyzed at beamline L, HASYLAB synchrotron, Hamburg, by means of micro-X-ray fluorescence (µ-XRF) and micro-X-ray powder diffraction (µ-XRPD), in confocal and tomographic mode.

While the µ-XRF and µ-XRD techniques provide 2D maps showing the distribution of elements and minerals on a single virtual slice, µ-CT allows us to obtain a full 3D volume reconstruction. The combination of these techniques can provide valuable information on chemical solid speciation of an entire volume (e.g. 1 mm^3) in a time efficient manner. This study focused on different samples: heterogeneous alum shale rock fragments from Gran, Hadeland; very heterogeneous Th and lanthanide containing soil particles originating from the Fen region, Norway; and biota samples, notably fish eggs (*Salmo salar*) and earthworms (*Eisenia fetida*), exposed to U nanoparticles in laboratory experiments. The use of model biota for aquatic and terrestrial ecosystems is important in assessing the impact of U NP exposure. The exact location of U particles within earthworms and salmon eggs.was imaged Elemental mapping (3D) of U within the organisms was performed with confocal micro-XRF.

The nano/micro-CT analysis of alum shale samples (RV4 project) demonstrates the presence of inclusions of dense phases in the rock The most abundant phases in the Fen area particle were identified by µ-XRD as quartz and chlinochlore, while the denser phase inclusions have been proven by µ-XRF tomography to contain Th, the distribution of which is correlated with yttrium.



Micro-CT x-ray absorption tomography image of an alum shale rock fragment collected at Gran, Hadeland showing numerous high density inclusion

The combination of laboratory micro-CT with the synchrotron based XRF/XRD tomography has also shown a clear added value, for instance when tracking down in the CT data the XRF/XRD virtual slices, allowing us to observe in 3D the distribution of the univocally identified minerals or particles we are interested in. Thus, the combined tools should be highly beneficial for state-of-the-art research within environmental radioactivity. *s*

Participants: S. Cagno, DH. Oughton, B. Salbu, HC Teien (NMBU), K. Janssens, F. Vanmeert, G. Nuyts (University of Antwerpen), M. Alfeld, G. Falkenberg (HASYLAB P06), J. Jaroszewicz (Technical University of Warsaw).

Other Information: Simone Cagno held a CERAD postdoc position (2012-2014).

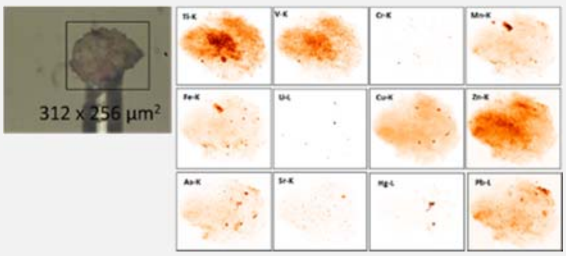
LOW-LEVEL RADIOACTIVE RIVER SEDIMENT PARTICLES ORIGINATING FROM THE CHALK RIVER NUCLEAR SITE CARRY A MIXTURE OF RADIONUCLIDES AND METALS

Ole Christian Lind, NMBU

The Chalk River Laboratory of Atomic Energy of Canada Ltd., site is located on the Ottawa River approximately 200km northwest of Ottawa, Canada. The site has two large research reactors: NRX, which operated from 1947 to 1991 and NRU, which continues to operate and is used to produce a significant fraction of the world's supply of medical isotopes. During the course of the operation of the NRX reactor small quantities of radioactive particles were discharged to the Ottawa River through a process sewer discharge pipe (AECL, 2005). These are now located in river bed sediments within a 0.08 km^2 area close to the discharge pipe. In the present study, selected particles were isolated from riverbed sediments. These were then characterized by environmental scanning electron microscopy with energy dispersive micro X-ray analysis (ESEM-EDX). This was undertaken to obtain information on particle size, structure and the distribution of elements across particle surfaces. Based on the results of ESEM-EDX, particles were selected for X-ray absorption nanotomography analysis, which provides videos showing the 3D density distribution of the particles. Furthermore, 2D and 3D Synchrotron Radiation based X-ray techniques (µ-X-ray fluorescence; µ-XRF, µ-X-ray absorption near edge spectroscopy; µ-XANES and µ-X-ray diffraction; µ-XRD) with submicron resolution (beam size 0.5 µm) were employed to investigate the elemental and phase composition (µ-XRF/XRD) and oxidation states (µ-XANES) of matrix elements with high spatial resolution and sensitivity. Results show that the investigated particles varied according to: 1) <~40 µm diameter sized U fuel particles similar in structure to particles observed from Chernobyl and Krasnoyarsk-26 and 2) larger particles with diameters up to several hundred µm. The larger particles comprised a matrix of low density, sediment material with high density inclusions that contained a range of metals including Cu, Cr, As, Zr, Mo, Hf, Hg, Pb and Th in addition to U. Solid state speciation by means of µ-XRF/XRD tomography showed that the low-density sediment matrix was composed of kaolinite ($Al_2Si_2O_5(OH)_4$), anatase / rutile (TiO_2) and calcite ($CaCO_3$). Metal species in the inclusions identified by µ-XRF/XRD tomography included molybdenite (MoS_2), metacinnabar (β-HgS) and UO_2 with some indications that some U may be present in an inter-metallic form.

Participants: S. Cagno, H.C. Teien, B. Salbu (NMBU), K. Janssens, F. Vanmeert, G. Nuyts (University of Antwerpen), M. Alfeld, G. Falkenberg (HASYLAB P06), ND. Priest, M. Audet (AECL Chalk River Laboratories), J. Jaroszewicz (Technical University of Warsaw).

Other Information: Simone Cagno has held a CERAD postdoc position (2012-2014).



Microscopy of a radioactive particle from Ottawa River sediment. Light microscopy (left) and elemental maps (right) based on synchrotron radiation based µ-X-ray fluorescence show the presence of a mixture of toxic metals

WORST CASE METEOROLOGICAL SCENARIO FOLLOWING A HYPOTHETICAL ACCIDENT IN THE RUSSIAN SUBMARINE K-27

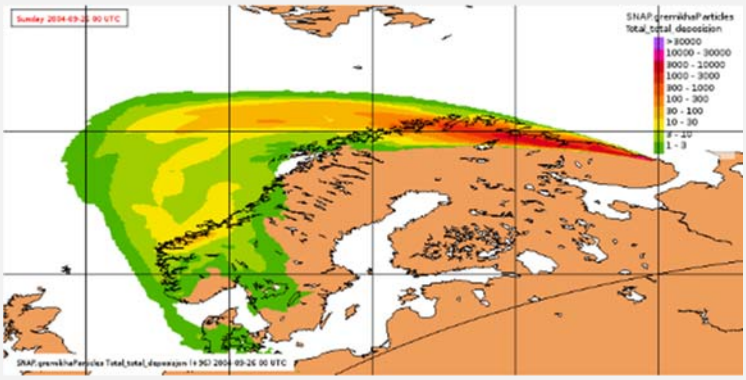
Jerzy Bartnicki, MET

This study is a part of the Norwegian project led by Norwegian Radiation Protection Authority, co-funded by CERAD, assessing risks related to plans of salvaging and decommissioning of the Russian nuclear submarine, K-27. In September 1981, the K-27 submarine was scuttled at a very shallow depth of 33 meters in the outer part of Stepovogo Bay, north-eastern coast of Novaya Zemlya.

One of the scenarios in the assessment is to lift the submarine and subsequently transport it to the Murmansk area for decommissioning. A risk of accidents as a consequence of an uncontrolled chain reaction event cannot be ruled out. Such a hypothetical accident might pose a threat to Norwegian territories and possible consequences should be assessed from different perspectives. Here, we focus on the worst case meteorological scenario for Norway, but the same approach can be applied to other Scandinavian countries and Russia. As a first step, a large database with meteorological data has been prepared for the period of thirty years (1980-2010). These meteorological data are available in the domain with a size of 1000 km×1000 km which includes both the entire Norwegian territory and the region of Novaya Zemlya. The spatial resolution of the meteorological data is 11 km and temporal 3 hours. The vertical structure includes 40 layers. The second step was the development of the source terms for potential accidents which caould be used by the dispersion model SNAP (Severe Nuclear Accident Program). Three locations for potential accidents with subsequent releases of radioactivity to the environment are assumed: 1) in the present location of K-27, 2) on the way to Murmansk and 3) in the Murmansk region. In the third step, the SNAP model was run, starting every 6th hour of each day of the 30 years period with meteorological data. As a result of the model simulations, surface concentration field and deposition fields will be calculated for radioactive particles in the entire model area.

Using the model results, the worst case meteorological scenario was selected. The model results corresponding to the worst case meteorological scenario are presented in Fig. 1, as a deposition field of Cs-137.

Participants: I. Amundsen, A. Hosseini (NRPA), H. Haakensta., H. Klein (MET), O.C. Lind, B. Salbu (NMBU).



Results of the model run for the worst case meteorological scenario for Norway, in case of potential accident at K-27 submarine. Total deposition of Cs-137 in Bq m^{-2}.

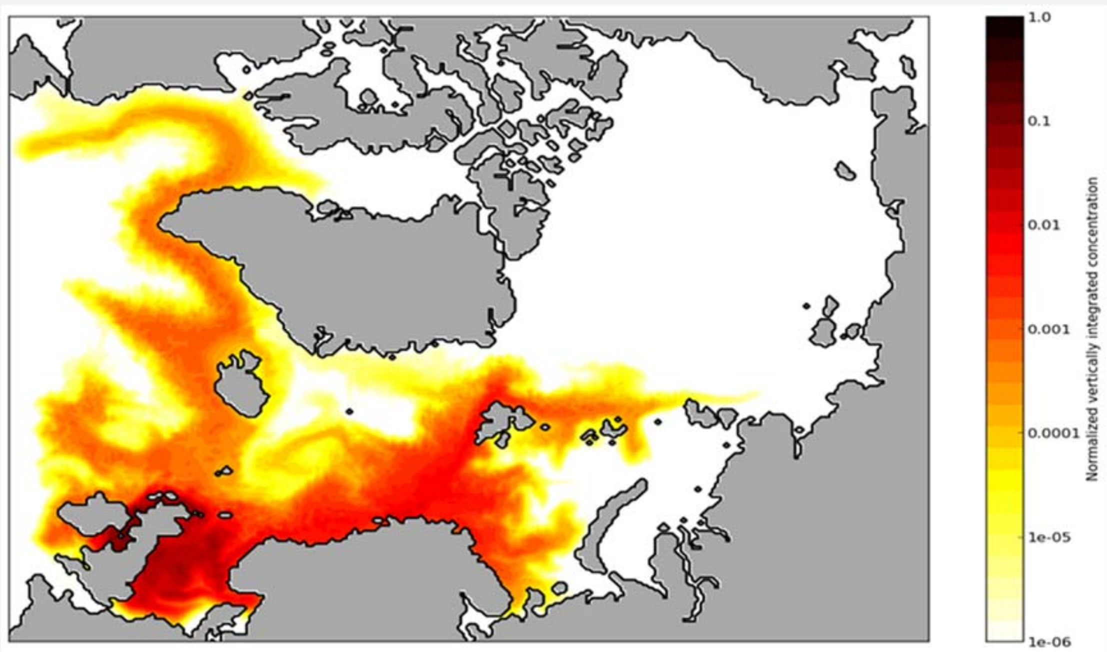
MARINE TRANSPORT MODELLING

Magne Simonsen, MET/NMBU

A numerical ocean model system (ROMS) has been implemented for simulations of marine radionuclide transport. The ROMS model system, which is the main ocean forecasting system at the Norwegian meteorological institute, computes the ocean circulation dynamics, and has built-in routines for computation of transport of different species. There are mainly two fundamentally different methods for transport modeling: particle tracking and tracer concentration fields. In this project, both methods are relevant for computation of the radionuclide dispersion. At this early stage, the radionuclides are implemented as passive particles/tracers following the water masses with no interactions with the environment. A preliminary test scenario has been created, "the Irish Sea experiment". This experiment consists of a simulation of more than four years of direct releases from Sellafield disposal into the Irish Sea. The three-dimensional model domain covers the North Atlantic and Arctic oceans with a horizontal resolution of 20 km and 35 terrain-following vertical layers. Dispersion and travel paths into the North Atlantic and Arctic oceans have been investigated with a special focus on transport at different depths. Experiences from this preliminary scenario will be the basis for future model simulations of historical as well as hypothetical release scenarios.

Participants: P.E. Isachsen (MET), Ø. Sætra (MET), O.C. Lind (NMBU).

Other Information: Magne Simonsen holds a CERAD PhD fellowship (2013-).



Modeled concentration of conservative radionuclides from a hypothetical Irish Sea release scenario, 20 months after hypothetical discharge in Irish Sea. Values are normalized.

UPTAKE OF URANIUM IN ATLANTIC SALMON GILLS FOLLOWING EXPOSURE EXPERIMENTS DEMONSTRATED BY SR-XRF TOMOGRAPHY

Ole Christian Lind, NMBU

A major challenge in monitoring the behaviour of U in complex media, such as soils, sediments and water is to identify mobile and bioavailable U species, interactions with environmental components, transfer to organisms via sorption to surfaces and across membranes, and the internal distribution reflecting target organs. As part of a larger study (See report H.C. Teien), U accumulation in gills and internal organs (e.g. liver) as well as mortality of Atlantic Salmon (*Salmo Salar*) was studied as a function of U concentrations as well as pH in the exposure water. As Atlantic salmon does not ingest freshwater, the major pathway for uptake of U in liver is hypothesized to be due to transfer across the gills. However, to our best knowledge, active uptake of U within gill filaments has never been proven up to now. In the present work, we demonstrate that following 96 hours exposure of 6 mg U/L in freshwater at pH 7, U was actively taken up in the Atlantic Salmon gill filaments. The internal distribution of U within exposed organisms was visualized inside fish gill filaments of Atlantic salmon by utilizing µ-XRF/µ-XRD two-dimensional scanning and XRF/XRD tomography at the P06 beamline at PETRA III. The recently developed and highly efficient Maia detector array was successfully employed to record extended high-resolution conventional 2D µ-XRF maps of the tissue samples, which allowed to identify the axial planes in the samples actually containing U. On the same samples, higher resolution virtual cross-sections were obtained (18 keV, 600 nm beam size) by means of µ-XRF/µ-XRD tomography of the planes in which U was encountered. The result proved that U not only adheres to the external boundary of the fish gills, but it is also taken up via gills. The results of this work serve as an important input to understanding of transfer mechanisms of U across biological membranes and thus improve the basis for dose-assessment models applied in environmental impact assessment work.

Participants: S. Cagno, H.C. Teien, B. Salbu (NMBU), K. Janssens, F. Vanmeert, G. Nuyts (University of Antwerpen), M. Alfeld, G. Falkenberg (HASYLAB P06).

The 3rd Generation Synchrotron Radiation Source at DESY: PETRA III. With a circumference of 2.3 km PETRA III is the biggest and most brilliant storage ring light source in the world. PETRA III provides advanced visualisation with micro/ nanoscopic spatial resolution using different X-ray techniques.

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BIOACCUMULATION AND TOXIC EFFECTS OF DEPLETED URANIUM (DU) IN PLANKTONIC ORGANISMS (ALGAE AND CRUSTACEANS)

Anders Ruus, NIVA

This sub-project aims to quantify bioaccumulation and toxicity of depleted uranium (DU) in planktonic organisms (the base of the food chain), by the use of algae (*Clamydomonas reinhardtii*) and cladoceran (*Daphni magna*) as model organisms. Initially organisms will be subject to water borne exposures to determine the direct uptake from water, followed by a dietary exposure to quantify food web transfer of DU in later phases of CERAD. The work in 2013 has been predominantly focused on optimizing the exposure system for DU, by determining optimal exposure media composition for DU, as well as optimal culture and exposure conditions for the two species. Suitable exposure facilities that may accommodate the exposure of aquatic organisms to single and multiple stressors (ionizing radiation, UV, metals, organics and global climate change) have been successfully established at NIVA and is currently assessed for reproducibility in studies with both algae and crustaceans.

Participants: A. Ruus, Y. Song, T. Gomes, KE. Tollefsen (NIVA), HC. Teien (NMBU).


Optimization of incubator and exposure unit for running studies with single and multiple stressors in algae and crustaceans
Photos Tania Gomes and You Song

LONG-TERM CONSEQUENCES OF CHRONIC EXPOSURE TO RADIONUCLIDES AND CHEMICAL STRESSORS: FIELD STIDIES IN KOMI, RUSSIA

Yevgeniya Tomkiv, NMBU

Industrial areas in the proximity to the Vodny settlement in the Komi Republic, Russia, have been contaminated by uranium mill tailings and radium production wastes due to activities in the 1950s. Mining sites and territories contaminated with uranium-radium production wastes tend to have high activity concentrations of both naturally occurring radionuclides (NOR), heavy metals, and rare-earth elements, and constitute a valuable field laboratory where the effects of the combined chronic exposures to α-, β-, and γ-emitting radionuclides and conventional chemicals pollutants on natural plant and soil invertebrate populations can be studied. In order to study the ecosystem impacts of chronic exposure of plants and soil invertebrates to enhanced radioactivity and chemical pollutants, two fieldworks were carried out in 2012 and 2013. Pilot studies show reduced abundance of a number of soil invertebrates at contaminated compared to control sites. Species diversity of soil invertebrates in ongoing by DNA barcoding and diversity of the microbial communities by metabarcoding, together with analysis of radionuclide and metal concentrations.

The results of the sample analysis are expected to be ready by the end of 2014.

Participants: E. Lapied, Y. Tomkiv, T. Hertel-Aas, D.H. Oughton, (NMBU), V. Zainullin, E. Belykh, A. Kaneva, I. Velegzhaninov, T. Evseeva (The Institute of Biology, Komi Scientific Center of UB RAS).

Other information: This project is partly financed by the Norwegian Research Council as a part of EANOR, ERANET EU-project.

Sample collection during the fieldwork in July 2013

Photo D.H. Oughton

CAENORHABIDITUS ELEGANS AS A MODEL FOR MIXTOX STUDIES

Dag Anders Brede, NMBU

Multiple stressor scenarios occur in nature, but there are large knowledge gaps concerning long term effects on the lifespan and reproduction of individual species. One of the main objectives of CERAD is to characterize biological effects of mixtox exposures and elucidate the mechanisms that determine combined effects of toxic compounds. The soil nematode *Caenorhabditis elegans* is a recognized test organism in ecotoxicology. The short reproductive cycle and lifespan, combined with a fully sequenced genome, makes it an attractive animal model to study a variety of reproduction and hereditary effects of chronic exposures to environmental stressors. In CERAD, we have established high throughput procedures, combined with models for studying mixture toxicity. Below three major finding are highlighted:

Adult C. elegans ingesting Co-NP., Photo D.A. Brede

Characterization of the toxicity and fate of Co-nanoparticles (NP) in live organism (*C. elegans*).

NPs are widely used in industry and in numerous household products and clothing, but little is known about how NPs behave in ecosystems. Using *C. elegans* we have seen that Co-NPs are readily ingested and accumulate without acute lethal effects. However, Co-NP aggregates that immobilized and killed *C. elegans* were formed. In follow-up studies, the accumulation of NPs in specific organs or tissues in *C. elegans* will be characterized using high resolution x-ray absorption tomography and synchrotron based x-ray nano-XRF mapping at the ID16A nanobeamline, ESRF, Grenoble. These highly sophisticated experiments will provide information on the 2D and 3D distribution of nanoparticles within the organisms.

Common effect of pH on the toxicity of uranium. An ongoing project in CERAD identified pH as a major factor determining the toxicity of uranium to Salmon parr (See report H.C. Teien). Using *C. elegans* we were able to confirm that toxicity of uranium decreases with pH above 7.3. Current investigations are focused on characterizing the effect of the pH on the speciation of the uranium, in order to identify which forms of uranium exert the toxic effect.

Mixtox effect of metals and gamma irradiation. This project aims to investigate a variety of biological effects, including transgenerational endpoints, in *C. elegans* induced by chronic gamma irradiation in combination with toxic metals (e.g.,Co, Cd and U). Exposure to cadmium and gamma, to which *C. elegans* is highly tolerant, revealed that combining the two stressors lowered the cadmium LD_{50} from 1.2 to 0.2 mg/L. Currently the effect on reproduction is being characterized to assess critical level exposures that affect the sustainability at the population level.

Participants: D.A. Brede, S. Cagno, O.C. Lind, H.C. Teien, S.M. Tvetene, D.H. Oughton, B. Salbu (NMBU).

MALE REPRODUCTIVE CAPACITY IN MICE IS IMPEDED FOLLOWING EXPOSURE TO CHRONIC LOW-DOSE GAMMA IRRADIATION, AND IS AGGRAVATED BY LOW AVAILABILITY OF SELENIUM

Ann-Karin Olsen, NIPH

There is little information of potential effects of radiation on reproduction following relevant exposure scenarios, including the potential interaction of such exposures with antioxidant levels such as selenium (Se). Investigation of combined effects of radiation and the antioxidant Se is particularly relevant due to declining Se levels of observed in the Norwegian population. Low Se levels represent potential health problems also in other parts of the world. Based on a RCN and CERAD funded project (See report B. Salbu), we designed a mouse experiment to study effects of both low dose rate gamma irradiation and Se deprivation separately or in combination. Male mice were continuously deprived of Se from before conception (by a Se-poor diet based on wheat grain grown in the field at NMBU). The young adult males were continuously exposed to low dose rate gamma irradiation (1.63 mGy/h) for 45 days, followed by a 45 day recovery period. The male mice were mated with unexposed females and reproductive parameters were measured such as fertility, time-to pregnancy, litter sizes and sex ratios. After sacrificing the mice, complementary parameters such as relative testis weights, testicular pathology, testicular sperm counts, testicular cell DNA damage levels as indicators of sperm integrity were measured. We observed that the male reproductive capacity was indeed hampered by the low dose rate gamma irradiation employed. Moreover, Se deprivation by itself led to sterility, whereas combined effects of radiation and

Se deprivation led to aggravated testis pathological changes and increased testicular DNA damage levels. Our findings suggest that exposure of mice to low dose rate chronic gamma irradiation, representing relevant humans exposures via the environment, have negative effects on male reproductive capacity, and low Se availability may aggravate such effects.

Participants: A. Graupner, J. Andersen, C. Instanes, H. Rasmussen, G. Brunborg, A.K. Olsen (NIPH), O.C. Lind, B. Salbu, D.H. Oughton A. Brandt-Kjeldsen, E. Govasmark (NMBU) H. Bjerke (NRPA).

Other Information: AnneGraupner is a PhD student partly financed by CERAD. Anicke Brandt-Kjeldsen completed her PhD in June 2013. The work has been co-funded by RCN.




RADIATION QUALITY EXPERIMENTS (AM-241 ALPHA AND CO-60 GAMMA) EXPERIMENTS WITH ZEBRAFISH

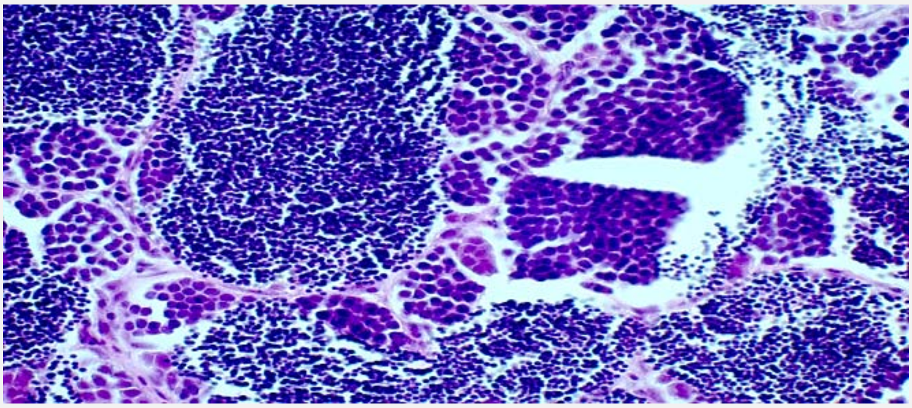
Jan Ludvig Lyche, VetBio, NMBU

The type or quality of radiation can influence the biological effect, with alpha irradiation having a greater potential for biological damage as compared to gamma of beta irradiation. However little is known about impacts on ecologically relevant effects. The aim of this study was to assess the impact of radiation quality on the biological response in zebrafish, by comparing the effect of alpha (^{241}Am) and gamma (^{60}Co) irradiation. Adult fish were exposed to five different doses (0.005, 0.01, 0.1, 1, 10) mGy/h of gamma irradiation for 26 days. Samples for analysis were collected at exposure day 6, 21 and 26. The results from the lower dose gamma irradiated samples will be compared with a similarly designed study with exposures of zebrafish to alpha irradiation (^{241}Am). Blood samples were collected for assessing group differences in micronuclei which is an indication for DNA damage. Whole zebrafish were collected for histology/morphology analyses.

Tissue samples (brain, liver, intestine, testis, muscle) were collected for assessing potential exposure induced changes in organ specific gene transcription. RNA has been isolated and selected samples will be analysed by RNA-seq,, with the majority analyzed by RT-qPCR. Analyses are in progress and results will be available during March/April.

Participation: The study is a collaboration between NMBU/Vetbio, NMBU/IS and IRSN (C. Adam-Guillermin), France and is supported by the EU STAR project.

Participants (NMBU/Vetbio): J.L. Lyche, V. Berg, S. Hurem, P. Alestrøm (NMBU/IS) H.C. Teien, O.C. Lind, D.A. Brede, T. Hertel-Aas, L. Sørlie Heier, D.H. Oughton, B. Salbu.



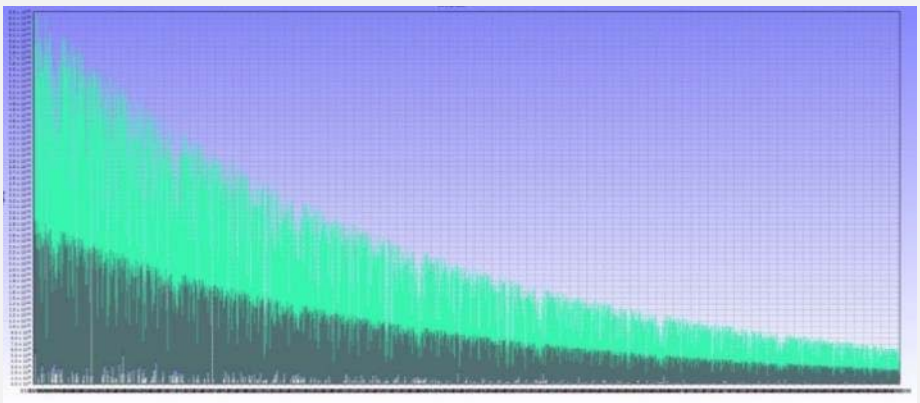
Hematoxylin/eosin stained testis tissue

MODELLING RADIOACTIVE PARTICLE DISTRIBUTION AND TRANSPORT AT CATCHMENT SCALE

Yan Lin, NIVA

NIVA has developed a river transport prototype model for radionuclides such as Cs-137. Trial runs indicate that the majority of the radioactivity will be retained by particles and be transported to streams through rainfall erosion. Due to the existence of a large deep lake in the catchment stream network, much of the radioactive particles will be stored due to sedimentation. Hydrologic conditions are important in controlling the erosion process, so there is a need to develop proper climate scenarios for the future. Simulations of Cs-137 concentration in suspended particles in the stream in a simulation of 100 years period show a steady decrease of Cs-137 in the stream suspended particles due to decay; with little daily variation discernable at this time scale. The temporal variation at a daily scale is largely controlled by the hydrology of the river.

Participants: Y. Lin, R.M. Couture, Ø. Kaste (NIVA).



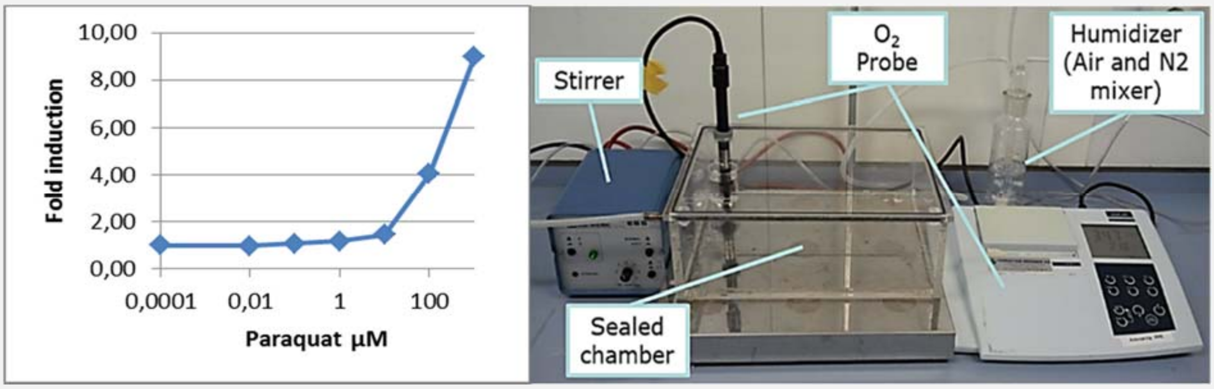
Cs-137 concentrations in suspended particles in a stream.

ESTABLISHMENT OF DOSE-RESPONSE RELATIONSHIPS FOR THE ROS FORMATION AND EFFECTS OF DIFFERENT INTENSITIES AND WAVELENGTHS OF UVA AND UVB ON A VARIETY OF SELECTED ORGANISMS (FISH HEPATOCYTES AND ALGAE)

Karina Petersen, NIVA

In order to set the ground for future effect studies of UV alone and in combination with metals and/or radionuclides, methods for detection of common effects of these stressors needs to be established. As these stressors are known to induce oxidative stress in organisms, two methods to detect oxidative stress were sought developed, one for detecting reactive oxygen species (ROS assay) and one for measuring depletion of the antioxidant glutathione (GST assay) in algae and primary fish hepatocytes. The ROS assay was successfully established in algae, and is under development in hepatocytes and Daphnia magna. The GST assay is working, but not optimal in hepatocytes. An exposure box (sealed chamber) with possibilities for controlling several parameters including oxygen level, temperature, and light has been developed, with modification to allow UV exposure. The methods and exposure equipment is expected to be included in the UV effect/response toolbox used later in the CERAD project.

Participants: K. Petersen, K.E. Tollefsen (NIVA), T. Christensen (NRPA) J. Martos Bernan (University of the Basque Country).



Left: Fold ROS production in algae exposed to paraquat for 5 hours, detected by the probe H_2DFFDA. Right: Sealed exposure chamber for controlling oxygen level, temperature, light and/or UV exposure.

RISK PERCEPTION AND WILLINGNES-TO-PAY: HEALTH DAMAE COSTS AND RISK PERCEPTION OF RADON, UV AND COMBINED EXPOSURE.

Ståle Naverud, HH-NMBU

The Damage Function Approach (DFA) for modelling emissions through exposure impacts and finally damage costs from nuclear accidents (and other radiation threats such as radon) as well as UV was outlined. Plans were developed for a project testing the approach for radon and UV exposure and associated cancer risk damage costs. The aim of the project is to apply DFA (to get input for Cost-Benefit Analyses) in order to: i) map and model the UV and radon indoor exposure of Norwegian households, ii) assess health risks (lung and skin cancer from radon and UV, respectively) from exposure –response functions and consider the contribution of exposure to overall health burden, and through surveys assess, iii) individuals´ perceived health risk, iv) their mitigating/averting behavior to reduce exposure; and v) their willingness-to-pay (WTP) to avoid the disutility of long term cancer risks. In 2013 information was collected in order to establish the knowledge base on indoor radon measurement in Norway, mitigation measures, associated lung cancer risk and exposure-response relationships, and WTP studies of risk reductions for fatal illnesses; and from this information to construct an internet panel survey of households in selected communities with moderate, high and very high radon concentrations. Data on averting and mitigating behavior with respect to cancer risks from both radon and UV exposure will also be collected.

The project is a collaboration between HH-NMBU, NRPA, NIPH, NMBU and NIVA; and is relevant also for RA1, RA3 and RA5.

ULTRAVIOLET RADIATION

Terje Christensen, NRPA

The UV RA group is composed of representatives from all participating institutions in CERAD. NRPA and in particular the Optical Laboratory and the team dealing with UV-network have been central in the formation of the RA. An important part in RA5 has been studies of UV effects on terrestrial plants. The CERAD plant group has long-term experience with research on effects of UV and other environmental factors such as climate, and the work will in 2014 be extended to include also ionizing radiation. At the outset, we have assumed that UV-radiation has positive as well as negative impact on health and environment. In 2013 RA5 has put a major emphasis on construction of exposure equipment and to monitor the output of the irradiation sources.

We have produced a limited amount of data on exposure of biological samples (see below), mainly in order to test the UV-sources and their effects as single stressors. Later co-exposures with ionizing radiation will be performed. Exposure values for UV-radiation from the sun on a country-wide scale have been estimated on the basis of measured values and modeling. Dosimetry-models will be further refined in the future.

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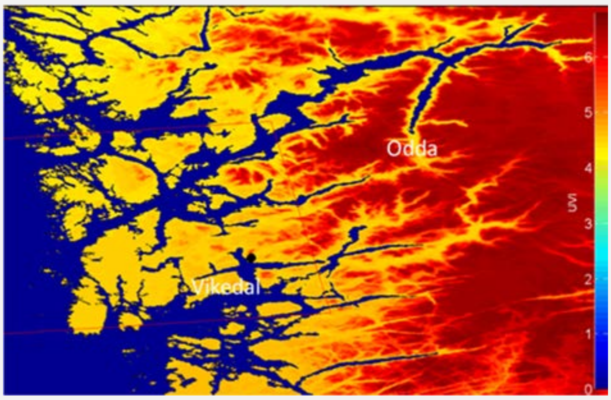
Temperature calibration of a double irradiation configuration constructed for irradiation of small samples like tissue cultures or zebrafish embryos with UVA-radiation. Photo T. Christensen, T. Aleksandersen, NRPA



UVI calculated for the Vikedal-Hardanger area on a clear day in May, with the snow level set at 500 m.o

TESTING PLANT SENSITIVITY TO RADIATION BY ANALYSIS OF DNA DAMAGE

Jorunn E. Olsen, NMBU

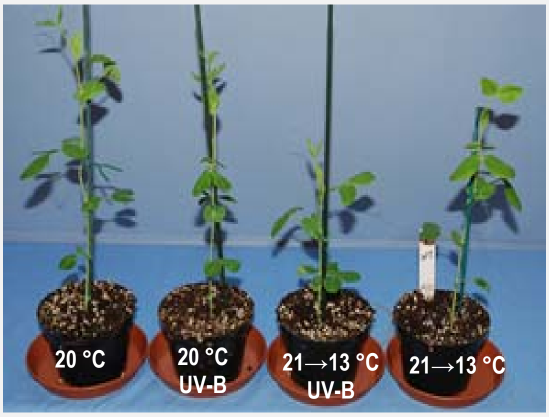
As is well known, UV and ionizing radiation (IR) may result in DNA damage in biological systems. Plants and lichens are among the groups of organisms which will be studied within CERAD. To be able to evaluate the sensitivity to UV and ionising radiation particularly in plant and lichen species, we aimed at establishing methodology for analysis of DNA damage in such species in the plant cell laboratory at NMBU. As a first test system, pea plants (*Pisum sativum*) have been used, since this is model organism in one of the CERAD plant group`s ongoing in kind projects aiming at understanding interactive effects of UV-B and temperature (Report A. Roro) successful establishment of immunological methodology (ELISA) for analysis of cyclobutane pyrimidine dimers (CPDs) and 6-4-photoproducts (6-4-PPs) in plants using specific antibodies has been obtained. In the pea test system, more and less UV-sensitive genotypes showed higher and lower CPD levels, respectively, whereas there were no significant differences in 6-4-PPs between UV-B exposed and control plants. Also, lower CPD levels were observed when UV-B at relatively high doses was provided together with a period of reduced temperature, compared to exposure to UV-B alone. This correlated with reduced visible UV-B-related damage. In cooperation with FHI, in April 2014 the COMET assay for DNA strand breaks will be adapted for plant materials. These methods for analysis of the different types of DNA damage will be an important tool in further CERAD work on effects of ionising radiation and UV in plants and lichens, but also in other organisms. In an ongoing CERAD project DNA damage analysis will be performed in zebra fish embryos exposed to UV in combination with other stressors. Also, in the work of a CERAD-granted post doc on IR and UV dosimetry in different organisms including plants, DNA damage analysis will be important.

Participants: J.E. Olsen, T. Melby, A.G. Roro, S. Torre, K.A. Solhaug, L. Nybakken, Y. Lee (NMBU), G. Brunborg (NIPH), T. Christensen(NRPA).

INTERACTIVE EFFECTS OF UV-B AND TEMPERATURE ON PLANT MORPHOLOGY – UV-B SIGNALING AND PROTECTION

Amsalu G. Roro, NMBU

Rather than solely being a damaging agent in plants, ambient UV-B radiation is also an important regulatory factor. Although information about UV-B signaling in plants is limited, a UV-B receptor was recently characterized in *Arabidopsis thaliana* and shown to promote synthesis of UV-protecting flavonoids through action of the HY5 transcription factor. Also, information about interactive effects of UV-B and other environmental factors is scarce. In studies aiming at investigating interactive effects of UV-B and temperature as well as extending knowledge of UV-B signaling to other plants, pea (*Pisum sativum*) was used as model system. Consistent with responses in a range of species, UV-B reduced plant height, particularly when combined with decreased temperature (Fig. 1). Mutation in a pea HY5 ortolog (LONG1) rendered the plants more sensitive to UV-B. Also, mutation in a protein down-regulating LONG1, resulted in higher UV-B tolerance, supporting the importance of LONG1 in UV-B signaling. Under high UV-B levels, these mutants showed higher and lower levels, respectively, of DNA-damage (CPDs). This correlated with lower and higher contents of specific flavonoids. In all genotypes investigated, pea plants appeared less susceptible to UV-B-related damage under lowered temperature. Whereas there were no significant differences in flavonoid levels, the CPDs levels appeared lower under lower temperature. Field studies of pea and rose plants grown under UV-transmitting or blocking films at different altitudes in Ethiopia (1700 and 2800 m asl) confirmed reduced growth, but also showed delayed flowering in response to UV-B and temperature-modulation of the responses. These studies have demonstrated temperature-dependence of UV-B-responses and provided information about UV-B signaling in pea. Shifts in timing of reproduction may have significant economic and ecological consequences. Given that funding will be available for plant studies, these studies will provide basis for mechanistic studies of interactive effects of ionizing radiation, UV and temperature.



Effect of 6 h daily UV-B exposure in pea plants grown at 20 °C or in plants given a 6 h daily period of reduced temperature from 21-13 °C (20 °C average daily temperature).

Left and right: Control plants not exposed to UV-B.

Photo Amsalu G. Roro

Participants: S.F. Dukker[1], M.T. Terfa[1], T. Melby[1], M. Siira[1], S. Abrams[2], I. Zaharia[2], K.A. Solhaug[1], L. Nybakken[1], S. Torre[1], J. E. Olsen[1]

1) NMBU
2)National Research Council Lab, Saskatoon, Canada

EFFECTS OF UV-B AND TEMPERATURE ON PHENOLOGY IN TREES

Christian Bianchi Strømme, NMBU

To survive the winter, trees of the boreal and temperate zones must cease their growth and attain dormancy and cold hardiness in time before the winter. It is well known that tree species of a wide distribution include a range of latitudinal and altitudinal ecotypes which are adapted to the local climatic conditions at their site of origin. Photoperiod and the ratio of red-far red light are primary signals in this respect and temperature modulation of the responses has been demonstrated. However, information about modulating effects of other environmental factors such as UV-B and other abiotic stressors is scarce although e.g. UV levels vary with e.g. time of the year, latitude and altitude. Aiming at shedding light on effects of UV-temperature interactions on phenology in tree species, a field study of young aspen plants (*Populus tremula*) was undertaken at the University of Eastern Finland (Joensuu). Increased UV-B, corresponding to 30 % decrease in ozone layer, was provided by UV-B fluorescent tubes, and 2°C increase in temperature was obtained by using heating lamps (Fig. 1). Accelerated winter bud formation in response to UV-B was observed in male clones, but 2°C temperature increase counteracted this to a certain extent. Both increased UV-B and temperature in the growth season resulted in subsequent earlier spring bud burst. Effects of UV on phenology might affect the growth potential and survival of trees particularly since early bud burst makes plants more susceptible to damage from spring frost. Given that funding will be available for plant studies, the present results provide basis for investigating interactive effects of ionizing radiation, UV and temperature on climatic adaptation in ecologically and economically important trees.

Participants: C.B. Strømme, J.E. Olsen, L. Nybakken (NMBU), R. Julkunen-Tiitto, U. Krishna[2], A. Lavola[3], (Univ. of Eastern Finland).

Field study at University of Eastern Finland, (Joensuu) for investigation of effects on phenology of increased UV-B and temperature provided by UV-B fluorescent tubes and heating lamps.

Photo Line Nybakken

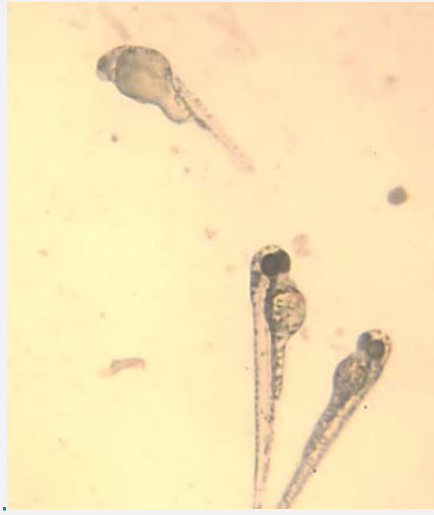
MULTIPLE STRESSOR EFFECTS ON ZEBRAFISH EMBRYOS

Terje Christensen, NRPA

Embryos of fish with pelagic eggs may be exposed to high doses of natural UV-radiation. Short waved UV, UVB as well as UVA may penetrate several meters down into the water column. The penetration depth differs depending on the contents of particles, dissolved matter or pollutants. Pollutants may also interact photochemically with UV- and visible radiation.

The aim of this study was to establish the dose-effect relationship of phenotypic changes caused by UV in order to plan further multistressor studies including ionising radiation. A modification of the antioxidant defence was studied by adding a methacrylate that is known to decrease the amount of glutathione in organisms.

The zebrafish embryo test was applied to score toxic effects of UVA and UVB. Embryos were treated in the period including mid-blastula stage, i.e. until 5 hours post fertilization. It was concluded that UVB had a much stronger effect on the survival and morphology of the exposed embryos than UVA. Hydroxyethylmethacrylate (HEMA) increased the UVB-induced effects on the embryos significantly. This finding may indicate that synergistic effects may be induced if UV-radiation and chemical pollutants interact in the environment.



Newly hatched zebrafish embryos at 78 h post fertilization treated with 0.1 J/m^2 broadband UVB and 1 mM HEMA in the mid-blastula stage. A malformed embryo can be seen at the top.

Photo T. Christensen, T. Aleksandersen, NRPA

Participants: T. Christensen, NRPA, J.L. Lyche, NMBU, E. Bruzell, NIOM (Nordic Institute of Dental Materials), P. Aleström, NMBU, T. Aleksandersen, NRPA.

NATIONAL AND INTERNATIONAL COLLABORATION

International collaboration in CERAD includes the international network, participation within EU projects and platforms, and collaboration and representation in international bodies such as IAEA, NATO SfP, ICRP and IUR.

The CERAD international network includes highly merited experts in specific fields, with whom NMBU and NRPA have established collaboration. This includes world leading experts from: Glenn Seaborg Institute, Lawrence Livermore National Laboratory (LLNL), USA; McMaster Univ., Canada; Ukrainian Institute of Agriculture Radiology (UIAR), Ukraine; Univ. of Antwerp and Centre d'Etude de l'Energie Nucléaire (SCK-CEN), Belgium; Institut de Radioprotection et de Sûreté Nucléaire (IRSN) and Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France; Univ. of Stockholm and Chalmers University of Technology, Sweden; Czech Technical University (CTU), Tjekkia; University of Helsinki (UH), Finand; National Nuclear Laboratory Ltd (NNL), University of Leeds (UL), Natural Environment Research Council (NERC-CEH) and Loughborough University (LU), UK; Gottfried Wilhelm Leibniz University Hannover, Germany; Centro de Investigaciones Energetical, MedioAmbientales y Tecnologicas (CIEMAT), Spain; ANL and Curtin Univ., Australia; the leader of EU COST Action UV-B program/University College Cork, Ireland. Other important network initiated through CERAD include collaboration with Woods Hole Oceanographic Institute on measurement of radionuclides in marine samples off Fukushima.

CERAD features prominently in Europe with connections to both the STAR alliance and the European Radioecology Alliance that have been established between the radiation protection organisations in Europe to pool knowledge and research efforts and train new experts in the field: Indeed, NMBU now runs the only European MSc in radioecology to facilitate this aim. CERAD members also collaborate on both the Open Project for the European Radiation Research Area (OPERRA) and the COordination and iMplementation of a pan-European instrumenT for radioecology (COMET).

CERAD works together with the IUR in the development of an Ecosystem Based Approach in radioecological assessment where the goal is to assimilate necessary information and experience to construct a practical method for ecological risk assessment of environmental radioactivity for ecosystems.

CERAD has been involved in UNSCEAR, where development of the ERICA tool by incorporating kinetic modelling has allowed for a more dynamic appraisal of the effects from the Fukushima-Daiichi nuclear power plant accident. The CERAD MG is represented on two ICRP committees, and the research director chairs the task group on ethics. 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. In addition, NMBU has been involved in NATO Science for Peace and Security programs for many years, NRPA has been elected president of the European orgasnisation against skin cancer (EUROSKIN) and CERAD is currently involved with project planning related to Central Asia. CERAD members have also participated in six ICRP co-expertise dialogues in Fukushima. Finally a number of members are involved in IAEA activities, including, revision of technical safety guides and co-ordinating work on the societal consequences of Fukushima for the IAEA comprehensive report.

Access to Experimental Facilities 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 these scientific outputs, CERAD CoE have the possibility to perform cutting edge research due to access to unique experimental facilities and tools, both within CERAD and partner institutions and also internationally. Below the experimental facilities and tools are listed in short.

The NMBU low Dose Gamma Radiation Exposure Facility (FIGARO)

The gamma irradiation source at CERAD/NMBU 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 facility was opened in 2003, and upgraded in 2012. The facility has been used for *in vivo* irradiation of fish, earthworms, plants, rodents (GMO mice), and cell cultures, for up to three month exposure times. The facility is utilized for a series of chronic exposure experiments (including combined gamma/alpha and multiple stressor studies) on various organisms.

Associate professor Ole Christian Lind at the Co-60 gamma source

Photo Brit Salbu

UV-A and UV-B Exposure

UV-A and UV-B are examined separately and in combination at the NRPA UV lab, NMBU/NVH and in the phytotron at NMBU/UMB. UV-A/UV-B sources will also be installed in the NMBU gamma facility to explore effects of both gamma and UV radiation. 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.

Radionuclide and Element Determination

At NMBU/UMB and NRPA instrumentations and methods for determination of both gamma- beta- and alpha emitting radionuclides are available. NMBU/UMB also has two Agilent 8800 Triple Quadrupole ICP-MS (ICP-QQQ-MS) for determination of long-lived radionuclides and a large range of elements, including isotope ratios. Cooperation with Australian National University gives access to Accelerator Mass Spectrometry for determination of low level elements and long-lived radionuclides and isotope ratios.

Speciation and Particle Characterization Techniques

In situ fractionation systems: hollow fibres, FFF-ICP-MS. SEM/TEM, TOF-SIMS, Synchrotron radiation based X-ray nano-/microscopic techniques (PETRA/Germany, ESRF/France, Stanford/USA): 3D element distribution: tomography, structure: µ-XRF, µ-XRD/nano-XRD, oxidation states: µ-XANES/nano-XANES i.e. methods developed by NMBU and Univ. Antwerp. The Imaging Centre Campus Ås aiming at a state-of-the-art status within microscopy (SEM/TEM, confocal laser SEM, light microscopy, live cell imaging and spectroscopy (x-ray, RAMAN micro imaging) etc. was established in 2012, in which CERAD should act as a future key node (stereo microscope with micromanipulation, micro-XRF, micro-XRD).

Ecotoxicology – Biomarkers and Biological Response

CERAD has a series of advanced biomarkers to identify the induction of biological responses, DNA damage and DNA repair incl. germ cell mutagenesis and transgenerational effects, bystander effects and genomic instability, biomarkers and advanced toxicogenomics (genomics, proteomics, metabolomics, transcriptomics and epigenomics) to uncover novel and interrelated effects. Expertise is provided by a combination of national partners and CERADs international network.

NIVA has a well-equipped ecotoxicological laboratory with availability of a suite of marine and freshwater plants, algae and crustaceans. This lab serves the need to perform regulatory and research studies using a combination advanced biomarker, toxicogenomic and effect endpoints. The lab is accredited to GLP (Good Laboratory Practice) and may accommodate regulatory testing according to international standardization criteria when required.

Available Test Organisms

Aquatic organisms: Zebrafish, salmonids and a suite of crustaceans, algae and plants to perform multigenerational studies.

Plants: e.g. *Arabidopsis thaliana*, Norway spruce/pine.

Terrestrial: Earthworm (*E. fetida*), *C. elegans*. Mouse lines relevant as experimental models for effects of radiation on humans, with deficiencies in DNA repair pathways and/or carrying reporter genes for mutation assessments are available at NIPH.

Most of the test organisms are included in the ICRP reference animals and plants list, and, thus, relevant to radiation research.

Fish Experimental Facilities - Transfer and Effects Experiments on Fish - both Freshwater and Marine Fish Species.

At NMBU, one room at the Fish laboratory is specifically designed for using radionuclides in experiments with aquatic organisms including fish. The facility includes a temperature controlled room with logging system for water variables; pH, temperature and oxygen. The facility are so far limited to batch/flow through experiments, but with large flexibility to use different fish species, life stages and different types of freshwaters (both naturally and synthetic). Facilities to do experiments on different life stages of fish are available, e.q., the early life stages that includes the period from fertilisation of egg until hatching and swim up stage, start feeding, juvenile and adult fish. In addition, canulated fish could be used to follow uptake from water into blood over time *in vivo* in 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 use of advanced analytical techniques will allow different controlled test to obtain information on the bioavailability, uptake and toxic effects of different radionuclides and evaluate the sensitivity of different fish species, the sensitivity of different life sages and sensitivity.

ZEBRAFISH PLATFORM – TRANSFER AND EFFECT STUDIES ON ZEBRAFISH

The Norwegian Zebrafish Platform (http://zebrafish.no) was established at NMBU/NVH in October 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 with focused on microgravity effects on biological functions. More recently plans are extend to include cosmic radiation effects are discussed. The Zebrafish Platform will organize the European Zebrafish Meeting 2015 with 800 participants (www.zebrafish2015.org).

MOUSE PLATFORM –TRANSFER AND EFFECT STUDIES ON MICE

The Division of Environmental Medicine at NIPH comprises an animal facility which is extensively used by The Department of Chemicals and Radiation (MIKS, partner in CERAD) for in vivo investigations of responses to chemicals and radiation in mice and other rodents for many years. NIPH thus exhibit the expertise to conduct comprehensive rodent experiments. The NMBU Co-60 gamma radiation source was established in 2003, and upgraded in 2012 (FIGARO). NIPH and NMBU made a coordinated effort to get permits/approvals and establish the necessary infrastructure (both physical and organisational) to work with rodents, including gene-modified rodents, in FIGARO. The conjunction of the animal facility at NIPH with the low dose gamma radiation facility FIGARO enables studies of biological effects of low dose rate/low doses of gamma radiation, alone, or in combination with other stressors. This platform allows research within one of the main goals for assessment of the biological effects of environmental radiation in CERAD. CERAD has bred mice in the NIPH-facility, transported them to FIGARO for exposure, after which mice have been terminated. Biological material have been prepared for endpoint analyses at FIGARO, or the mice have returned to NIPH for endpoint analyses. The basic infrastructure including lab benches, refrigerators, freezers, centrifuges etc are available at FIGARO.

Looking in on Mice exposed to gamma radiation. Photo: Signe Dahl

Greenhouses/Plant uptake and effect experiments (phytotron)

At the Centre for Plant Research in Controlled Climate (SKP) at NMBU, greenhouse compartments and growth chambers are available on a rental basis. This enables plant experiments under controlled conditions. Specific CERAD-funded prototype climate and growth chamber with UV and visible/infrared sources is under construction, to be used for single and multiple stressor experiments at the gamma facility.

Transfer and effect studies on earthworms

NMBU has facilities to study transfer and effects of both radionuclides and metals on earthworms. These include earthworm farms for the culture and maturation of earthworms to give homogeneous populations for uptake studies under controlled conditions. Transfer studies are often combined with effect studies (growth, maturation, reproduction, mortality and other sub-lethal endpoints). These include studies at the gamma source which allow combination of internal and external exposure, as well as sampling and dissection for a whole range of targeted immunohistochemical and histology studies in specific organs.

Models

Advanced air/marine transport models and real time/historic/future prognostic meteorological data are available at MET and NRPA.

Ecosystem transport models (NIVA, NRPA), advanced models on dosimetry (NRPA), models for impact and risk assessment including the ERICA assessment tool (NRPA, NMBU) and contemporary economic models (NMBU) are available. All models will be further developed as process understanding and parameterizations improve and more site specific data become available. Mechanistic models related to high and low LET radiation will be combined with UV, to evaluate biological radiation effects for organisms (NRPA).

To evaluate biological responses to multiple stressors, species sensitivity tools and population dynamics/DEBTOX will be applied (NIVA, NMBU).

NRPA in cooperation with the Norwegian Environment Agency/NILU is responsible for nine monitoring stations in Norway. Monitoring data is available on-line, real time. Based on almost 20 years of such monitoring data and a widely used radiative transfer model, NRPA in cooperation with met.no are 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 used as input variables in the model.

FIELD STUDIES AND EXPEDITIONS

A fundamental aspect of CERAD is that the research is based on a combination of model experiments, mechanistic studies and laboratory and field studies. Results will be compared and, where possible, evaluated by field investigations using representative field sites:

1) ACCIDENTAL RELEASE:

- The Chernobyl 30 km zone: for a range of released radionuclides, including U fuel particles containing fission products and transuranics (Pu), varying with respect to particle characteristics and weathering rates,
- Mayak PA area in Chelyabinsk, Ural, Russia, a site contaminated by several sources back from 1950ies.
- Kara Sea expedition 2012: marine samples.
- Fukushima marine samples: collected by Woods Hole, USA.

2) NORM SITES:

- The Fen and the Hadeland alum shale areas, with elevated levels of Th, U and other stressors (As, Cd, etc). Additional contaminated sites of interests can also be included.
- Komi, Russia: Contamination from Ra production in the 1950ies.
- Uzbekistan where local U rich fertilizer is used and studies on NORM transfer into food.

Every year there are a number of expeditions and fieldwork performed. Just for 2013 there were fieldwork done in several countries (Russia, Belarus, Uzbekistan, Norway) and more are planned for 2014.

Collaborative agreement with Institute of Nuclear Physics, Tashkent, Uzbekistan, November 2013. From left: Professor Lindis Skipperud, director Omar Salibekov, professor Brit Salbu and senior scientist Alexander Kist

Photo Hans Christian Teien

Tårnbygningen, NMBU, Photo Signe Dahl

CERAD Education Program

An essential ingredient in CERAD is researcher training and education (MSc, PhD) to provide an internationally attractive research environment, and to produce candidates that are internationally competitive. The EU supported MSc in Radioecology is unique in Europe. Joint MSc in Radioecology has been initiated with the University Paul Cezanne/Aix-Marseille, France, and with the Moscow State University, forming a useful recruitment base for PhD education. All courses are given in English and some courses are run intensively to make access possible for students from all over Europe.

Already in 2000, the OECD/Nuclear Energy Agency's report: "Nuclear Education and Training: Cause for Concern?" demonstrated that many nations probably were training too few scientists to meet the needs of their current and future nuclear industries. Additional studies undertaken by different European projects (EURAC, ENEN-II, FUTURA) and international organizations (IUR) confirmed the OECD/NEA findings; decreasing student interest, decreasing course numbers, ageing faculty members and ageing facilities. Consequently, the European educational skill base has become fragmented to a point where universities in most countries lack sufficient staff and equipment to provide education in all, but a few, nuclear areas. 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, environmental modelling, radiation protection including radiobiology and dosimetry.

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 institutions from different countries in Europe and in North America. Initiatives have been taken to establish Joint MSc degree between universities in Europe.

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, where students can take all necessary courses if needed, and obtain permits to work with open ionizing sources (passport). But, as for any EU MSc, students are free to obtain credits by taking ECTS accredited courses at other institutions and at collaborating universities (e.g. University Aix-Marseille, Moscow State University).

Within CERAD, the focuses on the MSc programs are towards radioecology and radiochemistry. The courses are implemented in large European projects (STAR, COMET, CINCH-II) 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 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.

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

THE RADIOECOLOGY RESEARCH SCHOOL

The Radioecology Research School is an international networking forum hosted by CERAD/NMBU 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 professional training as well. The research school is open to PhD students worldwide. Benefits for research school students include priority to join CERAD and associated project organized student and training courses; and opportunities for PhD exchange visits and work placements.

The PhD course in Environmental Radiobiology (MINA 410) is a 5 ECTS course, and is part of the international Radioecology Research School and aims to give students an overview of the fundamental principles of radiobiology, but within the context of effects on non-human biota. The course covers both the history and the state-of-the-art of our knowledge on the biological effects of radiation on humans, including how recent studies are challenging established paradigms, but concentrated specifically on those issues and applications of most relevance for other organisms. This included effects and endpoints significant for non-human organisms, ways in which radiobiology methods and biomarkers are being applied in ecological research, factors influencing radiosensitivity in different organisms, and ecological risk assessment based on the ERICA tool. Case studies included ecological research in Chernobyl and Fukushima, and laboratory work focuses on biomarker analysis in exposed model organisms.

Department Engineer Lene Valle preparing samples for ICP-MS analysis

Photo Signe Dahl

CERAD/UMB COURSES AVAILABLE

Course code	Title	ECTS	Course syllabus in short	Course responsible
KJM350	Radiation and Radiochemistry	10	http://www.umb.no/search/courses/kjm350	Lindis Skipperud
KJM352	Radiation and Radiation Protection	5	http://www.umb.no/search/courses/kjm352	Lindis Skipperud
KJM351	Experimental Radioecology	10	http://www.umb.no/search/courses/kjm351	Ole Christian Lind
KJM353	Radioecology	5	http://www.umb.no/search/courses/kjm353	Ole Christian Lind
MINA310	Project Management and Research Methods	10	http://www.umb.no/search/courses/mina310	Lindis Skipperud
KJM360	Assessing Risk to Man and Environment	10	http://www.umb.no/search/courses/kjm360	Deborah H. Oughton /Per Strand
MIN410	Environmental Radiobiology	5	http://www.umb.no/search/courses/mina410	Deborah H. Oughton
FMI309	Environmental Pollutants and Ecotoxicology	10	http://www.umb.no/search/courses/fmi309	Hans Christian Teien
FMI310	Environmental Pollutants and Ecotoxicology	15	http://www.umb.no/search/courses/fmi310	Hans Christian Teien

Sampling of alun shale containing rocks. Photo Brit Salbu

Photo Signe Dahl

CERAD Economy 2013

(NOK 1.000)	Accounts 2013	%	Budget 2013	Budget 2014
Revenues				
RCN funding	12 000	32.5 %	12 000	16 500
UMB (NMBU) funding	1 250	3.4 %	2 778	2 824
NRPA	1 000	2.7 %	1 000	1 000
Other RCN projects	2 785	7.5 %	2 786	2 302
Partners (in kind)	19 941	53.9 %	18 411	20 723
Total funding	36 976		36 975	43 349
Expenditures				
Salaries	29 625	80.1 %	24 031	29 000
FoU	0	0.0 %	300	256
Equipment	2 556	6.9 %	2 300	2 000
Seminars etc.	426	1.2 %		
Other operational costs	4 369	11.8 %	10 344	12 093
Total expenditures	36 976		36 975	43 349
Specification of partners in kind contributions:				
UMB (NMBU)	11 649	58.4 %	9 272	9 272
NRPA	3 624	18.2 %	3 624	3 624
FHI	1 070	5.4 %	1 070	1 070
NIVA	1 500	7.5 %	1 500	1 500
NVH	745	3.7 %	1 487	1 487
Met	1 353	6.8 %	1 500	1 500
Total	19 941		18 453	18 453

CERAD Funding and Expenditures 2013

The accounts reflect a high level of activity in CERAD.

Project financing constitutes of two major funding sources; the RCN and *In kind* contributions from all partner institutions. In addition, there are several ongoing externally funded projects in which NMBU and CERAD partners are involved.

The turnover for CERAD in its first operational year is NOK 36.9 million.

The Research Council of Norway (RCN) and other projects from RCN are a substantial sources of financing for CERAD. RCN direct contribution, core funding, in 2013 is NOK 12.0 million, 32.5 % of total. Other cash contributors are the NMBU and the NRPA. Contributions from partner institutions, mainly personnel, amount to NOK 19.9 million of total (53.9 %).

On the expenditure side, salaries amount to NOK 29.6 million, 80.1 % of total. The sum includes overhead covering indirect costs. Equipment amounts to NOK 2.5 million, seminars etc. 0.4 million and other running expenses NOK 4.4 million. The equipment investment was relatively high the first operational year , but will fall in a few years time.

The funding and expenditure are in accordance with the CERAD budget. CERADs financial situation provides a solid foundation for stable and flexible project management and long term research the years ahead.

NMBU, springtime

Photo Signe Dahl

NMBU Springtime, Photo Signe Dahl

Appendix A Research and Communication Output 2013

Scientific results	Number
Scientific Articles	19
Books/Monograph	1
Technical/Scientific Reports	5
Presentations internationally	28
Presentations nationally	2
Popular science presentations	5

CERAD Communications	Number
Popular science presentations	1
Oral presentations internationally	3
Oral presentations nationally	8
CERAD Seminars	2
Workshops by CERAD	3

Scientific Publications, Books, Reports, Conference Presentations

Scientific Articles in International Journals

Bernhard, G.; Dahlback, A.; Fioletov, V.; Heikkila, A.; Johnsen, B.; Koskela, T.; Lakkala, K.; Svendby, T., High levels of ultraviolet radiation observed by ground-based instruments below the 2011 Arctic ozone hole. Atmos Chem Phys 2013, 13, (21), 10573-10590.

Bernhard, G.; Heikkila, A.; Johnsen, B.; Koskela, T.; Lakkala, K.; Manney, G.; Müller, R.; Svendby, T., Ozone and UV radiation. Bull. Amer. Meteor. Soc. 2013, 94, (8), 114-116.

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Heier, L. S.; Teien, H. C.; Oughton, D. H.; Tollefsen, K. E.; Olsvik, P. A.; Rosseland, B. O.; Lind, O. C.; Farmen, E.; Skipperud, L.; Salbu, B., Sublethal effects in Atlantic salmon (*Salmo salar*) exposed to mixtures of copper, aluminium and gamma radiation. Journal of Environmental Radioactivity 2013, 121, 33-42.

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Lind, O. C.; Stegnar, P.; Tolongutov, B.; Rosseland, B. O.; Stromman, G.; Uralbekov, B.; Usubalieva, A.; Solomatina, A.; Gwynn, J. P.; Lespukh, E.; Salbu, B., Environmental impact assessment of radionuclide and metal contamination at the former U site at Kadji Sai, Kyrgyzstan. Journal of Environmental Radioactivity 2013, 123, 37-49.

Oughton, D. H.; Stromman, G.; Salbu, B., Ecological risk assessment of Central Asian mining sites: application of the ERICA assessment tool. Journal of Environmental Radioactivity 2013, 123, 90-98.

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Wendel, C. C.; Fifield, L. K.; Oughton, D. H.; Lind, O. C.; Skipperud, L.; Bartnicki, J.; Tims, S. G.; Hoibraten, S.; Salbu, B., Long-range tropospheric transport of uranium and plutonium weapons fallout from Semipalatinsk nuclear test site to Norway. Environment International 2013, 59, 92-102.

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Johnsen, B., Christensen, T., Nilsen, L.T., Hannevik, M., Ultrafiolett stråling, solskader og forebygging. Strålevern Rapport 2013:2. Østerås: Statens strålevern, 2013.

Liland, A., Strålevernet deltar i nyopprettet Senter for fremragende forskning, Strålevern Info 2013:6, Østerås, Statens Strålevern, 2013.

Heldal, H. E., Lind, B., Gwynn, J. P., Teien, H-C., Lind, O. C., Sidhu, R. S., Bakke, G. O., På jakt etter radioaktivt avfall i Karahavet. Havforskningsrapporten 2013.

Salbu, B., Brandt-Kjelsen, A., Valle, L., Skipperud, L., Govasmark, E., Screening undersøkelse: Spormetaller og radionuklider i økologisk dyrkede grønnsaker. UMB rapport, 2013, ISSN 0805 – 7214

Scientific Presentations Internationally

Anicke Brandt-Kjelsen *et al,* Selenium from feed to fork, 10th conference: trace & mineral elements in health & disease, Loen, Norway

Ann-Karin Olsen *et al,* Genotoxic and reproductive effects of chronic low dose-rate gamma- irradiation and reduced selenium status in repair-deficient male mice, 5th MELODI Workshop, Brussels, Belgium

Ann-Karin Olsen *et al,* Genotoxic and reproductive effects of chronic low dose-rate gammairradiation combined with selenium deficiency in dna repair-deficient male mice, 11th International Conference on Environmental Mutagens, Foz do Igaucu, Brazil

Anne Graupner *et al,* Low dose-rate gamma irradiation in combination with low selenium diet - genotoxic effects in blood, NSFT vintermøte, Beito, Norway

Brit Salbu, Speciation analysis of radionuclides in the environment, NKS workshop of Radio-analytical Chemistry, RISØ, Denmark

Brit Salbu and Ole Christian Lind, Challenges associated with radioactive particles in the environment, The 1st Russian-Nordic Symposium on Radiochemistry, Moscow, Russia

Brit Salbu and Ole Christian Lind, Linking Nano-Micrometer Sized Radioactive particle characteristics to Environmental behavior and biological responses, IAEA CRP Environmental Behaviour and Potential Biological Impact of Radioactive particles, 1st research coordination meeting, Brussels, Belgium

Deborah Helen Oughton, E&T in the Radioecology Alliance, 5th MELODI Workshop, Brussels, Belgium

Deborah Helen Oughton, Societal and Ethical Aspects of Radiation Risk Perception, Fukushima Medical University, Fukushima Radiation and Health Symposium, Japan

Deborah Helen Oughton, Challenges in Radiation Risk Communication, Fukushima Medical University, Fukushima Radiation and Health Symposium, Japan

Deborah Helen Oughton, Chernobyl and UK sheep farmers, ICRP dialogue meeting Iwaki City, Fukushima, Japan

Deborah Helen Oughton *et al,* A worm's eye view of transgenerational effects, 5th MELODI Workshop, Brussels, Belgium

Dukker Alten SAF *et al,* Effects of UV-B radiation on morphology and flavonoid content in pea plants. UV-B radiation: A specific regulator of plant growth and food quality in a changing climate, UV4growth COST action FA0906, 2nd annual network meeting, Mikulov, Czech Republic

Hans Christian Teien, Radioecology projects with relevance to Mayak, Joint Meeting for Russian and Norwegian Participants in Mayak, Related Cooperation Projects Chelyabinsk, Mayak, Russia

Brit Salbu, Overview of the former CRP "Radioactive particles in the Environment: Sources, particle characteristics and analytical techniques", IAEA CRP Environmental Behaviour and Potential Biological Impact of Radioactive particles, 1st research coordination meeting , Brussels, Belgium

Lene Sørlie Heier *et al,* Trace elements bioaccumulation and effects in indigenous brown trout (Salmo trutta) and caged brown trout eggs exposed to shooting range run off, SETAC Europe 23rd annual meeting, Glasgow, UK

Lindis Skipperud *et al,* Radionuclide and metal contamination in pit lakes in former U sites in Central Asia, The 1st Russian-Nordic Symposium on Radiochemistry, Moscow, Russia

Simone Cagno *et al,* LA-ICPMS Imaging and Nuclear Forensics: Pu Isotope Ratios in Sediments from Mayak PA, Russia, XXXVIII Colloquium Spectroscopicum Internationale (CSI), Tromsø, Norway

Simone Cagno *et al,* Combined Tomographic Techniques for the Characterization of TENORM particles, 1st International conference on Tomography of Materials and Structures, Ghent, Belgium

Simone Cagno *et al,* Uptake and distribution of uranium in Atlantic salmon gills following exposure experiments demonstrated by XRF tomography at PETRA III P06, 22nd International conference on X-ray Optics and Microanalysis (ICXOM), Hamburg, Germany

Strømme CB, *et al,* UV-B and temperature enhancement have contrasting effects of autumnal bud set in Populus tremula, UV4growth COST action FA0906, 2nd annual network meeting, Mikulov, Czech Republic

Suthaparan A, *et al,* Suppression of powdery mildew in greenhouse roses and cucumber by brief exposure to supplemental UV-B radiation. UV-B radiation: A specific regulator of plant growth and food quality in a changing climate, UV4growth COST action FA0906, 2nd annual network meeting, Mikulov, Czech Republic

You Song *et al,* Use of gene expression responses to evaluation combined effects of low dose gamma radiation and uranium on Atlantic salmon (Salmo salar), SETAC North America 34th Annual meeting, USA

Iosjpe M, *et al,* Evaluation of consequences of the potential accident with the modern operative nuclear submarine in the Iceland coastal waters. ERR2013 conference, Dublin, Ireland.

Ole Christian Lind, NORM particle characterization, Joint Norwegian-Uzbekistan meeting, Tashkent, Uzbekistan

Lindis Skipperud, Mobility of radionuclides using sequential extraction, , Joint Norwegian-Uzbekistan meeting, Tashkent, Uzbekistan

Hans Christian Teien, Environmental aspects: Uptake of NORM nuclides and metals in aquatic organisms, Joint Norwegian-Uzbekistan meeting, Tashkent, Uzbekistan

Brit Salbu, Uptake of NORM nuclides and metals in vegetables from alunshales, Joint Norwegian-Uzbekistan meeting, Tashkent, Uzbekistan

Scientific Presentations Nationally

Brit Salbu and Bjørn Olav Rosseland, Fisk full av miljøgifter og radioaktivitet eller sunnheten selv?, UMB vårkonferansen, Ås, Norway

Brit Salbu, Atomtrusler - hva kan vi lære av historien, PensjonistUniversitetet, Vitensenteret, UMB, Ås, Norway

Lene Sørlie Heier, Brit Salbu, Coctaileffekten – blir stoffer mer giftige i blanding? Byggavfallskonferansen, Oslo, Norway

Brit Salbu, Uptake of NORM nuclides and metals in vegetables from alum shales, Kriseutvalget Matgruppe, Mattilsynet, Oslo, Norway

Brit Salbu, Radioactive particles in the environment: Sources and potential impact, NTNU, Trondheim, Norway

CERAD Communications

Presenting CERAD Internationally – articles/popular science

Salbu, B., Oughton, D.H., Skipperud, L., Strand, P., CERAD COE, Center for Environmental Radioactivity, Public Service Europe Journal, 2013

Presenting CERAD Internationally – oral presentations

Brit Salbu, CERAD, a Norwegian Centre of Excellence for environmental Radioactivity, Russian-Norwegian Expert Group on Investigation of Radioactive Contamination in the Northern Areas, IAEA meeting, Brussels, Belgium

Per Strand, CERAD - a new Norwegian initiative, Meeting of the European Radioecology Alliance, Brussels, Belgium

Lindis Skipperud, CERAD CoE for Environmental Radioactivity, CINCH-II annual meeting, Warsaw, Polen

Presenting CERAD Nationally – oral presentations

Brit Salbu, CERAD, a Norwegian Centre of Excellence for environmental Radioactivity, Norwegian-Russian Meeting, NRPA, Norway

Brit Salbu, CERAD CoE for Environmental Radioactivity, NFR SFF Forum, Oslo, Norway

Brit Salbu, CERAD, nytt SFF ved UMB, Forskningsnemda ved UMB, Ås, Norway

Brit Salbu, Senter for radioaktivitet, mennesker og miljø, NMBU fellesstyre, Ås, Norway

Brit Salbu, Presentasjon av Centre for environmental Radioactivity – Senter for Radioaktivitet, mennesker og miljø, UMB Fellesstyre, Ås, Norway

Terje Christensen, CoE: CERAD - Centre for Environmental Radioactivity, Årsmøte og fagligmøte i Norsk Forening for Fotobiologi og Fotomedisin, St. Olavs hospital, Trondheim, Norway

Lindis Skipperud, Kvinnesuksess bak Senter for fremragende forskning CERAD, Kvinnedagen, UMB, Ås, Norway

Brit Salbu, CERAD Centre of Excellence - Presentasjon av Centre for Environmental Radioactivity - Senter for Radioaktivitet, mennesker og miljø, NINA, Trondheim, Norway

Appendix B CERAD Meetings/Workshops

WORKSHOPS FOR SUCCESSFUL INTEGRATION IN RISK ASSESSMENT

Astrid Liland (NRPA)

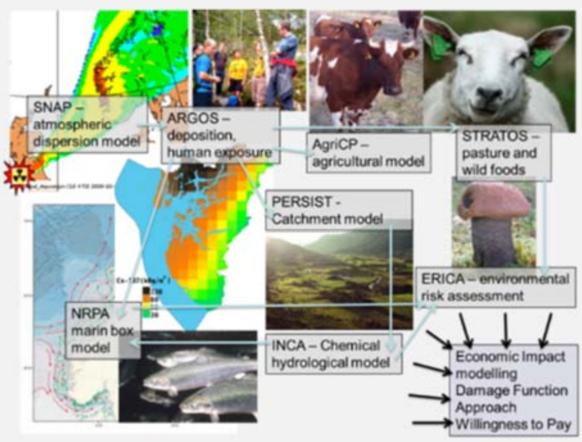
Given the diversity of experience and application fields of the various CERAD partners, it was considered that a series of workshops would be beneficial for the common scientific understanding and integration within the RA4 area of risk assessment. The first workshop in August gave basic lectures on the concept of radioactivity and dose, the concept of UV and dose, and the concept of risk assessment. It included visits to the NRPA facilities of relevance to CERAD, namely the UV monitoring platform, the Secondary Standard Dosimetry Laboratory, and the laboratories for measurements of environmental samples and people. The second workshop in September was arranged at NIVA and focused on how the different CERAD partners are doing their risk assessments for various contaminants and exposures, and for various environmental species and for humans. The workshops were open for all CERAD RAs and were attended by more than half of all CERAD researchers. The workshops contributed to a common understanding of the various elements in risk assessment and how UV, ionising radiation, chemicals and additives are treated in various risk assessment approaches and models. The framework and philosophy is similar for all stressors, but the models and tools applied by different CERAD institutions vary.

A third workshop was arranged in October to look at models and model uncertainties. The aims were to:

- see how different models could be used in a chain for an overall risk assessment
- identify the most important uncertainties in parameters and models

A specific scenario was chosen as a case study: explosion in the liquid waste tanks at Sellafield reprocessing plant. 1% of the inventory of Cs-137 is transported to Norway by air dispersion and deposited over Norwegian sea and land areas. The consequences for terrestrial, freshwater and marine ecosystems will be modelled as well as the impact on different economic sectors, producers and the public. The workshop revealed that the models can be used in a chain with compatible input and output data. The figure presents the various models we will link in the Sellafield case study on model/uncertainty.

Partners: NRPA, NIVA, MET, NMBU-HH, NMBU-IS, NIPH, NVH



CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

KICK-OFF MEETING FOR CENTRE FOR ENVIRONMENTAL RADIOACTIVITY, A NORWEGIAN CENTRE OF EXCELLENCE

OSCARSBORG FORTRESS, OSLO FJORD, APRIL 17TH-19TH 2013

VISION CERAD:

Centre for Environmental Radioactivitywill provide new scientific knowledge and tools for better protection of people and environment from harmful effects of radiation

PROGRAM

WEDNESDAY, APRIL 17TH

09:20	Ferry to Oscarsborg				
10:00 - 11:00	Guided tour at the fortress				
Check-in from 15:00					
11:30 – 13:00	Lunch				
Chair Brit Salbu					
13:00 – 13:10	Welcome, *Ruth Haug, UMB*				
13:10– 13:20	Opening address from the Research Council of Norway, *Liv Furuberg, RCN*				
13:20 – 13:40	Presentation of CERAD CoE, *Brit Salbu, CERAD*				
13:40 – 14:00	Strategic Research Agenda, *Deborah H. Oughton, CERAD*				
14:00 – 14:20	Education and training, *Lindis Skipperud, CERAD*				
14:20 – 14:30	Presentation of the international network, *Brit Salbu, CERAD*				
14:30 – 15:00	Coffee				
15:00 – 18:00	Parallel Sessions, breakout discussions:				
Discussion:	The Strategic Research Agenda and contribution from the international network				
Introduction: Deborah H. Oughton					
Room A	Room B	Room C	Room D	Room E	Room F
Cerad Board Meeting	RA1	RA2	RA3	RA4	RA5
19:00	Reception				
19:30	Dinner				

THURSDAY, APRIL 18TH

09:00 – 09:20	CERAD
09:00 – 09:20	Summary CERAD CoE, *Brit Salbu*
09:20 – 18:00	State-of –the-art and contribution from the international network
09:20 – 11:30	*Chair: Ruth Haug*
09:20 – 09:40	The Norwegian Threat Assessment, *Per Strand, CERAD*
09:40 – 10:00	Exposure associated with the Chernobyl accident, *Valery Kasparov, Ukraine*
10:00 – 10:20	Challenges associated with NORM*, Peter Stegnar, Slovenia*
10:20 – 10:40	Coffee
10:40 – 11:00	Particle characterization techniques, *Koen Janssens, Belgium*
11:00 – 11: 15	Linking radionuclide speciation to source and release scenarios, *Ole Christian Lind, CERAD*
11:15 – 11:30	Discussion
11:30 – 13:00	*Chair: L. Skipperud*
11:30 – 11:50	Ecosystem transfer, the relevance of radionuclide speciation, *Hans Chr. Teien, CERAD*
11:50 – 12:10	Challenges in dosimetry, *Justin Brown, CERAD*
12:10 – 12:30	Extrapolating from individuals to population, *Clare Bradshaw, Sweden*
12:30 – 13:00	Discussion
13:00 – 14:00	Lunch
14:00 – 16:00	*Chair: D.H. Oughton*
14:00 – 14:20	Environmental radiobiology incl. multiple stressors, *Carmel Mothersill, Canada*
14:20 – 14:40	RBE challenges *,Colin Seymour, Canada*
14:40 – 15:00	Discussion
15:00 – 15:20	Relevance of UV for man and the environment, *Janet Bornman, Australia*
15:20 – 15:40	Challenges in combining ionizing radiation and UV exposures, *Terje Christensen, CERAD*
15:40 – 16:00	Discussion
16:00 – 16:30	Coffee
16:30 – 18:00	*Chair: P. Strand*
16:30 – 16:50	Uncertainties in risk assessments, challenges identified in STAR, *Tom Hinton, France*
16:50 – 17:10	Societal aspects of radiation risk regulation, Case Fukushima, *Lavrans Skuterud, CERAD*
17:10 – 18:00	General Discussion
19:00	Reception
19:30	Kick-off dinner

Friday, April 19th

09:00 – 09:20 Integration and added value, *Marcel Jansen, Ireland*

09:20 – 11:30 Parallel Sessions, breakout discussions

Finalizing discussions on the Strategic Research Agenda, including performance indicators and the identification of the contribution from the international network

Room A	Room B	Room C	Room D	Room E	Room F
Relevance Advisory Committee	RA1	RA2	RA3	RA4	RA5

Checking out at the latest 11:00

11:30 – 12:30 Plenary feedback from the Breakout discussions *Chair: D.H. Oughton*

RA1-5 leaders

Closing: Brit Salbu

12:30 – 13:30 Lunch

NMBU, Photo Signe Dahl

CERAD SEMINAR PROGRAM LYSEBU 11. DESEMBER 2013

PROGRAM

09:00 Welcome v/*Brit Salbu*

09:15 - 10:15 Results from the first year, and further plans RA1

/Ole Christian Lind and Jerzy Bartnicki

Chair: Brit Salbu

Ole Christian Lind: Short introduction to RA1 projects.

Yan Lin: Integrated model for catchment run-off and estuary processes.

Jerzy Bartnicki: Atmospheric transport modelling within CERAD.

Magne Simonsen: Presentation of plans for PhD project "Marine Ecosystem Modeling".

Simone Cagno: Results from experiments with nano- and microanalytical techniques performed within RA1 and RA2.

Discussion

10:15 – 10:30 Coffee

10:30 – 11:30 Results from the first year, and further plans RA2

v/Justin Brown & Hans Christian Teien

Chair: Halvor Hektoen

Justin Brown: ERICA Tool Dynamic Module.

Justin Brown: Felt Tracer forsøk.

Håvard Thørring: TRAP - Tjøtta Reference Animals and Plants.

Hans-Christian Teien /Justin Brown: Komi Project.

Hans-Christian Teien /Justin Brown: Fukushima Marine Analysis.

Hans-Christian Teien: BLM, U laks forsøk.

Hans-Christian Teien: Videre arbeid og fokus.

Discussions

11:30 -12:30 Lunch

12:30 12:30 - 13:45 Results from the first year, and further plans RA3 *v/Peter Aleström and Ann Karin Olsen*

Chair: Lindis Skipperud

Jan Lyche: Studies using the zebrafish model: Results from single stressor exposures in 2013 towards multi-generational studies and multiple stressors in 2014/2015

Anne Graupner, Ann-Karin Olsen and Oddvar Myhre: Effects of chronic low dose exposure to ionising radiation, alone or in combination with low selenium levels, in exposed mice and their offspring

Dag A. Brede: Caenorhabiditis elegans model for mixtox studies in Cerad

Knut Erik Tollefsen: Development of Adverse Outcome Pathways (AOP) for single and multiple stressors

Peter Aleström and Ann Karin Olsen: Wrap up

Discussion

13:30 13:45 – 14:45 Results from the first year, and further plans RA5

v/Terje Christensen and Jorunn Olsen

Chair: Ole Christian Lind

Jorunn E. Olsen: Progress with climatically regulated chambers, UV-B plant experiments and assessment of DNA damage.

Terje Christensen: Konstruksjon av UV-kilder, effekter på sebrafisk og UV-eksponering i miljøet.

Discussions

14:45 -15:00 Coffee

15:00 – 17:15 Results from the first year, and further plans RA4

v/Knut Erik Tollefsen and Astrid Liland

Chair: Per Strand

Knut Erik Tollefsen: RA4 Risk/impact: Hensikt, grupper og status.

Ståle Navrud: Radiation - from physcical damages to damage costs.

Astrid Liland: Modeller og sensitivitetsanalyser

Knut Erik Tollefsen: Hazard and risk assessment of multiple stressors.

Astrid Liland/Knut Erik Tollefsen: Planer for 2014.

16:15 Discussions

17:00 Summing up, future plans and challenges *v/Brit Salbu*

18:00 Dinner and awards

CERAD CoE Workshop: Epigenetics

NRPA, Østerås, mandag 19.08 kl 10:00 – 18:30, kaffe fra kl 09:30

Program

10:00 - 10:15	”Velkommen” *Astrid Liland/ Brit Salbu*, CERAD/NRPA/UMB
10:15 - 10:45	“Novel epigenetic modifications in DNA and RNA” - *Arne Klungland*, Oslo Universitetssykehus
10:45 - 11:00	*Diskusjon*
11:00 - 11:30	”CERAD SRA/EU Comet and Figaro”, - *Deborah Oughton/Ole Christian Lind*, CERAD/UMB
11:30 - 12:30	*Lunch*
12:30 - 13:30	”Epigentics ved Radiumhospitalet”, - *Leonardo Meza-Zepedia og Ola Myklebost*, Oslo Universitetssykehus (OUS)
13:30 - 14:30	”FHI activities”, *Gunnar Brunborg*, CERAD/FHI
	“Paternal exposure and effects on miRNA and mRNA expression”, Nur Duale, FHI
	“Proposals for activities related to epigenetics under CERAD”, *Ann-Karin Olsen (Anka)*
14:30 - 15:00	*Coffee*
15:00 - 15:30	“Epigenetics in aquatic plants, invertebrates and vertebrate models”. *Knut Erik Tollefsen*, CERAD/NIVA
15:30 - 16:00	“Correlations between gene expression and epigenetic markers as a result of single and multiple stressor exposure induction, studied in zebrafish founder and offspring generations”,
Chair: Peter Aleström, CERAD/NVH	
16:00 - 16:30	"Epigenetics in human cells and zebrafish embryos",- *Philippe Collas*, UiO
16:30 -17:00	*Coffee*
17:00 - 17:30	“NVH Fish'n ChIPs in the lab”, *Leif Lindeman*, OUS
17:30 – 18:00	“Reproduction as endpoint”, *Ian Mayer*, NVH
18:00 - 18:30	Diskusjon – veien videre, *Brit Salbu*
19:00	Middag, Haga Golfklubb

CERAD Workshops on Radiation and Risk Assessment

Monday 26.08 at NRPA (Grini næringspark 13)

09:00 – 09:10	Welcome (NRPA)
09:10 – 09:40	The concept of radioactivity and dose (Astrid Liland)
09:40 –10:25	The concept of UV and dose (Terje Christensen)
10:25 – 10:40	Coffee
10:40 – 11:15	Omvisning på Strålevernets fasiliteter* (deler oss i 4 grupper)
11:15 – 12:00	The concept of risk assessment (Jan Erik Paulsen)
12:00 – 12:45	Lunch
12:45 – 13:30	Benefit-cost models and damage-cost approaches (Ståle Navrud/Olvar Bergland)
13:30 – 14:05	Omvisning på Strålevernets fasiliteter* (deler oss i 4 grupper)
14:05 –14:15	Coffee
14:15 – 15:00	Risk assessment at UMB (Deborah Oughton)
15:00 – 15:30	Discussion and summary (Astrid Liland and Knut Erik Tollefsen)

Monday 02.09 at NIVA (CIENS, Gaustadalléen 21)

08:30 – 09:00	Coffee and welcome (NIVA)
09:00 – 10:00	Risk assessment at NIPH (Christine Instanes og Anka Olsen)
10:00 – 11:00	Risk assessment at NIVA (Knut Erik Tollefsen)
11:00 – 11:15	Coffee
11:15 – 12:15	Risk assessment at NRPA (Astrid Liland)
12:15 – 13:00	Lunch
13:00 – 14:00	Risk assessment at NVH (Jan Erik Paulsen)
14:00 – 14:15	Coffee
14:15 – 15:15	Risk assessment at MET (Jerzy Bartnicki)
15:15 – 16:00	Discussion and summary (Knut Erik Tollefsen and Astrid Liland)
16:30	Dinner at CIENS

*Fasiliteter: UV lab og UV overvåkning; Tåkekammeret – her kan du se radioaktivitet;
Lab for måling av radioaktivitet i miljøprøver og mennesker; Sekundær standardlab. for dosimetri

WORKSHOP I MODELL/USIKKERHETSGRUPPA I CERAD

ONSDAG 30. - TORSDAG 31. OKTOBER 2013 KL. 09:30-15:30 PÅ STRÅLEVERNET

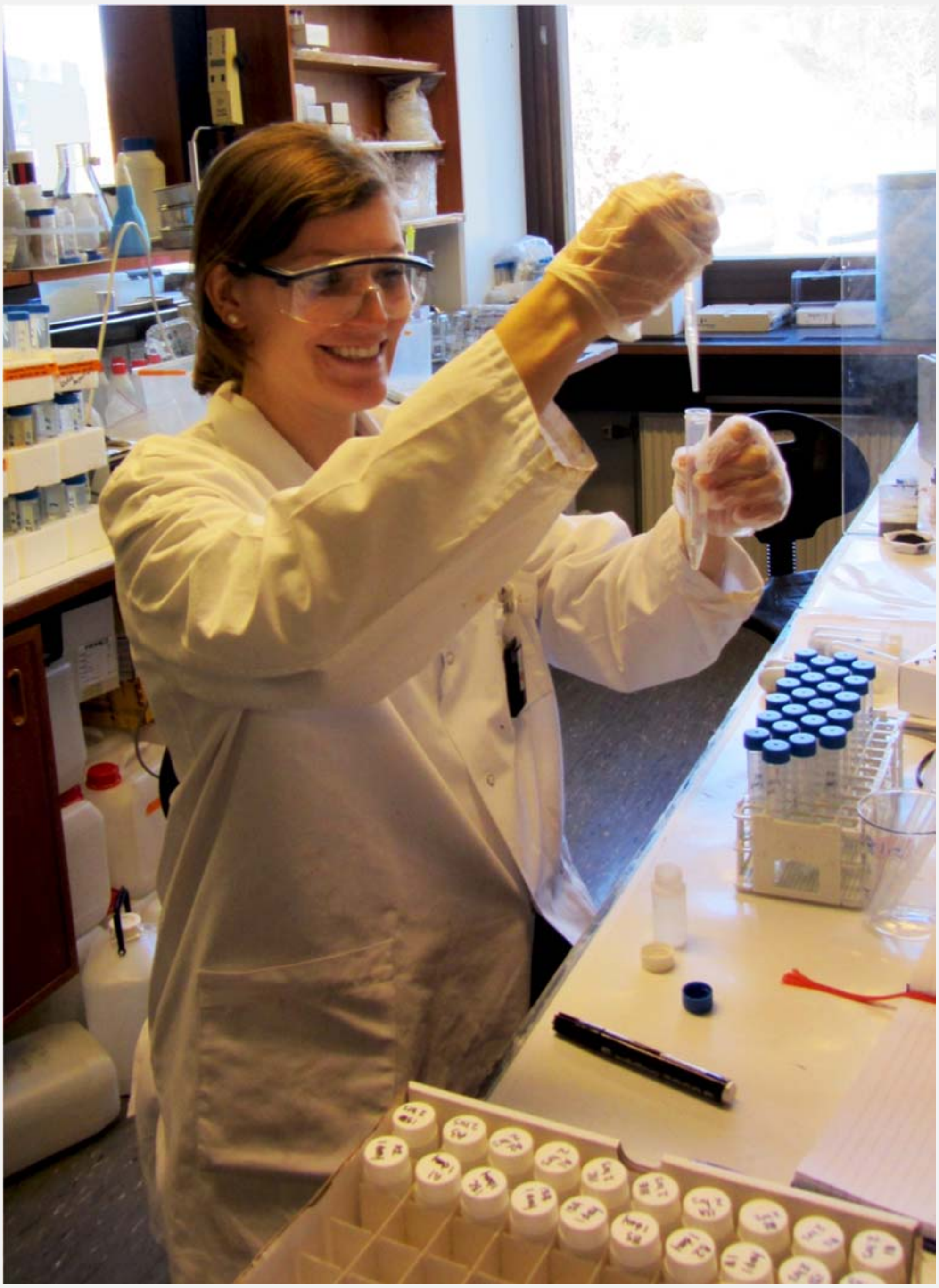
Agenda

ONSDAG 30. OKTOBER

09:30 - 10:00	Bakgrunn for og mål med arbeidet i gruppen for modeler/usikkerheter - (Astrid) Presentasjon av Western Norway-scenariet (Astrid/Ole Christian)
10:00 – 10:30	Atmospheric Dispersion Modelling and Data Exchange at MET (Heiko Klein)
Kaffe	
10:45 - 11:15	ARGOS og AgriCP - (Jan Erik Dyve)
11:15 - 11:40	Modeling environmental contaminants transport in watershed and uncertainty analysis (Yan Lin)
11:40 – 12:00	Uncertainty in extrapolation of effects from individuals to populations - (Jannicke Moe)
Lunsj	
12:45 – 13:15	The NRPA marine compartment model: complexity, sensitivity and uncertainties - (Mikhail Iospje)
13:15 – 13:45	Langsiktige terrestriske konsekvenser av radioaktivt nedfall i Norge - (Martin Ytre-Eide)
Kaffe	
14:00 – 14:45	Model uncertainty in economic models of uncertain events - (Olvar Bergland)
14:45 – 15:30	Diskusjon

TORSDAG 31. OKTOBER

09:30 – 10:15	ERICA Tool – concentrations, exposure and effects for biota from environmental radioactivity (Ali Hosseini)
Kaffe	
10:30 – 11:30	Hvordan kan vi bruke modellene i kjede?
Lunsj	
12:15 – 15:30	Hvordan kan vi kvantifisere usikkerhet på en ensartet måte? Hvordan kan vi beskrive den totale usikkerheten? Arbeid videre og input til Kunnskapsstatus på modellsiden



Researcher Tari Helmers preparing sequential extraction samples for ICP-MS analysis.

Photo Signe Dahl

Appendix C - CERAD Personnel 2013

Name and Title	Academic Grade	Employed
Brit Salbu, Professor	Dr. Philos	UMB
Lindis Skipperud, Førsteamanuensis	Dr. Scient	UMB
Ole Christian Lind, Førsteamanuensis	PhD	UMB
Deborah H. Oughton, Professor	PhD	UMB/CERAD
Bjørn Olav Rosseland, Professor	Dr. Philos	UMB
Eirik Romstad, Forsker	PhD	UMB
Ståle Navrud, Professor	Dr. Scient	UMB
Knut Einar Rosendal, Professor	PhD	UMB
Olvar Bergland, Professor	PhD	UMB
Jorun Olsen, Professor	Dr. Scient	UMB
Sissel Torre, Førsteamanuesis	Dr. Scient	UMB
Hans Christian Teien, Førsteamanuesis	Dr. Philos	UMB/CERAD
Lene Sørlie Heier, Førsteamanuesis	PhD	UMB/CERAD
Dag Anders Brede, Forsker	PhD	UMB/CERAD
Per Strand, Avdelingsdirektør	Dr. Scient	NRPA
Justin Brown, Senior forsker	PhD	NRPA
Astrid Liland, Seksjonssjef	Cand. Scient	NRPA
Håvard Thørring, Forsker	Cand. Scient	NRPA
Martin Ytre-Eide, Forsker	Cand Scient	NRPA
Ali Hosseini, Forsker	Cand. Scient	NRPA
Christina Hassfjell, Forsker	PhD	NRPA
Mikhail Iospe, Forsker	PhD	NRPA
Alicia Jaworska, Forsker	PhD	NRPA
Geir Rudolfsen, Forsker	PhD	NRPA
Terje Christensen, Forsker	Dr.Philos	NRPA/CERAD
Bjørn Johnsen, Forsker	Siv. Ing	NRPA
Lill Tove Nilsen, Seniorforsker	PhD	NRPA
Merete Hannevik, Seksjonssjef	Cand. Real	NRPA
Knut Asbjørn Solhaug, Professor	PhD	UMB
Line Nybakken, Førsteamanuensis	PhD	UMB

NAME AND TITLE	ACADEMIC GRADE	EMPLOYED
Øystein Hov, Direktør	Dr. Philos	NMI
Jerzy Bartnicki, Seniorforsker	PhD	NMI
Pål Erik Isachsen, Seniorforsker	Dr. Scient	NMI
Knut Erik Tollefsen, Senior Researcher/ Professor II	Dr. Scient	NIVA
Anders Ruus	Dr. Scient	NIVA
Karina Petersen	Dr. Scient	NIVA
Yan Lin	MSc	NIVA
Peter Aleström, Professor	Fil.dr.	NVH
Jan Erik Paulsen	Dr.med.vet	NVH
Elisabeth Lie, Førsteamanuensis	Dr. Scient	NVH
Ian Mayer, Professor	Dr. Scient	NVH
Jan L. Lycke, Forsker	Dr.med.vet	NVH
Ann-Karin Olsen, Forsker	Dr. Philos	FHI
Gunnar Brunborg, Avdelingsdirektør	Dr. Philos	FHI
Christine Instanes, Forsker	Dr. Philos	FHI
Nur Duale, Forsker	Dr. Philos	FHI
Kristine Bjerve Gutzkow, Forsker	Dr. Philos	FHI
Tim Hofer, Forsker	Tekn.Dr.	FHI
Birgitte Lindeman, Forsker	Dr. Philos	FHI
Oddvar Myhre, Forsker	Dr. Scient	FHI
Henrik Rasmussen, Avdelingsleder, ansvarshavende veterinær	Dr. philos	FHI
Forsker NN		UMB/CERAD
PHD STUDENTS		
Merethe Kleiven	MSc	UMB
PhD Anne Graupner (part time)		UMB
PhD NN		NVH
PhD Magne Simonsen		UMB/CERAD
Jelena Mrdakovic Popic	MSc	UMB

POST DOC		
Post Doc NN		UMB/CERAD
Post Doc NN		
Post Doc- NN		
Post Doc Simone Cagno	PhD	UMB
TECHNICAL/ADMINISTRATIVE		
Mirian Wangen	Higher Ex. Off..	UMB
Kirsti Pettersen	Ex. Off. Adm.	UMB/CERAD
Lene Valle	MSc	UMB/CERAD
Karl Andreas Jensen	Senior Ing	UMB
Marit Nandrup Pettersen	Senior Ing	UMB/CERAD
Jill Andersen	Siv.ing	FHI
Jan R Torp Sørby	Cand. Scient	NVH
INTERNATIONAL GUEST SCIENTISTS		
Dr David Clarke		
Dr Valeriy Kashparov		
Professor Koen Janssens		
Professor Peter Stegnar		
Professor Carmel Mothersill		
Professor Colin Seymour		
Dr Tom Hinton		
Dr Clare Bradshaw		
Dr. Marcel Jansen		
Professor Janet Bornman		

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

NMBU, autumn, Photo Signe Dahl

Norwegian Centre of Excellence

Norwegian University of Life Sciences

Statens strålevern
Norwegian Radiation Protection Authority

Norwegian Meteorological Institute

Norwegian Institute of Public Health

Norwegian Institute for Water Research