CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

Norwegian Centre of Excellence

The Research Council of Norway

ANNUAL REPORT 2018

Norwegian University of Life Sciences

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Coverpage: The Cooling Pond situated close to the damaged Chernobyl reactor, Ukraine. The water level has been significantly reduced and contaminated sediments are now exposed to air.
Photo: Estela Reinoso-Maset

Coverpage inside: Naturally occurring radioactive materials (NORM) associated with different mineral structures at Orrefjell, Norway.
Photo: Frøydis Meen Wærsted

Design & Layout: Design idea by Signe Dahl, NMBU. Layout by Quentin Mennecart.

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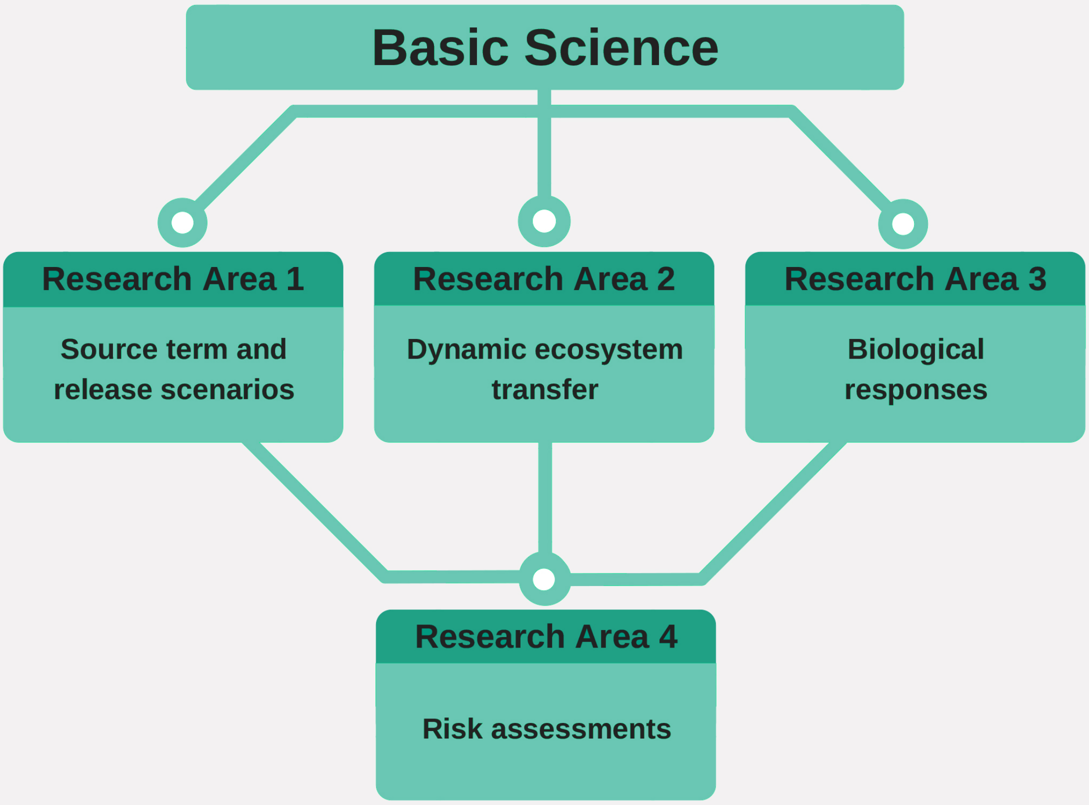
CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

WHO ARE WE?

CERAD Center of Excellence improves our ability to assess radiological impact and risks associated with environmental radioactivity, also in combination with other stressors. By focusing on key factors contributing to uncertainties, state-of-the-art tools and methods are developed to better manage those risks. The scope includes radionuclides released in the past, those presently released, and those that potentially can be released in the future from the nuclear weapons and fuel cycles as well as from non-nuclear industries.

RESEARCH ORGANIZATION



CERAD IN NUMBERS IN 2018

118 Full-time and part-time employees

9 Course modules at NMBU/CERAD

38 Internationally published articles

51 Revenues in MNOK

Visit our website: https://cerad.nmbu.no

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CERAD partners

Norwegian University of Life Sciences

DSA Norwegian Radiation and Nuclear Safety Authority

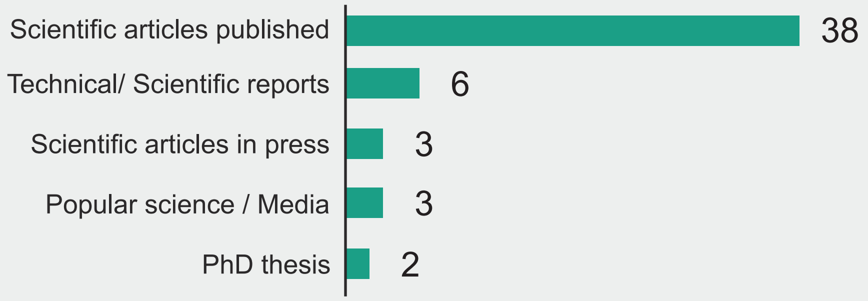
* NRPA changed name from 01.01.2019

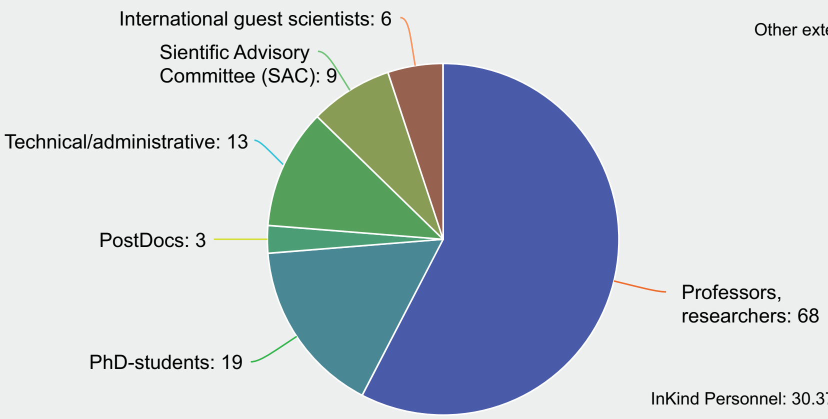
Norwegian Institute for Water Research

NIPH Norwegian Institute of Public Health

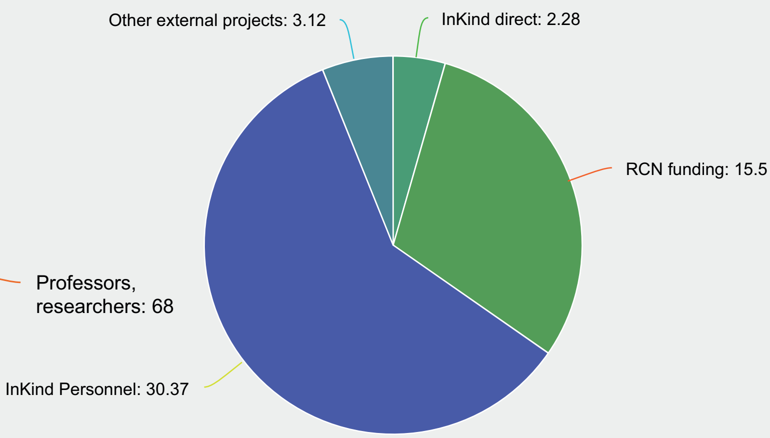
Norwegian Meteorological Institute

Scientific results in 2018





Full- and part-time personnel in 2018



Funding 2018 in MNOK

CERAD - In Short

Since 2013, the CERAD Center of Excellence for Environmental Radioactivity has improved the ability to assess the radiological impact and risks associated with environmental radioactivity. By focusing on key factors contributing to the uncertainties, new and state-of-the-art tools and methods have been developed to better manage those risks. In 2017, the Research Council of Norway (RCN) initiated the mid-term evaluation of CERAD CoE. Based on the positive recommendations given by the international Mid-term Evaluation Committee, RCN decided to fund the CERAD CoE until end of 2022. During the mid-term evaluation focus was placed on basic research performed since 2013, on the Strategic Research Agenda (2017-2021), on the promising research areas as well as on exit strategies.

A Memorandum of Understanding (MoU) was signed by the NMBU Rector and the Director General from the CERAD partner institutions in 2018. As history has shown, Norway is vulnerable to nuclear events and competence must be in place, when needed. Thus, there will be a continuing need for expertise that derives from research activities. It is also considered that the scientific output of CERAD is ambitious and that no single partner could achieve the obtained results without the strong support from other partners and international collaboration. Hence, the MoU reflects a clear intention of the CERAD partners to prolong the Consortium agreement and continue the close collaboration between the partners with respect to activities such as joint research, education, training and recruitment long term after the termination of the RCN funding of CERAD in 2022.

MG Group

Professor
Brit Salbu,
Centre Director

Professor II
Per Strand,
Deputy Director

Professor
Deborah H. Oughton,
Director of Research

Associate Professor
Ole Christian Lind,
Director of Research

Professor
Lindis Skipperud,
Director of Education

Jorunn Hestenes Larsen,
Management Director

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Comments from the CERAD Centre Director

Brit Salbu

Following the Mid-term evaluation of CERAD, I am very pleased that the Research Council of Norway (RCN) will follow the recommendations given by the international evaluation committee and thereby fully fund CERAD until December 2022. In 2018, the research is produced by more than 60 part time scientists representing different scientific fields, different scientific cultures and different partner institutions. The research program focuses on source and release scenarios, ecosystem transfer and biological effects from ionizing radiation to assess impact and risks. According to the evaluation committee: “The Strategic Research Agenda is very ambitious and relevant“, and by focusing on key factors contributing to the overall uncertainties, research topics have been prioritized within the Research Areas 1–4. Among these, four areas are considered very promising:

Potential nuclear events

There are many sources, both within Norway and abroad, that can contribute to releases of radioactivity in the future. Taking potential events (incidents/accidents/malevolent acts) into account, the risk is probably higher than previously assessed. As the present impact and risk assessment model outputs are associated with high uncertainties, the aim is to reduce the uncertainties by linking specialized and generic models into a chain, from the source to impact and risks. The most comprehensive case focuses on potential releases of radionuclides from waste tanks at Sellafield, UK, and deposition in Western Norway. Thus, 8 models are linked from a hypothetical source term and air transport (SNAP, grid resolution, particle codes) to deposition and human food chain (AgriCP, regional agricultural info, human dietary habits), ecosystem transfer models (STRATOS, transfer factors), exposure of wildlife (ERICA Tool, new extrapolation methods), freshwater run-off (INCA-RAD, transport codes) and to estuary (new dynamic model), and marine modelling (ROMS/TRACMASS, grid resolution, tidal transport, dynamic phase transfer). Furthermore, site-specific transfer data will also reduce uncertainties in model output. The combined model approach is also utilized for other accidental scenarios (e.g., sunken submarines or moving nuclear vehicles).

Linking particle characteristics to sources and effects

Following severe nuclear events, a major fraction of refractory radionuclides such as uranium and plutonium is associated with particles, ranging from submicrons to fragments. Based on the unique NMBU particle archive and international collaboration allowing access to advanced technology platforms, we have shown that the particle composition depends on the source, while particle properties (size, structure, density, oxidation state) also depend on release scenarios. Using state-of-the-art technology (e.g., ESEM, 2D and 3D synchrotron XAS, CT-tomo, AMS), particle characteristics are linked to specific sources as well as to ecosystem transfer, uptake and biological effects, being essential for impact assessment models. Particle retention in non-human organisms are observed in laboratory experiments (e.g., blue mussels, earthworm, nematodes) resulting in effects such as skin burn, reproduction failure and DNA damage. Uptake of particles has also been observed in the field (e.g., musk oxen, hare, snails, mussels). The particle work is highly relevant internationally (e.g., IAEA CRP, EU CONFIDENCE).

Comparative Radiosensitivity

Why are some organisms more sensitive than others? The aim is to identify differences in radiosensitivity between model species and to elucidate biological traits (e.g., nutrient/antioxidant status) that influence the sensitivity of species to ionizing radiation. Based on the unique NMBU gamma irradiation facility and the unique Biological Effect Toolbox, 12 different test organisms have been exposed to a range of gamma radiation dose rates/doses, also in combination with other stressors, to identify responses such as ROS/oxidative stress, growth/development, reproduction, genotoxicity and mortality, as well as transcriptomics, epigenetics and transgenerational effects. Effect endpoints, also utilized for adverse outcome pathway (AOP) analysis, are selected with emphasis on cellular processes that are particularly vulnerable to gamma radiation and on biological responses associated with protective mechanisms. Comparative studies have so far focused on laboratory experiments of model organisms, but will be extended to the field.

Differentiating Uncertainties – Variability

Extrapolation of impact from laboratory to the field is complicated by a number of confounding factors; results obtained in laboratories may not to be relevant under natural climate conditions, and proper dosimetry is difficult to attain in the field. Comprehensive fieldwork has therefore been initiated in Chernobyl and Fukushima to allow exposure and effects observations in the field to be compared, differences and similarities to be recognized, and field studies to be compared with laboratories experiments. Implementation of caged clean fish into a contaminated lake and caged contaminated fish into a clean lake within the Chernobyl zone demonstrated the seasonality of uptake, accumulation and depuration of radionuclides in fish, and that the “handbook” transfer coefficients to fish need revision. Doses to wild life have also been measured using GPS dosimetry (e.g., brown bear, wild boar).

According to the evaluation committee: “There is an excellent team spirit and enthusiasm making the Centre very attractive for collaborations, but also for PhD students and postdocs”. Education (MSc, PhD) and training are essential ingredients in CERAD. We are therefore very pleased that a total of 26 PhDs (8 have defended their work so far) and 9 PostDocs have been connected to CERAD since 2013. The MSc in Radioecology is unique in Europe, and course modules (in English) are run intensively to allow access for international students. An intensive field course in Chernobyl is also given in collaboration with National University of Life and Agricultural Sciences of Ukraine.

CERAD politics include close collaboration with other organizations, nationally and internationally. Thus, CERAD partners have participated in a series of EU projects since 2013 (e.g., Concert, Shamisen, Territories, Confidence). Within Confidence, CERAD partners (NMBU, NRPA, MET) are collaborating actively as the project focuses on uncertainties associated with nuclear accidents, a topic similar to the Western Norway case. CERAD plays an active role in other international arenas (e.g., ICRP, UNSCEAR, IAEA, OECD/NEA, IUR). Memorandum of Understanding agreements related to research and E&T have also been established with collaborating universities and research institutes nationally and internationally. During the years, CERAD has supported a series of conferences and workshops organized nationally and internationally, and 50-100 conference presentations are given annually.

As stated by the RCN evaluation committee, “CERAD is a global Centre of Excellence and a flagship for Norwegian Science”. It is therefore a privilege to act as director of CERAD. Then, a key challenge for the years to come will be the development of a sustainable exit strategy.

Professor Brit Salbu,
Centre Director
Photo: Gisle Bjørneby

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

Comments from the Chair of the CERAD Board
Øystein Johnsen

From 2013–2018, CERAD has provided scientific insight enabling us to reduce the overall uncertainties connected to assessments of risks and impacts associated with radioactive exposure. Impressive amount of work has been conducted in 2018, and the output of numerous scientific reports documents fundamental knowledge achieved so far, and yet, important societal impact is expected.

During the Annual Conference summing up the 2018 activities, I had the pleasure to listen to interesting presentations related to: biological effects following nuclear events, highlights from last years research on reducing uncertainties in environmental impact and risks assessments, stories from past nuclear events and lessons learned, analyses of knowledge gaps and new challenges, information about particle characteristics and nuclear forensics, reflection on multiple stressor exposure, including ionizing and UV radiation as well as mixed exposures connected to effects and risks. The reports from the young scientists were impressive. Indeed, these presentations demonstrate how complex all those issues are, and how important it is to build sustainable capacity of competence. We need to educate next generation of experts for developing and refining management systems and for making contingency plans to counteract harmful effects of possible future nuclear events. Moreover, we need experts who can work with future challenges such as the upcoming decommission of nuclear reactors.

The high ambitions and expectations from the members of the CERAD consortium have shown the importance of collaborative work and the establishment of network relations, nationally as well and internationally. To succeed, this calls for strong coordination among partners in order to find a fine-tuned balance between using external funding in combination with in-kind contributions from all the partner institutions. This close interplay among partners in joint research, education, training and recruitment should hopefully continue for a very long time. It was therefore important and promising that a Memorandum of Understanding (MoU) was signed by the NMBU Rector and the Director General from the CERAD partner institutions in 2018, with the aim to continue their collaboration in environmental radioactivity during the remaining program period, and even long time after the termination of RCN-funding in 2022!

CERAD is teamed up with devoted, hardworking scientists, outfitted with enthusiasm, strong motivation, endurance and bright minds. The center comprises a good mixture of experienced researchers and younger scientists. It is a pleasure for me, on behalf of the board, to thank all the partners that have contributed to great science. We are grateful for all the god advices and recommendations given by the international scientific advisory committee (SAC). The huge efforts from the researchers, research leaders and the administration are greatly appreciated. A special thank goes to the CERAD director, Professor Brit Salbu, for her strong leadership and impressive devotion to science.

It is great to be part of the CERAD Board together with representatives from NMBU and from our four partners, Norwegian Institute of Public Health, Norwegian Meteorological Institute, Norwegian Institute for Water Research and Norwegian Radiation Protection Authority. Thank you!

Øystein Johnsen,
Chair of the Board
Photo: Gisle Bjørneby

Urbygningen, NMBU.
Photo: Håkon Sparre/NMBU

Management and Administration

The CERAD Board

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

The CERAD Board members 2018 have been:

- Pro-rector Øystein Johnsen, NMBU, Chair
- Director General Ole Harbitz, NRPA, Deputy chair
- Dean Sjur Baardsen, NMBU/MINA
- Division Director Toril Attramadal, NIPH
- Deputy Managing Director Tor-Petter Johnsen, NIVA
- Research Director Lars-Anders Breivik, MET
- Scientist Dag Anders Brede, NMBU
- Centre Director Brit Salbu, CERAD

CERAD Scientific Advisory Committee

The CERAD Scientific Advisory Committee (SAC) is headed by the CERAD Research Director and includes 9 internationally well–merited scientists from 8 countries (USA, Ukraine, Slovenia, Belgium, Sweden, Canada, Australia, Japan). SAC members have been actively involved in the development of the Strategic Research Agenda (SRA) and are invited once a year to the CERAD annual conference. Members of the Scientific Advisory Committee (SAC) in 2018, have been:

- Dr. David L. Clark, National Security Education Center, Los Alamos National Laboratory, USA
- Professor Valeriy Kashparov, National University of Life and Environmental Sciences of Ukraine, Ukraine / Professor II, NMBU
- Professor Koen Janssens, University of Antwerp, Belgium
- Professor Peter Stegnar, Jožef Stefan Institute, Slovenia
- Professor Carmel Mothersill, McMaster University, Canada
- Professor Colin Seymour, McMaster University, Canada
- Professor Tom Hinton, Fukushima University, Japan / Professor II, NMBU
- Dr. Clare Bradshaw, Stockholm University, Sweden
- Professor Janet Bornman, Curtin University, Australia

CERAD Relevance Advisory Committee

The CERAD Relevance Advisory Committee (RAC) is headed by the CERAD Deputy Director and includes representatives from key Norwegian stakeholders/end-users. The RAC meets once a year at the CERAD annual conference. In 2018 the RAC includes members from:

- The Ministry of Health and Care Services, Lisbeth Brynildsen
- The Ministry of Climate and Environment, Ingvild Swensen
- The Ministry of Foreign Affairs, Anja Polden
- Norwegian Radiation Protection Authority, Kristin Frogg

CERAD Research Management

The CERAD Management Group (MG) is responsible for managing the research at the Centre and consists of the CERAD principal investigators, headed by the CERAD Director (Fig. 1). To strengthen the research effort Ole Christian Lind has been appointed research director for research area 1 and 2, while Deborah H. Oughton is in charge of research area 3 and 4. In addition, Anne Marie T. Frøvig, NRPA, is adviser to MG. The CERAD MG reports to the CERAD Board, and includes:

- CERAD Director: Brit Salbu, Professor, NMBU
- Deputy Centre Director: Per Strand, Department of Nuclear Safety and Environmental Radioactivity, NRPA / Professor II, NMBU
- Education Director: Lindis Skipperud, Professor, NMBU
- Research Directors: Deborah H. Oughton, Professor and Ole Christian Lind, Associate Professor, NMBU
- Management Director: Jorunn Hestenes Larsen, NMBU

The Extended MG includes the MG and the Research Area (RA) leaders (2 leaders per RA, RA1- 4), representing all CERAD partners. The RA leaders report to the CERAD MG and CERAD Research Directors. The CERAD research area leaders in 2018 were:

- RA1: Ole Christian Lind, NMBU and Heiko Klein, MET
- RA2: Justin Brown, NRPA and Hans-Christian
- Teien, NMBU
- RA3: Peter Aleström, NMBU and Ann-Karin Olsen, NIPH
- RA4: Knut Erik Tollefsen, NIVA and Deborah H. Oughton, NMBU

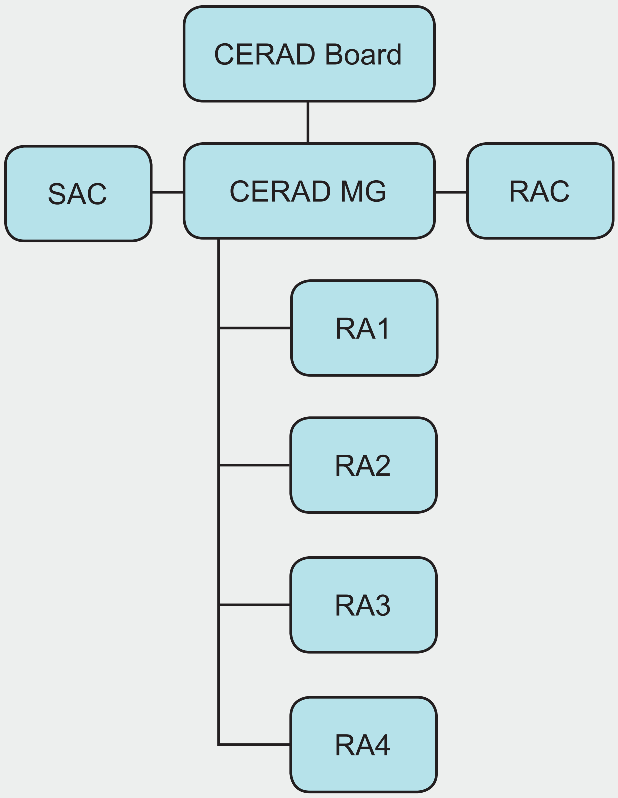

Figure 1. *The CERAD research organization*

The Extended MG meets once a month to follow the progression of the funded research, to report findings that should be pursued, to suggest new or revised research topics, and to ensure that the research is of an international standard.

CERAD Research and Strategic Research Agenda

The research within CERAD is organized around four Research Areas (RA) outlined in the CERAD Strategic Research Agenda (SRA). Thus, the CERAD research is structured according to science rather than partner locations, which fosters a high degree of interinstitutional and interdisciplinary collaboration. In addition to describing the overall challenges as well as key challenges within individual research areas, the SRA also forms the basis for decisions about priorities for personnel, experiments and equipment within CERAD.

The CERAD SRA (2017-2021) presents an overview of the CERAD research activities and achievements, hypothesis and approaches to testing those hypotheses, as well as priorities set for the next years (see www.nmbu.no/cerad). Based on the previous SRA and work performed so far, 4 promising research areas have also been identified: Potential nuclear events, Linking particle characteristics to sources and effects, Comparative Radiosensitivity, and Differentiating Uncertainties–Variability. All research areas include participation of at least three CERAD partners and are led by experienced scientists from across all CERAD partners.

Research Area 1 – Source Term and Release Scenarios (Ole Christian Lind and Heiko Klein)

A series of nuclear/radiological and non-nuclear sources have contributed, are contributing or can contribute in the future to the release of artificially produced or naturally occurring radionuclides to the environment. Following nuclear events, a major fraction of refractory radionuclides such as uranium (U) and plutonium (Pu) will be present as particles, ranging from sub-microns to fragments. Thus, particles are an essential part of the source term, and particle characteristics are essential for the ecosystem transfer, uptake, accumulation and effects. Focus areas (umbrella) of RA1 in 2018 have been:

Umbrella 1A: Particle Sources (Ole Christian Lind)
Umbrella 1B: Dispersion Modelling: Atmospheric and Marine (Heiko Klein)
Umbrella 1C: UV/Ionising Radiation and Dosimetry (Terje Christiansen)

Research Area 2 - Dynamic Ecosystem Transfer (Hans Christian Teien and Justin Brown)

In the field of radioecology and radiological protection, robust models are required to predict the partitioning of radionuclides between media compartments and their transfer through food-webs. Internationally, there are robust arguments to support the view that over-reliance is often placed on empirical transfer constants such as distribution coefficients: Kds, concentration ratios (CR) and transfer coefficients (TF/TC/Tag, BCR). Although available data compilations on such ratios are comprehensive, simple to use in screening assessments assuming equilibrium conditions, these approaches do not: a) capture the dynamics of environmental contamination situations; nor b) provide any insight to the underlying mechanisms influencing transfer. Thus, RA 2 focuses on radionuclide speciation, the influence of environmental physical-chemical conditions on transfer, and on interactions with other contaminants, linking toxico-dynamics to toxico–kinetics. Where data gaps with regards to transfer parameters are evident, various extrapolation methods are applied to provide surrogate values, such as the use of stable element analogues, the use of taxonomic (related to phylogeny) analogues, parameters based upon allometry, as well as the use of Bayesian statistics.

Research Area 3 - Biological Responses (Ann-Karin Olsen and Peter Aleström)

The main aim of RA3 is to generate new knowledge related to biological responses in organisms exposed to ionizing radiation that have implications for risk assessment and radioprotection of humans and the environment, also to reduce the existing uncertainties. In this respect a major data-gap exists on effects following exposure of low doses and low dose rates of ionizing radiation to both humans and wild-life. Such effects cover apical endpoints like reproduction, embryonal development, behavior, as well as transcriptomics, epigenetics and transgenerational effects. Focus areas (umbrella) of RA3 in 2018 have been:

Umbrella 3A: Radiosensitivity (Dag Anders Brede).

Umbrella 3B: Combined Toxicity and Cumulative Risk (Knut-Erik Tollefsen and Terje Christensen).

Umbrella 3C: Transgenerational and Reproduction Effects (Ann-Karin Olsen and Peter Aleström).

Research Area 4 - Risk Assessment and Ecosystem Approach (Knut-Erik Tollefsen and Deborah H. Oughton)

The aim of CERAD is to reduce the overall uncertainties in impact and risk assessments and thus increase the protection of man and the environment from harmful effects of ionising radiation, alone and in combination with other stressors. By interfacing models linking sources and release scenarios via ecosystems to impact and risk assessments (Fig. 1), the overall uncertainties associated with model predictions should be assessed. By focusing on those factors contributing the most to uncertainties, the predicting power should be improved. Secondly, there is an increasing focus on effects of low radiation doses at the community or ecosystem level, and to link exposure and effects observations in the field to results obtained from laboratories experiments. Finally, there is an increasing recognition that radiation protection needs also to address socioeconomic impacts. Focus areas (umbrella) of RA4 in 2018 have been:

Umbrella 4A: Ecosystem Approach (Tanya Hevrøy)

Umbrella 4B: Potential Nuclear Events - impact and risk assessment (Ole Christian Lind)

Umbrella 4C: Societal Impacts-socioeconomics, risk communication, risk perception and stakeholder dialogue (Deborah H. Oughton).

The following sections present selected research highlights from 2018 presented during the CERAD Annual Conference. An overview of the major achievements over the past five years can be found in the full SRA as well as the Annual Report in 2017. The full SRA also provides more details on the priority research areas for 2017-2021. References can be found in the publication list.

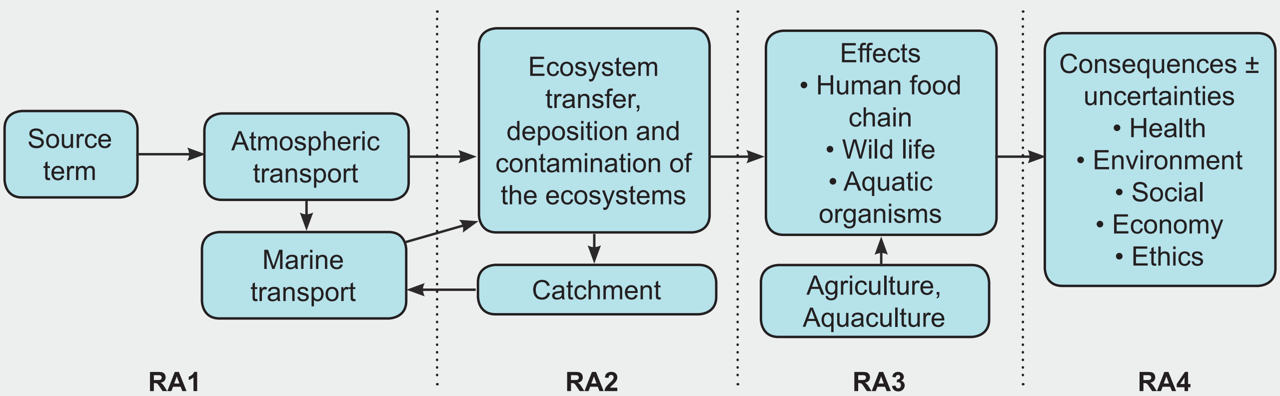

Figure 1. *Linking models from source term via an ecosystem transfer to the impact for humans and the environment, for the society, economy and ethics. The research within RA1 to RA4 should reduce the overall uncertainties associated with modelling the impact and risk.*

RA1: PARTICLE CHARACTERISTICS

NMBU: *O.C. Lind, B. Salbu, S. Cagno*
University of Antwerp: *K. Janssens, G. Nuts, F. Vanmeert, J. Van Beeck*
University of Seville: *R. Garcia-Tenorio, Ignacio Vioque, J. Galvan*
ANSTO: *D. Child, M. Johansen*
Warsaw University of Technology: *J. Jaroszewicz*

Objectives: In order to reduce uncertainties in environmental impact assessments, the objectives were 1) to link characteristics of radioactive particles released to the environment to defined sources, 2) to obtain relevant particle properties that can be implemented in air and marine transport as well as ecosystem transfer models and 3) to assess doses and effects from uneven distribution of activity.

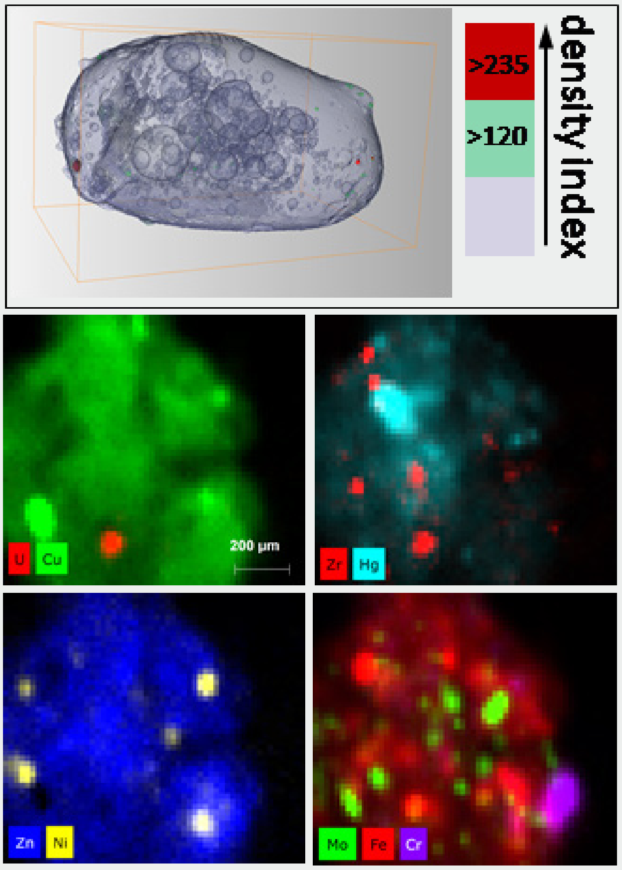

Figure 1. *Radioactive particle characterisation using nano-CT (upper; Maralinga) and micro-XRF (lower, Ottawa River).*

Methods: Screening soils, sediments and biota from contaminated sites for heterogeneties using digital autoradiography and gamma spectrometry, isolation of radioactive particles and characterization of particles with advanced submicron- and micro-analytical techniques such as electron microscopy with X-ray microanalysis, nano-CT, bench-top μ-XRF and synchrotron radiation based submicron XRF, XRD and XANES at beamline P06, Petra III, Hamburg. Mobility, potential availability and processes related to particle weathering were investigated using the EC-RATE/IAEA-CRP protocols for single particle and bulk sample extractions using abiotic and biotic leaching media (Salbu et al, 2018).

Results: Based on experience from >25 years of research on radioactive particles at sites contaminated by releases from nuclear events or TENORM activities worldwide, particles ranging from submicrons to fragments containing radionuclides and toxic trace elements should be expected as a major fraction of the source term.

In total, 12 nuclear weapon tests and several hundred safety tests were conducted during 1952-1957 at the former British nuclear test sites in Australia. Transparent 3D rendering based on computerized nanotomography of a radioactive particle from Maralinga with a glassy, melted appearance, showed a number of voids and 2-14 μm sized high density inclusions expected to contain Pu and U (Fig.1; upper section).

Due to the nuclear activities at Chalk River nuclear site on the Ottawa River, Ontario, Canada, river sediments close to the discharge process outlet are contaminated with low level radioactive particles. Using bench-top μ-XRF mapping on contaminated sediment grains (Fig.1; lower section), we demonstrated the presence of particulate material containing a suite of toxic stable elements such as Cr, Ni, Cu, Zn, As, Hg and Pb in addition to debris from several types of nuclear fuel material (U, Th and Pu). These findings reflected a variety of historical nuclear activities and associated incidents at the facility. The cocktail of radionuclides and toxic elements constitutes a multiple stressor exposure for the sediment dwelling organisms in the immediate vicinity of the process outlet of the facility, which needs to be addressed in future environmental risk assessments.

There is a risk from inhalation, dermal absorption, skin exposure and ingestion of radioactive particles. For biota, such as filter-feeders (e.g., molluscs) and soil-dwelling animals (e.g., gastropods), particles can be retained by the organism. Furthermore, particle weathering can increase the mobility and potential for the transfer of particle associated radionuclides into the biosphere. As a result of particle weathering or molecular growth processes, radionuclides may also occur as submicron or even nanoscale particles with biological uptake properties potentially quite different from those of ions. In the present work, transformation processes influencing weathering of radioactive particles were studied by employing well defined leaching experiments on well characterized single particles as well as bulk samples (Fig. 2). Results showed that the amount of Pu leached from single particles were comparable to that leached from 1 g of soil, with a large variety of leaching behaviour for particles. In general, rain water leaching induced initial mechanical disruption of U, Pu mixed oxide/oxyhydroxide particles transforming them to nm-μm sized particles. Dissolution, however, was the predominant transformation mechanism for simulated stomach juice (0.16 M HCl) extractions.

Conclusion: Radioactive particles represent point sources of potential radioecological and radioanalytical consequences and they often also constitute a multiple stressor issue. Information on the extent of particle contamination and their characteristics

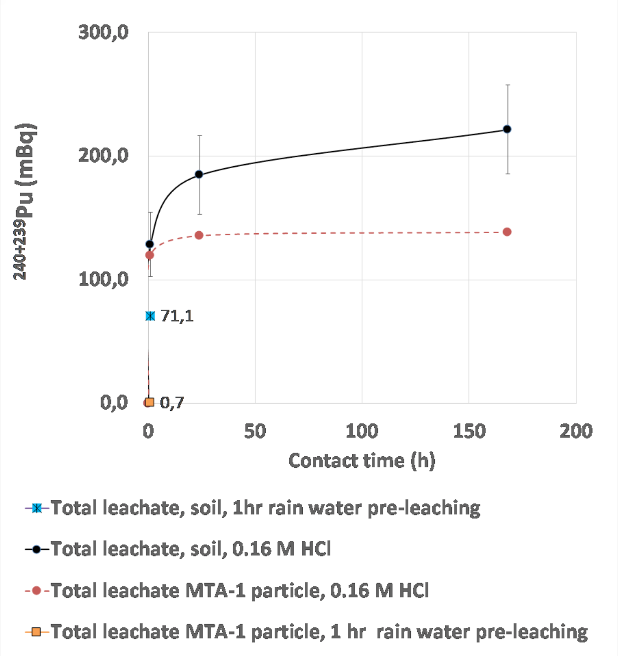

Figure 2. *Abiotic leaching of contaminated soil and a single particle from the Maralinga Taranaki test site, Australia*

including the potential bioavailability of particle-associated contaminants should be considered essential for assessing ecological risks both from radionuclides and toxic metals.

References:

- *Lind et al., 2014. Low-level radioactive river sediment particles originating from the Chalk River nuclear site carry a mixture of radio-nuclides and metals, Int. Conf. Radioecology & Environmental Radioactivity.*
- *Salbu et al., 2018. Challenges associated with the behaviour of radioactive particles in the environment. J Environ Radioact; 186: 101-115.*

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CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

RA1: ATMOSPHERIC MODELS FOR TRANSPORT AND DEPOSITION OF RADIOACTIVITY

MET: *H. Klein, J. Bartnicki, E. Berge, M. Ulimoen*
NMBU: *B. Salbu, O. C. Lind*

Objectives: Improve atmospheric models for transport and deposition of radioactive material.

Methods: Sensitivity studies of atmospheric modelling.

Results: Atmospheric processes are important for the transport and deposition of radioactivity. Shortly after a release, local winds, turbulence, plume rise and dry deposition are particularly important. If precipitation occurs, it also contributes to deposition in the early phase after the release. As time evolves, radioactive substances will be lifted to higher levels were wind speeds normally are higher and wind direction changes. At higher altitudes the radioactive compounds are incorporated in clouds and scavenged by wet deposition. The amount of dry deposition is reduced with distance from the source, since concentrations near the surface are reduced. Larger particles (with diameter above approximately 10 μm) can be quite efficiently deposited by dry deposition processes, while smaller particles (0.1 μm to 2 μm) are to a smaller degree dry deposited and wet deposition becomes dominant for these sizes.The fate of the particles is largely dependent on their size and density; how far they will be transported and whether they will be brought to the surface by dry or wet deposition.

The effects of the particle sizes on the transport of radioactivity in the atmosphere is simulated with an artificial release 200 km southwest of Stavanger. Figures 1 and 2 show simulations with 1 μm and 20 μm size particles, respectively. The simulations start 09 UTC 16.03.2017 with a 1 hour release up to 700 m and deposition is accumulated for 24 hours after the start of the release.

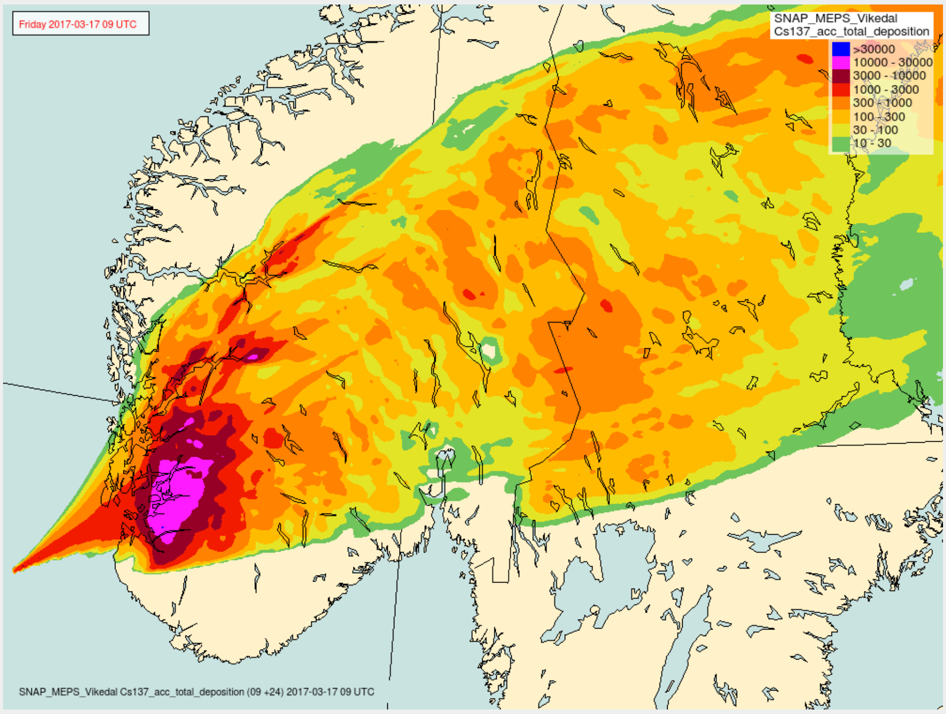

Figure 1. *24 h accumulated deposition assuming release of only 1 μm particles. Deposition as Cs-137 (Bq/m^2).*

The 20 µm particles are transported much shorter distances and the depositions are higher close to the source compared to the 1 µm particles. For both simulations we see a deposition maximum east of Stavanger due to heavy precipitation in this area. The deposition maximum of the 20 µm particles is up to 4 times higher than the deposition of the 1 µm particles assuming equal release rates. This demonstrates an effect of the particle size on the atmospheric dispersion in a range of 200 km, however, the magnitude of this effect needs to be analysed with a source-term describing a possible real event and a log-normal particle size distribution. Other important uncertainties of the atmospheric calculations are transport by the wind and the wet deposition (Wellings et al., 2018).

Conclusion: Sensitivity studies are important for quantifying atmospheric model uncertainties. Model runs with selective particles show that varying the particle sizes of the source term can have an impact on spatial deposition patterns even in the range of several 100 km. Further work on source term sensitivity will therefore be carried out. Focus will also be on uncertainties analysis and improved descriptions of wind fields and wet deposition.

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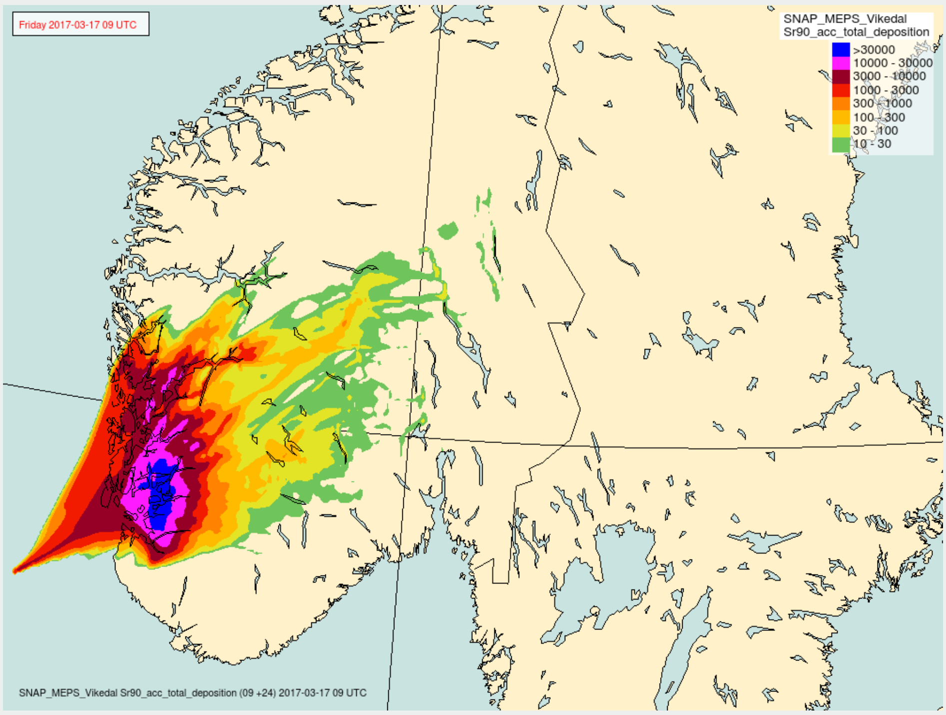


Figure 2. *24 h accumulated deposition assuming release of only 20 µm particles. Deposition as Cs-137 (Bq/m²).*

CERAD
CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

RA2: RADIOECOLOGICAL FOOD-CHAIN TRANSFER MODELLING: FIT FOR PURPOSE

NRPA: *J. Brown, A. Hosseini, H. Thørring*

Objectives: To consider how recent knowledge would change/improve terrestrial food and dose module predictions; and to characterise and analyse the underlying probability distribution functions associated with transfer parameters to better enable uncertainty/sensitivity analyses.

Methods: The 'Terrestrial Food Chain and Dose Module–FDMT', as used in the ARGOS emergency preparedness decision support systems, has been transferred to the modelling platform 'ECOLEGO'. This has enabled us to perform probabilistic modelling and to modify the model where this is deemed appropriate.

Results: The newly implemented model was tested through comparison between outputs from old (ECOSYS in EXCEL) and new versions. Results for given scenarios corresponded very closely for the two versions. Statistics for selected parameter values, primarily element-dependent/radioecological parameters were collated providing a comprehensive update to the old version. The impacts of 'Regionalisation' by including information on Norwegian conditions pertaining to growing season for crops, harvest time, animal feeding regimes etc. showed that such factors will also be important. Sensitivity analysis was undertaken using, inter alia, advanced variance-based methods for selected scenarios (given type of deposition, radionuclides and endpoints). Selected results are shown in figure 1.

Conclusion: A useful tool has been developed enabling us to 1) quantify the probability that a specified food product will exceed a given activity level and over which periods this will occur and 2) identify which parameters (for given time points) are important (contribute most to output variance) for a given deposition scenario.

References:

Brown J.E.et al., 2019. D 9.13 – Improving models and learning from post-Fukushima studies. EJP-CONCERT. http://concert-h2020.eu/en/Publications

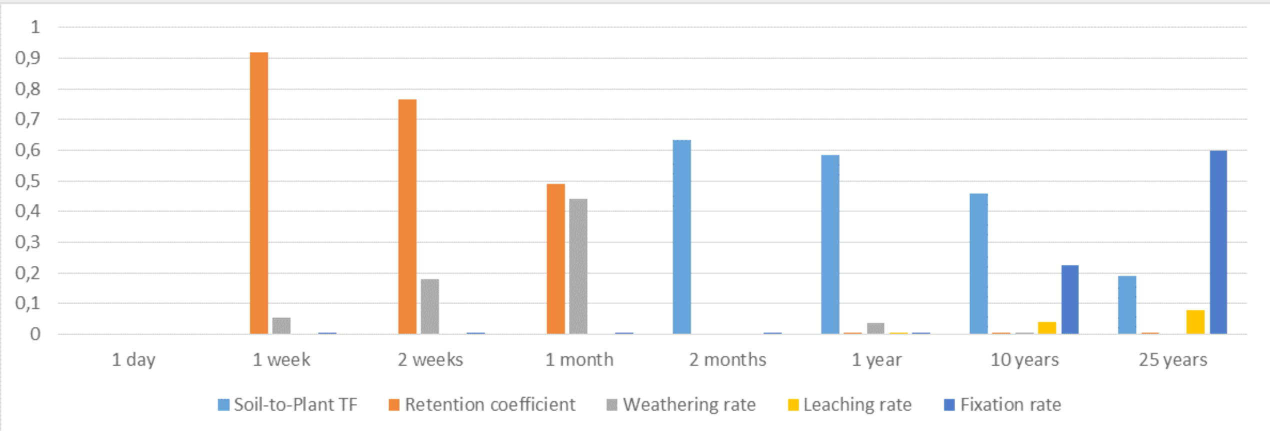


Figure 1. *Variance-based sensitivity (EASI method) as function of time–Cs-137 leafy vegetables: wet deposition. The y axis shows the fractional contribution to the variance observed in the output (^{137}Cs concentrations) attributable to the given parameter.*

I-131 tracer experiments, Furuneset, Norway.
Photo: Deborah H. Oughton

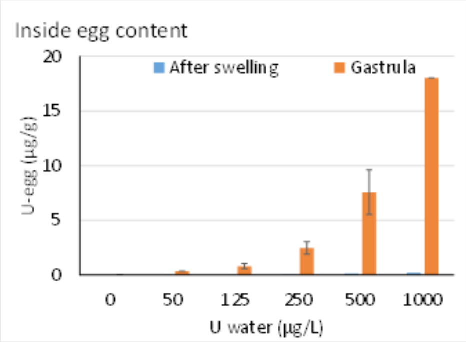
RA2: AQUATIC ORGANISMS – TRANSFER AND IMPACT OF RADIONUCLIDE EXPOSURES

NMBU: *H-C. Teien, D. Brede, A. K. Yetneberk, K. Zeng, S. Scheibener, Y.K. Lee, O.C. Lind, L. Valle, B.O. Rosseland, B. Salbu*
NIPH: *L. Sareisian, A-K.H. Olsen*
NIVA: *Y. Song, K.E. Tollefsen*
NRPA: *H. Thørring*
UIAR: *V. Kashparov, S. Levchuk, V. Protsak, E. Kashparov*
Fukushima University: *T. Wada, T. Hinton*

Objectives: In order to reduce uncertainties in impact assessment models, we aim to improve the characterisation of radionuclide exposures in the field and to link exposure to biological responses. Furthermore, the study included comparisons of data from laboratory with those from the field. Hypothesis 1: the transfer of radionuclides are dynamic and effects can correlate with activity concentrations in biota. Hypothesis 2: experimental results in the laboratory could be representative for field conditions.

Methods: In controlled model experiments, algae exposed to depleted uranium (DU) was used as food for daphnia to study the trophic transfer of U. Both juveniles and embryos of Atlantic salmon were also exposed to DU for 96 hours acute toxicity tests (OECD, 1992) and to 90 days chronic toxicity test (OECD 210), respectively. In addition, uptake and toxicity of DU were studied separately and in combination with gamma radiation or Cd for both juveniles and embryos, and as a function of varying water

__Figure 1.__ The contaminated Lake Globokeye, Chernobyl exclusion zone. Photo: Hans-Christian Teien.



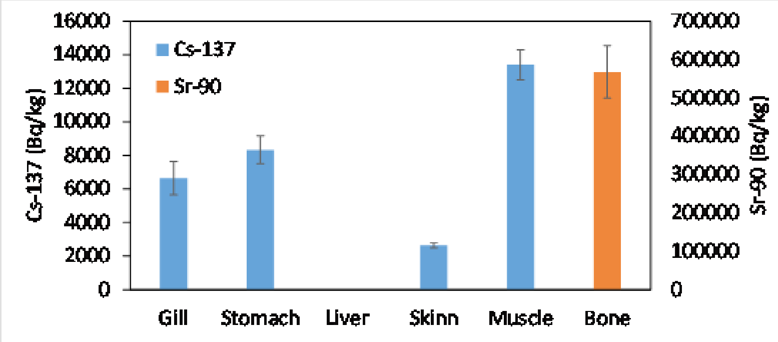


Figure 2. *Left: Correlation between concentration of U water and U inside Atlantic salmon egg. Right: Distribution of Cs-137 and Sr-90 in rudd from Lake Globokeye Chernobyl.*

ion concentrations (H^+, Ca^{2+}, Mg^{2+}, Na^+, K^+) in juveniles.

Sediment, water samples and fish tissues of different species were collected from contaminated ponds in Fukushima and from lakes in Chernobyl (Fig. 1) to determine the distribution of radionuclides.

Common garden field experiments with fish were performed during different seasons in contaminated and clean lakes in Chernobyl to identify the dynamics in uptake and elimination of radionuclides and to determine the impact of exposure.

Speciation of radionuclides in water, accumulation of radionuclides in tissues (gill, liver, egg) and induced response endpoints of exposure were determined using the CERAD tool box. Toxic mechanisms were explored by combining gene expression, metabolomics profiling, histopathology, DNA-damage, ROS-defence enzymes activity.

Results: Results from laboratory model experiments demonstrated uptake of DU in algae and food chain transfer to daphnia. However, the trophic transfer factors (TTF) were low.

Upon water exposure, DU accumulated in fish gills, which acted as an internal source for further accumulation in liver or within fish eggs. Accumulation increased with increasing DU concentrations and decreasing pH. Concentrations of DU in juvenile gills and within eggs (independent of water quality) were correlated with effect endpoints such as genotoxicity (Comet assay), impacts on the oxidative stress defense system (CAT and GPx enzyme activities) and ionoregulatory disruption in juveniles were demonstrated.

Based on field campaigns in Fukushima and Chernobyl, the distribution of I-129, Cs-137 and Sr-90 in sediment, water and fish demonstrated that the internal dose to fish was higher than the external. In Chernobyl, Sr-90 was the main dose contributor to fish. The present study has generated unique data on I-129 in freshwater fish. The RN and associated doses were unevenly distributed.

Based on field experiments in Chernobyl, seasonal variation in transfer of radionuclides to fish was observed, with high uptake and depuration rate during June-October with water temperature >15 oC, and low transfer at low temperatures (<10 oC, October-December). So far, no significant toxic effects have been identified in chronically exposed fish.

Conclusion: Uptake of RN is speciation dependent, and toxic effects correlate with the uptake. Embryogenesis is more sensitive towards U than juvenile stage, but opposite for Cd. Toxicokinetics can partly explain these differences. New dynamic radionuclide transfer data obtained for fish in the field differ significantly from those in the IAEA handbook.

RA3: SPECIES RADIOSENSITIVITY: COMPARISON OF BIOLOGICAL EFFECTS OF CHRONIC GAMMA RADIATION ON MODEL SPECIES

NMBU: *D.A. Brede, E. Maremonti, Y.A. Kassaye, K. Zheng, H.C. Teien, S. Hurem, J.H. Kamstra, L.C. Lindeman, L.M. Martin, J. Ballangby J.L. Lyche, P. Aleström, D. Blagojevic, Y. Lee, J. E. Olsen, O.C. Lind, D. Oughton, B. Salbu*
NIPH: *D.M. Eide, A. Graupner, H.G. Dahl, K. Gutzskow, N. Duale, E.S. E.S. Berg, A-K.H. Olsen*
NIVA: *Y. Song, L. Xie, T. Gomes, K.E. Tollefsen*
NRPA: *T. Christensen, E.L. Hansen*

Objectives: The overarching objective has been to characterize differences in radiosensitivity between selected biological model species and to elucidate biological traits that determine the sensitivity of these species. The main hypothesis is that an organism's capacity to mitigate oxidative stress and thus maintain essential enzyme functions determines a species ability to repair damage inflicted on essential macromolecules such as DNA (Fig. 1). The projects aims are: i) to improve current understanding of effects induced by low dose radiation; ii) to characterize the toxicological dose-response for ecologically relevant species: iii) to identify novel molecular effects or protective mechanisms, vulnerable cellular processes; and iv) to identify potential biomarkers.

Methods: The CERAD consortium has developed a framework with standardized set of Biological Effect Endpoints for systematic comparison of biological effects on ecologically important species. Research is focused on chronic low to medium dose rate gamma radiation using the NMBU Co-60 source FIGARO. For each species, a dose-response

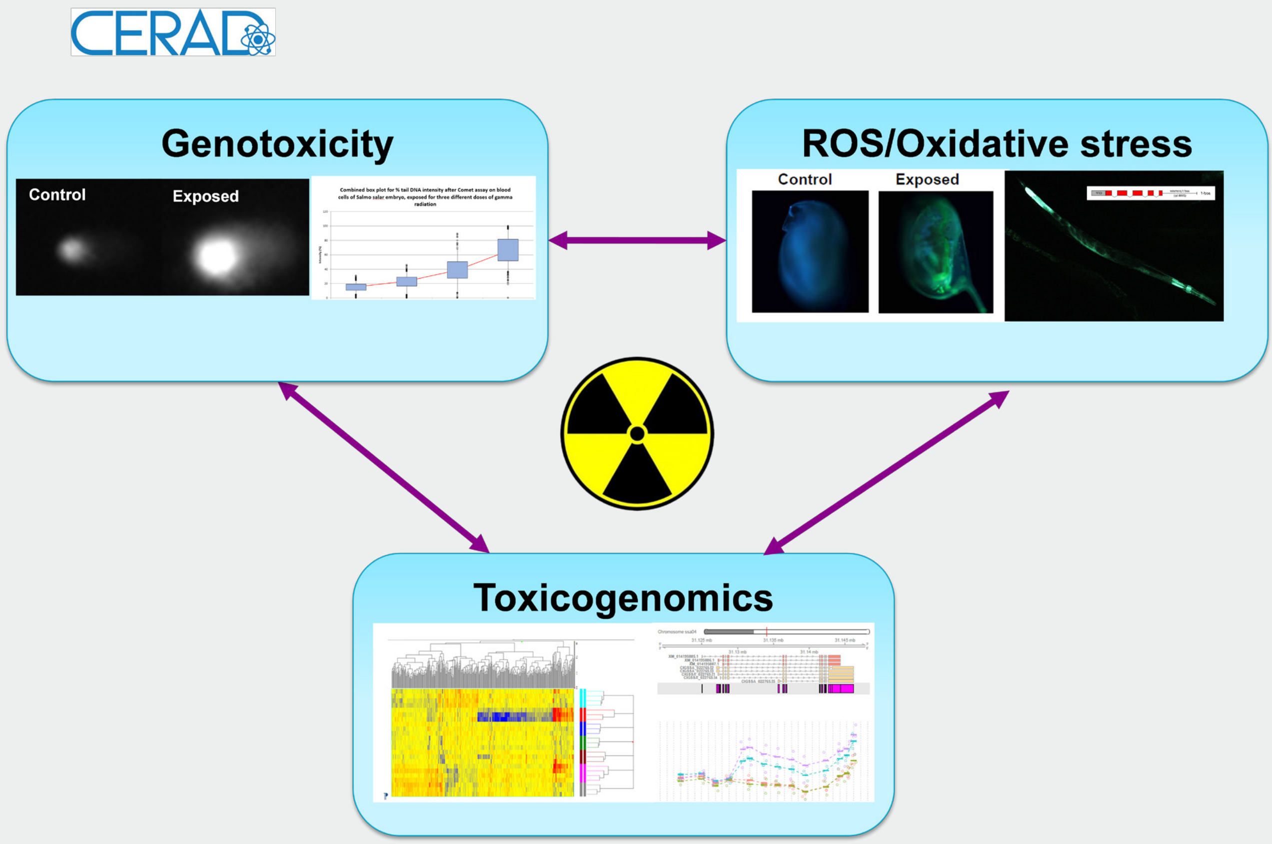


Figure 1. *Model for studying interaction between ROS formation/oxidative stress and genotoxicity linked to molecular responses and adverse effects of ionizing radiation.*

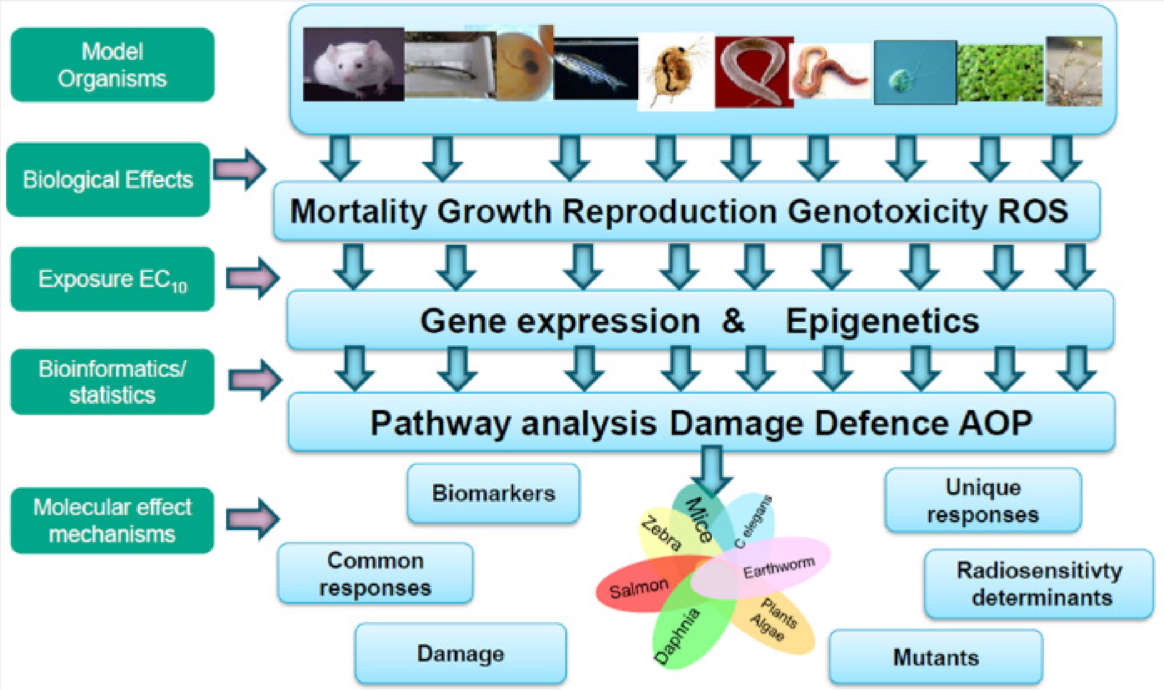


Figure 2. *Flowchart showing the structural design of the Biological Effects Toolbox for interspecies comparison of radiosensitivity. All model species are subject to standardized radiation exposure and a common set of Biological Effect Endpoints to delineate adverse outcome pathways.*

relationship of toxic effects has been established. These are then combined with info on molecular mechanisms to develop Adverse Outcome Pathway (AOP).

Results: A Biological Effects Toolbox spanning twelve model species has been produced (Fig. 2). AOPs have been established for these species. Exposure experiments have been conducted on different life stages of salmon, zebrafish and daphnia, as well as plants, nematodes, earthworms and mice. These have revealed a dose rate dependence in DNA damage for all species. Cellular ROS production and oxidative stress effects were highly organism dependent. All species appear to tolerate a substantial level of genotoxic effects without increased mortality. Furthermore, we observe persistent effects including genomic instability related to stem cell function, gametogenesis and embryonal development, all of which contribute to reprotoxic effects.

Conclusion: The sensitivity of the individual species is highly dependent on vulnerable life stages. The results from cross-species comparison emphasize stem cells as the organismal function most susceptible to damage by ionizing radiation. Furthermore, chronic exposure to ionizing radiation is associated with 'late effects' such as developmental malformations, or reproductive defects, consistent with damage to stem cell populations.

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- *Blagojevic et al. 2019. Photochemical & Photobiological Sciences. In press.*

RA3: ZEBRAFISH GAMMA RADIATION MODEL - EPIGENETIC CONTROL

NMBU: *P. Aleström, J. Ballangby, V. Berg, D.A. Brede, S. Hurem, J.H. Kamstra, Y.A. Kassaye, O.C. Lind, L.C. Lindeman, J.L. Lyche, L.M. Martin, I. Mayer, S. Mutoloki, D. Oughton, E.M.K. Rasmussen, B. Salbu, H.C. Teien*
NIPH: *K.B. Gutzkow, A-K.H. Olsen*
NIVA: *T. Gomes, K.E. Tollefsen*
NRPA: *T. Christensen, E.L. Hansen*
Camaguey Uni: *L.M. Martin, A. Arenal*
OUS: *H. Aanes, V. H. Lobert*
UiN: *I. Babiak*
Utrecht Univ: *J. Legler, J.H. Kamstra*

Objectives: : The objective is to study how exposures to sub-chronic gamma radiation (0.4-40 mGy/h) during embryogenesis affect gene networks that control development and organogenesis. Further, how exposures during gametogenesis affect reproductive organs and germ cells, F1 offspring and subsequent generations. We hypothesize that gamma radiation induces changes in the epigenome, which cause reprogramming events of the genome with immediate and/or delayed phenotypic effects. Correlations between phenotypes, gene expression and related epigenetic alterations are studied using omics sequence analyses.

Methods: Zebrafish (*Danio rerio*) wt embryos were exposed from 2.5 hpf (blastula stage) to gamma radiation (60Co) of 0.4-40 mGy/h for 3, 48, 72 and 96 hours. Adult fish were exposed to 8.7 mGy/h for 27 days (total dose 5.2 Gy). Macro/microscopic endpoints include fluorometric (ROS), colorimetric (LPO), Comet assay and histopathology (see ref. 1 and 6). Omics studies include: transcriptomics by mRNA (2) and short non-coding RNA (sncRNA) sequencing (7); DNA methylation by whole genome (WGBS) and amplicon (BisPCR2) bisulfite sequencing (4); chromatin structure analysis with locus specific histone modification (ChIP-PCR) and chromatin accessibility profiling (ATAC seq) (5,8).

Results: Results from mRNA sequencing are presented on page 35. The radiation induced changes in the methylome were assessed by WGBS Analysis in F1 embryonic offspring from

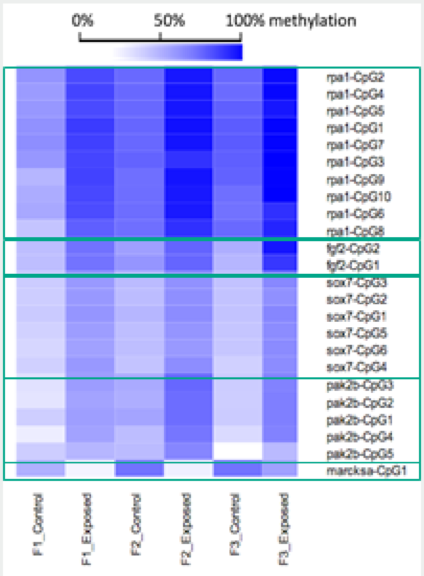

Figure 1. Transgenerational DMRs: 5 of 15 validated from WGBS dataset are persistent in F1-F3 offspring (5.5hpf embryos) from 8.7 mGy/h exposed parents.

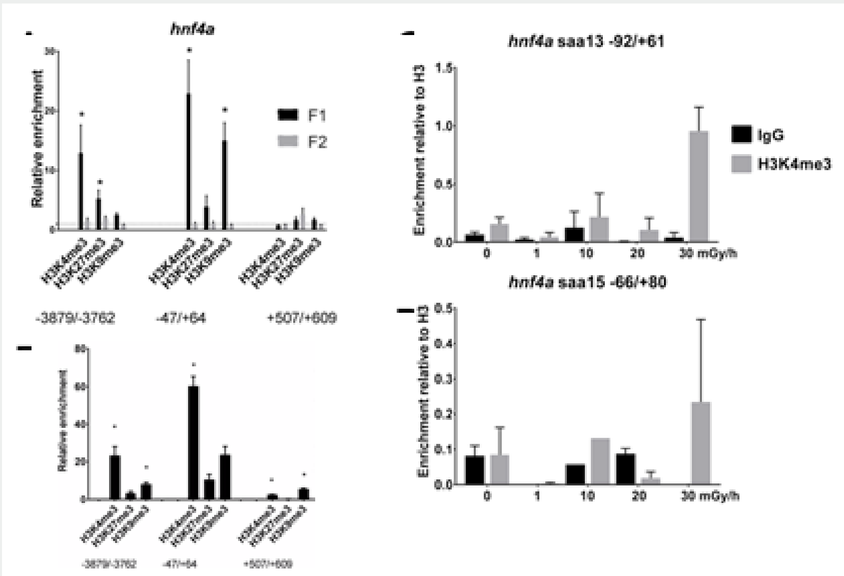

Figure 2. *ChIP analysis of indicated histone PTMs around TSS of HNF4a (A) F1 and F2 zebrafish offspring of exposed parents; (B) directly exposed zebrafish embryos; (C, D) Atlantic salmon (Salmo salar) embryos. A, B: embryos 50 % epiboly, *p<0.05. C, D: S.s. 60-degree days, 50 % epiboly Pa*

zebrafish exposed during gametogenesis revealed a non-random genome-wide pattern of 5658 differentially methylated regions (DMRs), with 33 DMR clusters, of which 7 enriched DMR clusters overlapped with differentially expressed genes cluster (DEGs)(2). Pathway analysis (IPA, Qiagen) revealed overlaps of enriched radiation relevant pathways between DEGs and DMRs (4). Of 15 selected DMRs, 5 were shown by BisPCR2 to have persisted in F2 and F3 generation (Fig. 1). ChIP-PCR analyses of F1 embryonic offspring from exposed zebrafish revealed significant enrichment, relative to controls, of histone H3 lysine 4 hypermethylation (H3K4me3) and lysine 9 hyperacetylation (H3K9ac) around transcriptional start sites of 4 genes, which were largely diminished in F2 as shown for hepatocyte nuclear factor 4 alpha (hnf4a) (Fig. 2a). Specific focus on hnf4a, which plays a role in development, organogenesis and cancers, displays a similar enrichment profile in both directly exposed zebrafish and salmon embryos, showing that this epigenetic mark was conserved in both hnf4a loci of Atlantic salmon compared to the phylogenetically distant zebrafish (Fig. 2B, C, D; 5). ncRNA-seq analysis revealed 12 up- and 10 down-regulated DEmiRNAs in the F1 embryos, of which some have previously been connected

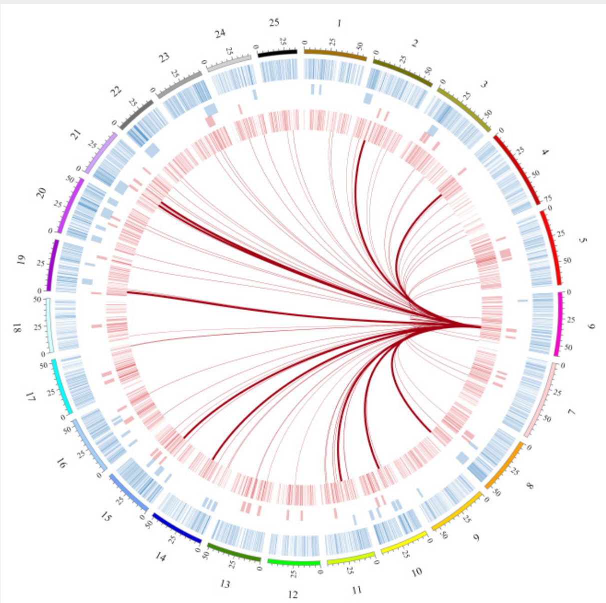

Figure 3. Target analysis of differentially expressed miRNA dre-let-7g-5p.

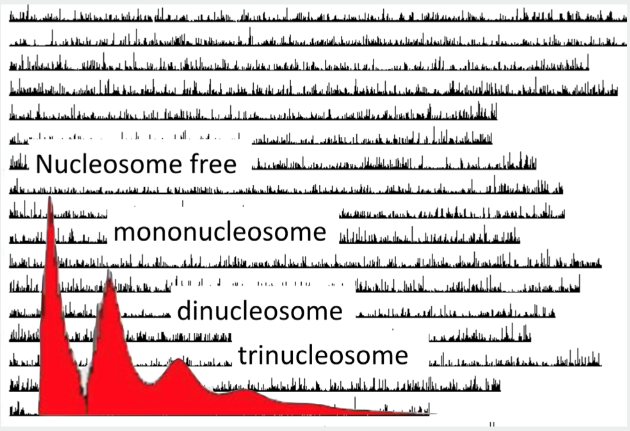

***Figure 4.** Chromatin Accessibility after gamma irradiation during embryogenesis measured by Assay for Transposase Accessible Chromatin sequencing (ATAC-seq).*

to ionizing radiation, such as miR-21, let-7g and miR-150). Gene target prediction analysis indicated 4,724 candidate mRNA targets for the 22 DEmiRs (Fig. 3; 7).

Conclusion: Embryogenesis and gametogenesis are two sensitive developmental windows for radiation induced adverse effects. At environmentally relevant dose rates, direct exposure of embryos revealed significant dose response on DEGs after 3h, but developmental phenotypes are observed only after exposures for >48hpf (1,6). With the aim to link different epigenetic marks from exposures into an epigenetic landscape, the epigenome, we have compared the transcriptome with the profiles of DNA methylation, histone modifications and noncoding RNAs in early gastrula stage embryos. To further elaborate on a systems biology understanding of the interactions between different epigenetic hallmarks we have introduced ATAC seq (Fig. 4; 8) to capture snap shots from the overall accessibility for gene expression of the genome.

References:
- *Hurem et al. 2018. Ecotox Environ Safe 154, 19–26.*
- *Hurem et al. 2018. Environ Poll 234, 855-863.*
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- *Ballangby J. MSc Thesis 2018, NMBU.*

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

RA3: EFFECTS OF LOW DOSE/DOSERATE) IONISING RADIATION IN MODELS MIMICKING HUMANS

NIPH: *D. Eide, N. Duale, H. Dahl, E.S. Berg, M. Amberger, B. Lindeman, K.B. Gutzkow, O. Myhre, T. Hofer, G. Brunborg, J. Andersen, A. Ihkansi, C. Instanes, A. Hauge, H. Dirven, A-K. Olsen*
NMBU: *P. Aleström, D.A. Brede, J.H. Kamstra. O.C. Lind, L. Lindeman, D.H. Oughton, B. Salbu, H.C. Teien., L. Valle*
NRPA: *T. Christensen*
PHE, UK: *C. Badie, M. Ellender, S. Bouffler*

Objectives: While there is deep knowledge on the biological effects of high dose/dose rate ionizing radiation, information on the effects of low dose/dose rate ionizing radiation is rather scarce. The overall objective of this work has been to contribute with novel scientific knowledge on the biological effects in mice of low dose/dose rate ionizing radiation. Research has been carried out in four areas, with different sub-aims.

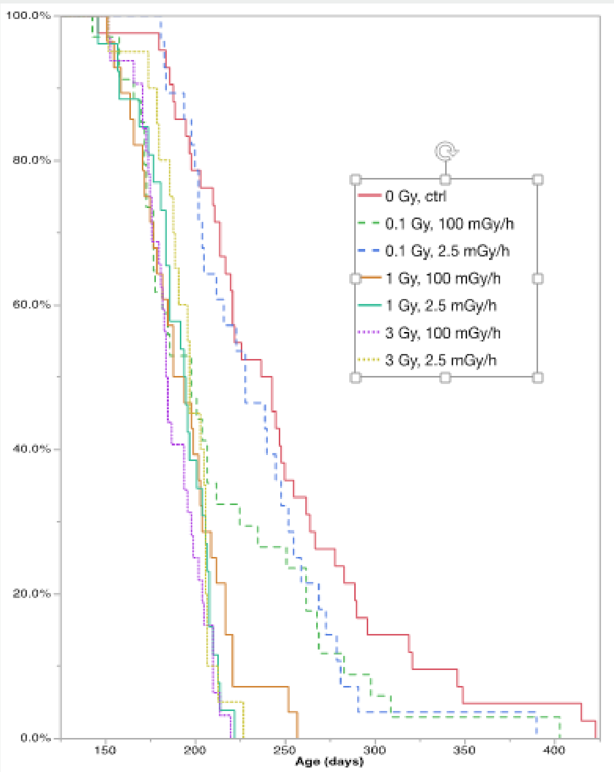

Figure 1. *Survival analyses of CBA Spm-mice exposed to ionizing radiation. Age in days at the x-axis and percentage surviving mice at the y-axis*

Sub-aims

1. Generate novel data on the risk of cancer following low dose rates or low doses ionizing radiation in a tailored mouse model.
2. Determine if paternal exposure to ionizing radiation can lead to changes in their 1st and 2nd generation progeny-transgenerational effect.
3. Identify a molecular biomarker signature for exposure
4. Develop an important CERAD toolbox assay (the Comet assay) in human metabolically active 3D-liver spheroids, in order to investigate effects of radiation alone, or in combination with the co-stressor arsenic, since human cells exhibit human-specific metabolic conversion of arsenic.

Results:
Sub-aim 1: We generated a mouse model that harbours a point mutation in one allele of a cancer-gene, and thus is more sensitive to development cancer (acute myeloid leukemia, AML) compared to alternative other mouse models. Mice were exposed to low to high dose rates (2.5-100 mGy/h) for 1 hour up to 3 months in the Figaro facility. Mice were kept until symptoms of AML, then culled and analysed. Our mouse model performs better than previous models for predicting AML from radiation exposure; since the mice acquire AML at an early age prior to the appearance of age-associated conditions that may hamper clear exposure-related AML-induction, which is a draw-back in previous studies. The CBA-Spm mouse model shows high sensitivity for discerning between doses in the low-to-intermediate range, whereas dose-rate differences were not detected (Fig. 1).

Sub-aim 2: In order to determine if paternal exposure to ionizing radiation can lead to transgenerational changes, progeny males from two strains of mice (c57BL/6 and CBA) were exposed to low-to-intermediate dose rates (2.5–100 mGy/h) for different time lengths to obtain a total dose of 3 Gy. The males were mated with naïve females after exposure. Offspring was fathered by males at ≤45 days after the end of exposure and fertilized with sperm containing high numbers of DNA lesions, or fathered by males at > 45 days after exposure where the fertilizing sperm originate from stem cell and containing no DNA damage. Epidydimal sperm was collected, somatic cell contamination removed, and then RNA was isolated and used for expression analyses of small non-coding RNA species. These small RNA molecules have been demonstrated to confer the message from the father to the next generation following paternal stress. The sncRNA expression analyses will be complemented with gene expression analyses in offspring of both F1 and F2-generations. Analyses are underway.

Sub-aim 3: The search for a molecular biomarker signature for exposure has been addressed in three different strains of male mice given different gamma dose rates, both low and high, for different time lengths to obtain a similar total dose. The chronic low dose rate gamma radiation (0, 2.5, 10, 100 mGy/h, total dose 3 Gy) caused a dose response relationship in micronucleated reticulocytes. We isolated RNA from livers and performed expression analyses of ~600 miRNAs by qPCR to identify differentially expressed miRNAs and to identify a molecular signature biomarker for radiation exposure. Results were subject to strict filtering, combined with advanced statistical analyses including machine learning and penalised regression methods. This approach led to the identification of a set of miRNAs that constitute a biomarker for responses in individuals exposed to a low gamma dose rate of 2.5 mGy/h alone (Tab. 1), or for individuals exposed to ≥ 2,5 mGy/h.

Sub-aim 4: Human liver organoids (Insphero 3D cell model) reflect the structure and biology, including the ability to metabolically activate compounds, of *in vivo* liver and is an attractive model to analyse genotoxicity. Previously, no methods were available for analysing genotoxicity in the Comet assay.

We succeeded in developing a method to process organoids into optimal amounts of single cells with high cell viability and DNA-integrity. We are the first to establish a protocol for comet assay in human 3D liver spheroids and demonstrate a clear dose response relationship following X-ray exposure (Fig. 2). DNA damage levels after arsenic-exposure are still under investigation.

Term	Estimate	Std Error	Wald ChiSquare	Prob > ChiSquare	Rank in Neural Network*	Rank in Boosted Tree*
Intercept	-107	16.9	40.01	<.0001*	na	na
mmu-miR-26a-5p	-13.9	1.11	158.2	<.0001*	1	3
mmu-miR-188-3p	-12.9	1.62	62.66	<.0001*	4	4
mmu-miR-140-3p	-8.88	1.31	46.01	<.0001*	5	-
mmu-miR-26b-5p	4.39	0.74	35.49	<.0001*	-	-
mmu-miR-181a-5p	7.65	1.73	19.6	<.0001*	3	-
mmu-miR-130a-3p	0	0	0	1.0000	2	-

Table 1. *Best miRNA-predictors for multivariate partition of 2.5 mGy/h irradiated versus control mice. Elastic net reduced the number of predictors from 21 to five. Ranking after effect size of miRNAs in Neural network and Boosted tree shown for comparison. N=19*

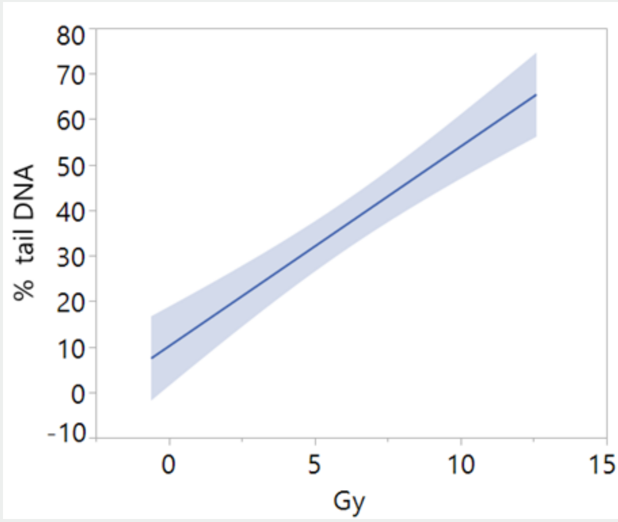

Figure 2. *Dose-response of X-rays in human Insphero 3D-liver spheroids in the comet assay*

Sampling in Fukushima, Japan
Photo: Deborah H. Oughton

RA3: RADIOSENSITIVITY IN TERRESTRIAL PLANTS

NMBU: *: J.E. Olsen, D. Blagojevic, Y.K. Lee, P. Bhattacharjee, D.A. Brede, O.C. Lind, K.A. Solhaug, L. Nybakken, B. Salbu*
NIVA: *L. Xie, K.E. Tollefsen*

Objectives: To compare sensitivity to gamma radiation in seedlings of Scots pine, Norway spruce and *Arabidopsis thaliana* and elucidate the mechanisms underlying their differential sensitivity. To assess whether UV-B affects the gamma sensitivity in a sensitive species (Scots pine) and if UV-B can possibly prime defence protecting towards low gamma levels.

Methods: Under controlled environmental conditions, seedlings were exposed to gamma dose rates of 1-540 mGy/h from NMBU ^{60}Co source for 144 h. Scots pine seedlings were also co-exposed to UV-B (0.35 W/m^2) and gamma radiation (10-100 mGy/h) with or without UV-B pre-exposure. Plants were phenotyped and genotoxicity and gene expression assessed.

Results: The two conifer species showed similar sensitivity to gamma with clear dose-response relationships with respect to growth inhibition (Fig. 1), cellular damage, mortality (≥40 mGy/h) and genotoxicity (≥1-10 mGy/h), with the latter persisting (genomic instability) 1.5 month post-irradiation. A persistent dose-response relationship for genotoxicity was evident also in *A. thaliana*, but no cellular damage or mortality and only a slight, transient developmental delay at ≥400 mGy/h (Fig. 1) were observed. UV-B co-exposure did not affect sensitivity to gamma radiation and we found no evidence of UV-B priming of defence systems protecting towards low level-gamma. Analyses of selected genes related to cell cycle control, DNA repair and antioxidants after gamma exposure did not reveal differences that could help to explain the differential gamma sensitivity between species. RNA seq of Norway spruce (1-100 mGy/h) showed up-regulation of DNA repair, energy metabolism and protein- and lipid degradation at ≥40 mGy/h, and down-regulation of photosynthesis at 100 mGy/h. A comparative RNA seq study in *A. thaliana* is ongoing.

Conclusions: Scots pine and Norway spruce show similar, higher sensitivity to gamma radiation as compared to the resistant *A. thaliana*. We have provided evidence that the two conifers are more sensitive to DNA damage than *A. thaliana*, in spite of gamma-induced up-regulation of DNA repair genes in conifers, as revealed by RNA seq of Norway spruce. Aiming at shedding light on differential sensitivity between species, RNA seq analyses of *A. thaliana* is in progress.

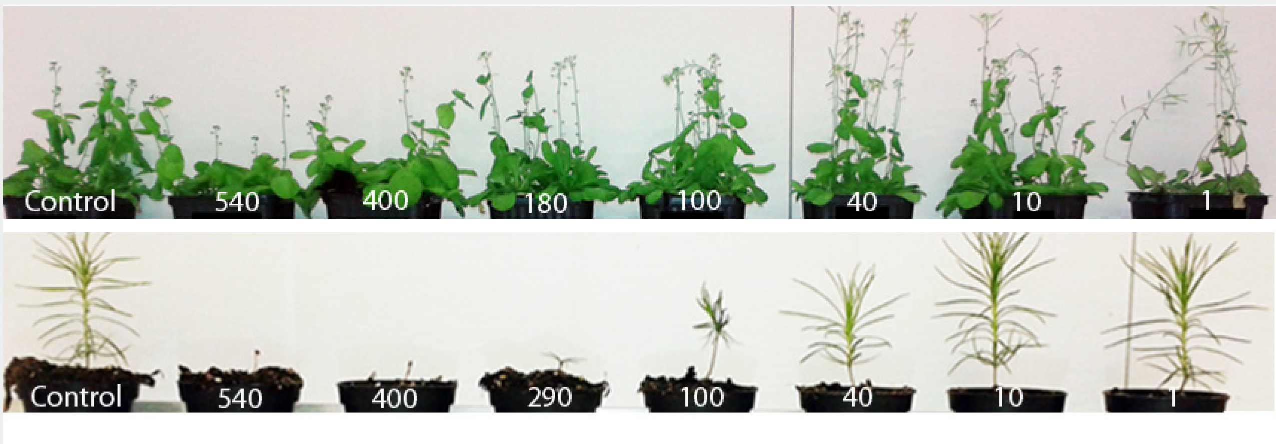

Figure 1. *Post-irradiation phenotype of A. thaliana (upper) and Scots pine (lower) 1.5 month after exposure to different gamma dose rates (mGy/h) for 144 h. (Plants are not shown to scale; A, thaliana in 8 cm pots, Scots pine in 5 cm pots)*

RA4: ADVERSE OUTCOME PATHWAY (AOP): A DATA AGGREGATION AND DATA MINING FRAMEWORK TO SUPPORT HAZARD AND RISK ASSESSMENT OF SINGLE AND MULTIPLE STRESSORS

NIVA: *K.E. Tollefsen, T. Gomes, K. Petersen, Y. Song, L. Xie*
NMBU: *L. Skipperud, H.C. Teien, B. Salbu*

Objectives: Develop Adverse Outcome Pathways (AOPs) as a framework to organize, integrate, evaluate and visualize the hazard and predict risk of single and multiple stressors.

Methods: Experimental and computational methods were developed for a number of CERAD-relevant biological species to characterise the toxic effects and populate Adverse Outcome Pathways (AOPs, Fig. 1) with relevant effect data for ionizing radiation (gamma), UV radiation (UVR) and chemical pollutants. A complementary suite of analytical methods was used to characterise external and internal exposure metrics. Effect and exposure data were aggregated into an AOP-informed database tool (NIVA RAdb™) to support hazard and risk assessments of single and multiple stressors.

Results: The CERAD effect toolbox have reached substantial maturity and data to populate the AOP from initial molecular interactions to adverse effects at the individual and population level (Fig. 1) are rapidly increasing for single stressors such as gamma and UV radiation (Gomes *et al.* 2018; Xie *et al.* 2019). Some of these data sets have been successfully assembled into high-quality AOPs and submitted to the AOP-wiki (https://aopwiki.org; AOP#216, 238, 245) for hazard characterisation of single stressors, but also to provide mechanistic explanations to interactions between multiple stressors along the AOP continuum (Song *et al.*, 2018). It is becoming increasingly evident that exposure metrics and the uptake of chemical stressors are affected by interactions between stressors, thus necessitating application of more holistic approaches to multiple stressor assessment (Salbu *et al.* 2019). Despite so, the AOP framework and extensions to more exposure-relevant aggregation and data mining frameworks such as the Aggregate Exposure Pathway, AEP (see www.niva.no/mixrisk and www.niva.no/nctp for details) seems to be required to adequately address ecologically-relevant multiple stressor exposure scenarios. Availability of high-quality exposure and

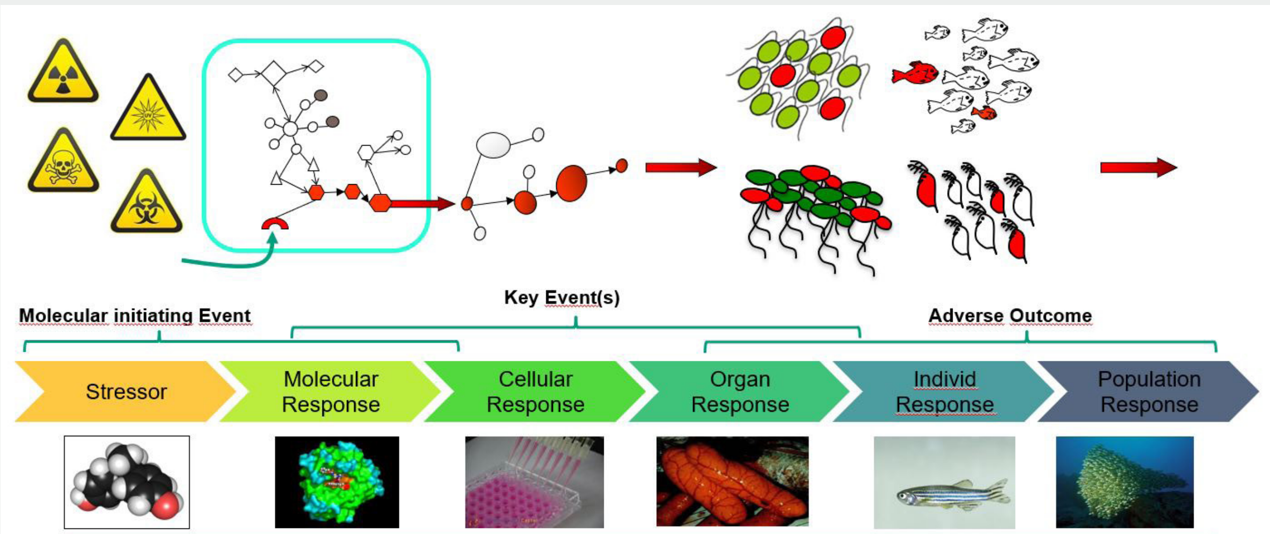

Figure 1. *Adverse Outcome Pathway (AOP) framework as data aggregation and data mining framework.*

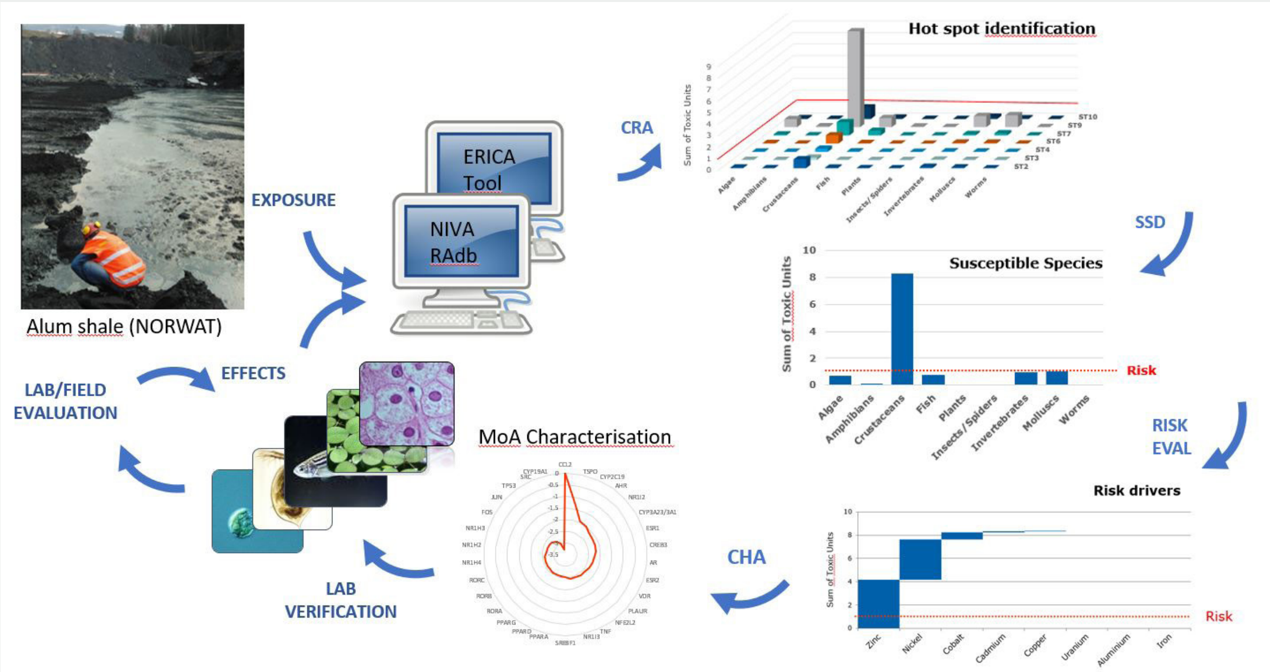

Figure 2. *AOP-informed cumulative hazard (CHA) and risk (CRA) assessment of alum shales from Gran (Norway) were performed using available exposure and effect data.*

effect data is nevertheless key to performing successful lab to field extrapolations. Recent effort to include gamma, UVR and radionuclides exposure and effect data into the NIVA RAdb™ (www.niva.no/radb) represent a novel step towards improving multiple stressor hazard and risk assessment (Skipperud *et al.* 2016; Petersen *et al.* 2019).

Conclusion: A combination of advanced experimental approaches (CERAD species assembly and effect toolbox), computational tools (toxicokinetics, toxicodynamics, and combined toxicity modelling) and conceptual exposure and effect aggregation and data mining frameworks (*i.e.* AOPs and AEPs) provide a novel approach to address hazards and risks of single and multiple stressors. Larger implementation of these approaches in case-specific impact assessments is expected to reduce model uncertainties and bridge the gap between lab- and field-based observations.

References:

- *Gomes, T., Song, Y., Brede, D.A., Xie, L., Gutkzow, K.B., Salbu, B., Tollefsen, K.E. (2018). Gamma radiation induces dose-dependent oxidative stress and transcriptional alterations in the freshwater crustacean Daphnia magna. Sci. Total Environ. 628-629: 206-216.*
- *Petersen, K., Brown, J., Tollefsen, K.E. (2019). Potential for environmental risk assessment of multiple stressors – chemicals and ionizing radiation. Environ. Sci. Manuscript.*
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- *Skipperud, L., Alvarenga, E., Lind, O.C., Teien, H.C., Tollefsen, K.E., Salbu, B, Meen Wærsted, F. (2016). Effekter og miljørisiko knyttet til inngrep i områder med sulfidrike mineraler. Ås, Norway: NMBU.*
- *Song, Y., Asselman, J., De Schamphelaere, K.A.C., Salbu, B., Tollefsen, K.E. (2018). Deciphering the Combined Effects of Environmental Stressors on Gene Transcrip-tion: a Conceptual Approach. Environ. Sci. Technol. 52: 5479-5489.*
- *Xie, L., Solhaug, K.A., Brede, D.A. Lind, O.C., Song, Y. Salbu, B., Tollefsen, K.E. (2019) Modes of action and adverse effects of gamma radiation in the aquatic macrophytes Lemna minor. Sci. Total. Environ. Submitted.*

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

Research performed by CERAD Young Scientists

An essential ingredient in CERAD is researcher training and education to provide an internationally attractive research environment, and to produce candidates that are internationally competitive within radioecology and ecotoxicology. In total, 26 PhD students and 9 PostDocs have been associated with CERAD since the start in 2013. Eight PhDs students have already defended their PhD thesis, and the opponents have been rather impressed.

CERAD/NMBU PhD Student Frøydis Meen Wærsted participated in the Forsker Grand Prix in 2018 (see photo). She presented results of her work on alum shale and leachate of both radionuclides and metals to the environment. She received good scores from the professional judges.

The young scientists (PhDs, Postdocs) are doing their research within the CERAD research areas RA1–RA4, usually in collaboration with different CERAD partners, also with international support. The research provided by the young scientist are judged to be of very good/excellent quality. Highlights from young scientists that were given during the CERAD Annual Conference are presented in the following pages. CERAD looks forward to their dissertations and future research work.

Frøydis Meen Wærsted participated in Forsker Grand Prix.
Photo: Yngve Vogt/UiO

RA1: BIOIMAGING OF URANIUM IN *Daphnia magna*

NMBU: *I. Byrnes, O. C. Lind, D. Brede, S. Scheibener, B. Salbu*
Warsaw UoT: *J. Jaroszewicz*

Objectives: Using advanced, laboratory based imaging techniques, the uptake and retention in biota of inorganic pollutants such as radionuclide ions or particles can be characterized. *Daphnia magna* exposed to uranium (U) ions were selected to demonstrate these methods.

Methods: Nano computed tomography (n-CT) and micro x-ray fluorescence (μ-XRF) were utilized and results combined to demonstrate the uptake and distribution of U in *Daphnia magna*. Organisms were exposed to 800 μg/L U ions in aqueous solution for 24 hours. Submicron resolution n-CT (XRadia 400) at the Warsaw University of Technology and μ-XRF elemental mapping (Bruker M4 Tornado) at the NMBU Isotope Laboratory with a ~20 micron spot size.

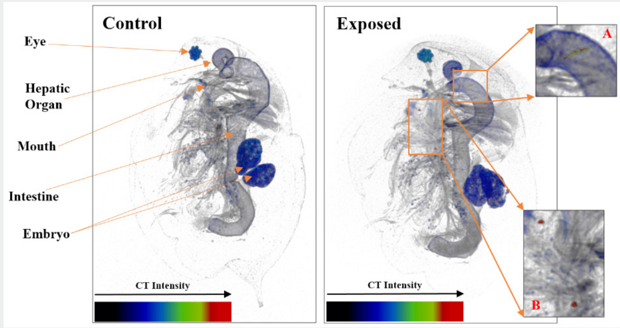


Figure 1. Reconstruction of control and exposed Daphnia magna by nCT. Areas of high density can be seen in A and B

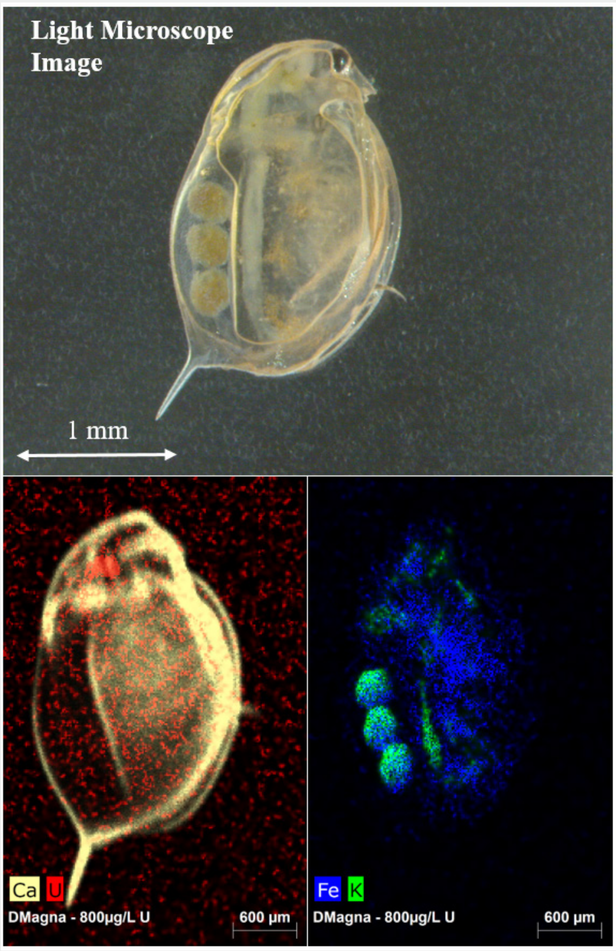


Figure 2. Elemental mapping using µXRF, of Daphnia magna with Ca and U shown on the left and Fe and K shown on the right.

Results: The results of the n-CT (Fig. 1) show the digital reconstruction of the control (left) and exposed (right) daphnia. In the exposed organism, areas of high density (shown in red) are located on the surface of the organism and inside the intestine. In figure 2, a light microscope image of the exposed organism is shown along with the elemental mapping based on μ-XRF. The yellow regions reflect calcium (Ca) in the carapace, while iron (Fe) and potassium (K) in the organism's internal organs are shown in blue and green. Finally, the U, in red, appears concentrated in the upper portion of the organism's intestine.

Conclusion: The objective of the presented work was to show the distribution of U in *Daphnia magna* through the combined use of n-CT and μ-XRF. As seen in figures 1 and 2, U is concentrated in the intestine of the organism and possibly in locations on the surface. Moving forward, this combined method will be used to examine U distributions at different concentrations in different organisms as well as comparing the distributions of U ions to U nanoparticles.

RA1: EXPOSURE CHARACTERIZATION AND GAMMA DOSIMETRY FOR DOSE-EFFECT STUDIES AT FIGARO

NRPA: *E.L. Hansen*
NMBU: *O.C. Lind, D.H. Oughton, B. Salbu*

Objectives: The FIGARO ^{60}Co gamma irradiation facility (Lind *et al.*, 2018) at NMBU is dedicated to the study of effects on living organisms from acute or chronic ionizing radiation exposures, either alone or in combination with other stressors such as UV radiation, metals or radionuclides. To ensure good dosimetry and to make exposures reproducible, we have developed a framework of working guidelines and computer software for FIGARO (Hansen *et al.*, 2018).
Methods: The software includes a Geant4 Monte Carlo radiation transport model of the FIGARO exposure hall and source (Fig. 1), along with applications for dose planning (under development) and for dose recording and reporting. The Geant4 model can be updated with the geometries of actual experimental setups.

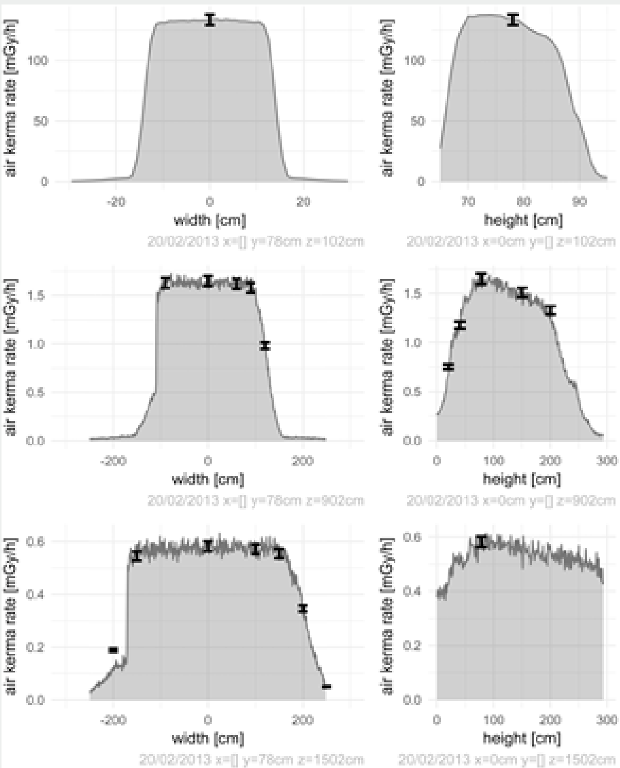


Figure 1. *Measured (error bars) and simulated air kerma rates over three cross sections of the FIGARO exposure hall.*

Results: The framework encourages users to devote adequate resources to planning of exposures and calls attention to the type of data that should be recorded so that exposures can be reproduced. Users are also strongly encouraged to present their effects data against whole-system or whole-body absorbed dose rates and accumulated doses, and with information on the type of exposure, in published work. When this information is missing, it is difficult to interpret results from exposures, to compare results with literature data and to put these results into context.

Conclusion: Several recent publications have pointed out the need for improved dosimetry in radiobiological or radioecological work, including improved reporting of dosimetry in papers. The dosimetry framework for FIGARO aims to give regular and expert users the tools required for adequate planning, recording and reporting of exposures in order to ensure good dosimetry.

References:
• *O.C. Lind, D.H. Oughton & B. Salbu (2018): The NMBU FIGARO low dose irradiation facility, International Journal of Radiation Biology, DOI:10.1080/09553002.2018.1516906*
• *E.L. Hansen, O.C. Lind, D.H. Oughton & B. Salbu (2018): A framework for exposure characterization and gamma dosimetry at the NMBU FIGARO irradiation facility, International Journal of Radiation Biology, DOI:10.1080/09553002.2018.1539878*

RA2: THE IMPORTANCE OF SELENIUM SPECIATION ANALYSIS ON ANTIOXIDANT STATUS MONITORING

NMBU: *E. Reinoso-Maset, P. Lebed, K. A. Jensen, B. Salbu*

Objectives: Selenium is an essential nutrient necessary for the proper functioning of many enzymes, has positive neuroprotective and immunological effects, and acts as an antioxidant agent via some key species that detoxify reactive components induced from free radicals and reactive oxygen species. Selenium deficient diets (such as in Norway) could result in negative health effects. This can be minimised by fortifying animal feed with Se compounds. However, Se uptake depends on the food consumed, the Se concentration as well as on the physico-chemical forms of Se (speciation). Therefore, this work has focused on optimizing the analytical methodology to determine Se and selenospecies in biological samples of feedstock animals that have been fed with different Se sources. Speciation results contribute to elucidate the Se uptake and metabolism, associated antioxidative activity, and its effect on animal growth and health.

Methods: Total Se concentration in feed, tissues, plasma, colostrum and milk was determined by inductively coupled plasma mass spectrometry (QQQICP-MS) after microwave acid digestion or an alkaline homogenisation. Determining the distribution of Se species in plasma, colostrum or milk (Fig. 1) required the fractionation of selenoaminoacids (SeMet, SeCys) from selenoproteins (GPx, SelP, SeAlb) by ultrafiltration prior to analysis using high performance liquid chromatography (HPLC) comprising high affinity or reverse phase columns (species separation) coupled to ICP-MS (detection).

Results: The developed sample preparation and analyses methodology was successfully applied to separate and quantify GPx, SelP, SeAlb and SeMet (Fig. 1) in plasma and colostrum/milk from sows or piglets that had been fed with diets enriched with either sodium selenite (inorganic) or selenomethionine (organic). The sows' trial showed that SelP, SeAlb and SeMet concentrations in colostrum and milk were significantly higher in the organic Se diet groups (Falk *et al.*, 2019). This increase of Se species levels might strengthen the antioxidative system and passive immunity of piglets at birth and during lactation.

Conclusion: Determining the occurrence and concentration of Se species during the animal life are key for understanding the contribution of Se from enriched diets to the animal's health.

References:
Falk M., Lebed P., Bernhoft A., Framstad T., Kristoffersen A. B., Salbu B., Oropeza-Moe M., J. Trace Elem. Med. Biol. 2019, 52, 176-185.

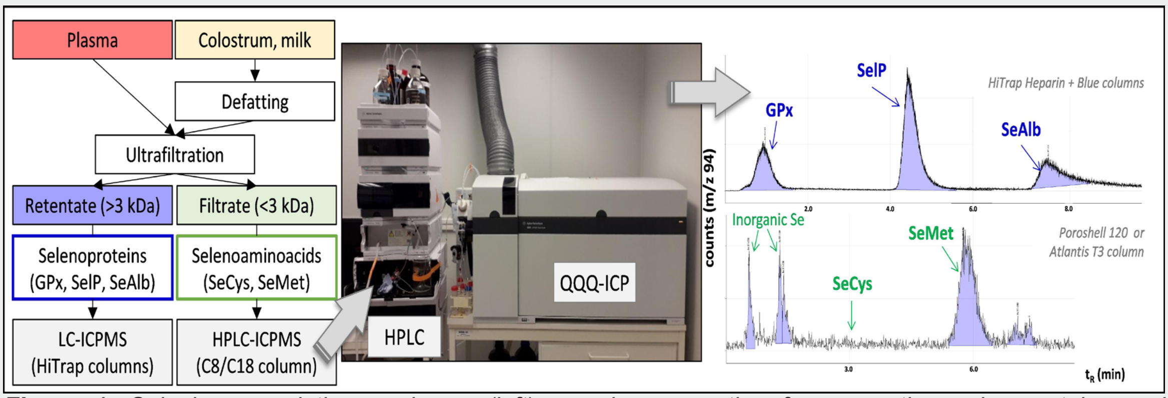


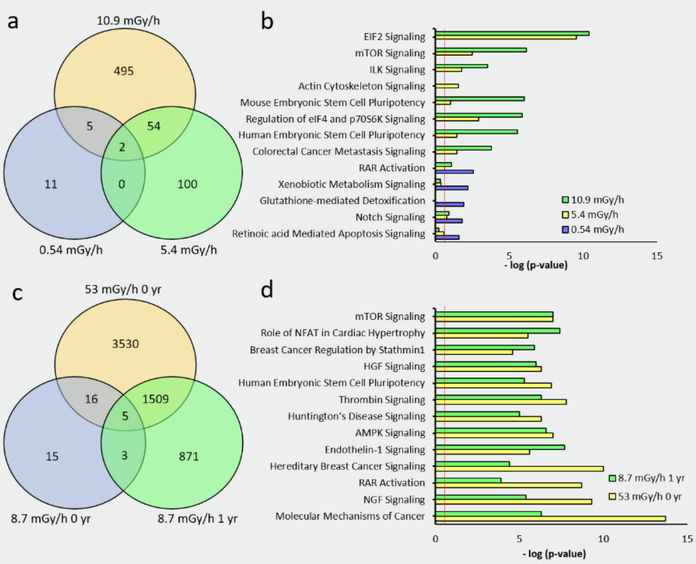
***Figure 1.** Selenium speciation analyses: (left) sample preparation for separating selenoproteins and selenoaminoacids; (center) HPLC-ICPMS instrumentation; (right) representative chromatograms (Se signal vs. retention time).*

RA3: REPROTOXICITY FROM GAMMA RADIATION EXPOSURE DURING SENSITIVE LIFE STAGES IN THE ZEBRAFISH (*Danio rerio*)

NMBU: *S. Hurem, J.L. Lyche, P. Aleström, D.H. Oughton, D.A. Brede, J. Kamstra, L.M. Martin, I. Mayer, R. Nourizadeh-Lillabadi, V.H. Lobert, V. Berg, S. Mutoloki, E. Skjerve, H.C. Teien, O.C. Lind, B. Salbu*
NIVA: *T. Gomes*
NRPA: *T. Christensen, E.L. Hansen*
NIPH: *K.B. Gutzkow, A.K. Olsen*
McMaster University: *C. Mothersill, C. Fernandez*

Objectives: To determine if parental gamma irradiation in gametogenesis causes heritable effects in offspring; and to compare effects in offspring of irradiated parents with those exposed during embryogenesis.

Methods: ABwt zebrafish were exposed during gametogenesis (27 days, 8.7 and 53 mGy/h) and embryogenesis, from 2.5 hours post fertilization for 3, 48, 72 and 96 hours (0.4, 0.54, 5.4, 9.6, 10.9, 15, 38 mGy/h). To assess exposure effects, microscopic observations, histopathology, ROS, LPO, Comet, MN and bystander assay and transcriptomics (RNA-seq, qPCR) were used.



Results: <u>Gametogenesis exposure</u> to 8.7 mGy/h caused reduced fertility, impaired oocyte growth and increased DNA damage and MN in adults, including teratogenicity (*e.g.*, eye development impairment), and genomic instability in offspring. Exposure to 53 mGy/h induced sterility for up to one year after exposure and 100% offspring mortality at gastrulation.
<u>Embryogenesis exposure</u>: Prolonged exposures to dose rates >0.4 mGy/h resulted in developmental disorders. Differentially expressed genes (DEGs) in embryos overlapped by 28 % between gametogenesis and embryogenesis (Fig. 1) and resulted in some common key regulators (*tp53* and *hnf4a*), and pathways (mTOR, RAR activation, cancer).

Conclusion: Radiation induced stress during parental gametogenesis causes heritable effects such as genomic instability in offspring. Obtained data can be used to identify effects related biomarkers, combined toxicity (*e.g.*, UV) and develop AOPs.

References:

- *Hurem, S., et al., 2018. Ecotox Environ Safe 166 359-365; Hurem, S., PhD Thesis 2018:11, NMBU;*
- *Hurem, S., et al., 2018. Environ Poll 234, 855-863;*
- *Hurem, S., et al., 2018. Ecotox Environ Safe 154 19-26; Hurem, S., et al., 2017. Env Res 159, 564-578; Hurem, S., et al., 2017. PLoS One 12(6)*

Figure 1. *Venn diagram analysis of the differentially expressed genes (left) and the comparison of most affected biological signalling pathways (right) derived from Ingenuity Pathway Analysis (IPA) in zebrafish embryos exposed to gamma radiation.*
(a-b) Embryogenesis 3-hour exposure (0.54, 5.4 and 10.9 mGy/h);
(c-d) Offspring of parents exposed during gametogenesis (27 days, 8.7 and 53 mGy/h) immediately and one year after exposure (at this timepoint the 53 mGy/h fish were sterile).

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RA3: GAMMA INDUCED REPROTOXIC EFFECTS IN *C. elegans* ARE LIFE STAGE DEPENDENT DUE TO IMPAIRED SPERMATOGENESIS

NMBU: *E. Maremonti, D.M. Eide, D.H. Oughton, B. Salbu, Y.A. Kassaye, F. Grammes, R. Guedon, C. Lecomte-Pradine, D.A. Brede*

Objectives: To assess the adverse effects induced by chronic exposure to gamma radiation in an organism tolerant to acute doses, such as the nematode *Caenorhabditis elegans*.

Methods: Determination of total brood size, growth effects, germ cell apoptosis, spermatid count, gene expression analysis, and Comet assay following exposure to chronic gamma irradiation (10-100 mGy/hr).

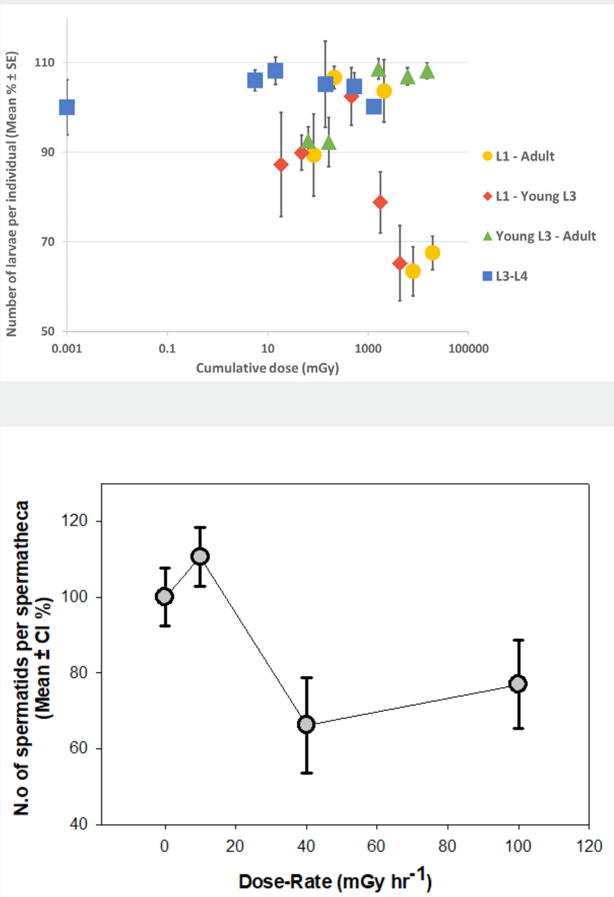

Figure 1a) *Total brood size assessed after target exposure of different developmental stages.* ***1b)*** *Spermatid reduction in hermaphrodites exposed to chronic doses of gamma radiation.*

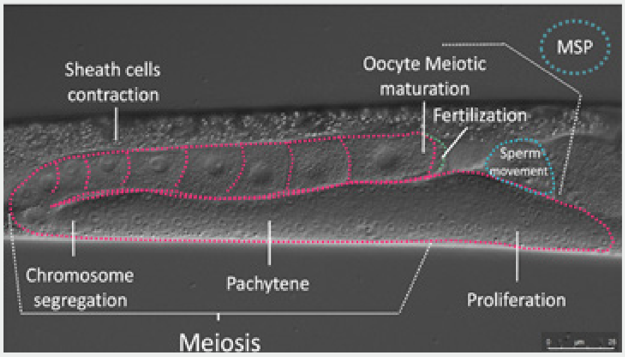

Figure 1. *Figure 1: Gene functions affected in the gonadal tissues by chronic gamma irradiation in the nematode C. elegans. Pink and blue dashed line indicates the gonadal arm for the production of oocytes and spermatids respectively. (MSP -> Major Sperm Proteins)*

Results: At dose rates greater than 40 mGy/hr, gamma irradiation induced life stage-dependent reprotoxic effects (Fig.1a), enhanced germ cell apoptosis, reduced number of spermatids (Fig.1b), down regulation of genes with essential reproductive functions (Fig. 2) and embryonic DNA damage.

Conclusion: The early life stages of development (L1-Young L3) in the nematode *C. elegans* have shown to be the most sensitive in terms of reproduction, under exposure to chronic doses of ionizing radiation. This effect was due to the impairment of gonadal development and gamete meiosis, leading to spermatids reduction. Our results suggest that the molecular initiating event of the shown adverse effects is the genotoxic effect in the gonadal tissue, resulting in enhanced defence mechanisms such as germ cell apoptosis, but also in defective sperm meiosis, which lead to sperm reduction and reproductive failure.

References:

Maremonti, E., et al. "Gamma induced Reprotoxic effects in C. elegans are Life Stage dependent." 3rd European Radiological Protection Research Week (ERPW); 2018-10-01 - 2018-10-05

RA3: THE *DAPHNIA* MODEL FOR MECHANISTIC UNDERSTANDING OF RADIATION EFFECTS IN AQUATIC INVERTEBRATES

NIVA: *Y. Song, L. Xie, J. Thaulow, K. E. Tollefsen*
NMBU: *D. A. Brede, Y. Lee, Y. Kassaye, B. Salbu*

Objectives: 1) Characterize critical toxicity pathways in *Daphnia magna* exposed to ionizing (gamma) and non-ionizing (UVB) radiation; 2) Develop Adverse Outcome Pathways (AOPs) for radiation-mediated effects in aquatic invertebrates.

Methods: *Daphnia magna* were exposed to 0-100 mGy/h gamma radiation for 8-21 days, and to 0-0.4 w/m^2 UVB radiation for 2-7 days to characterize the toxicity mechanisms involved in reproductive disruption. The NIVA *Daphnia* effect toolbox (https://www.niva.no/en/projectweb/nctp) was employed to measure biological effects at different levels of biological organization, such as changes to reproductive output, mitochondrial and lipid peroxidation-related reactive oxygen species (ROS) formation, changes to the mitochondrial membrane potential, lipid storage, ATP levels, biomarker gene expression and changes to tissue structures in *D. magna*.

Results: The bioassay results clearly suggested that four toxicity pathways were commonly involved in the reproductive effects of gamma and UVB radiation: the DNA damage-apoptosis pathway, mitochondrial membrane dysfunction-ATP depletion pathway, abnormal lipid metabolism pathway and abnormal calcium signalling-associated pathway. Both stressors also affected genes involved in the epigenetic regulation. Based on these findings and existing knowledge, a conceptual network of AOPs was developed to improve understanding of radiation-mediated reproductive effects in aquatic invertebrates (Fig. 1.).

Conclusion: Ionizing and non-ionizing radiation affected reproduction and triggered multiple toxicity mechanisms relevant for reproduction in *Daphnia*.

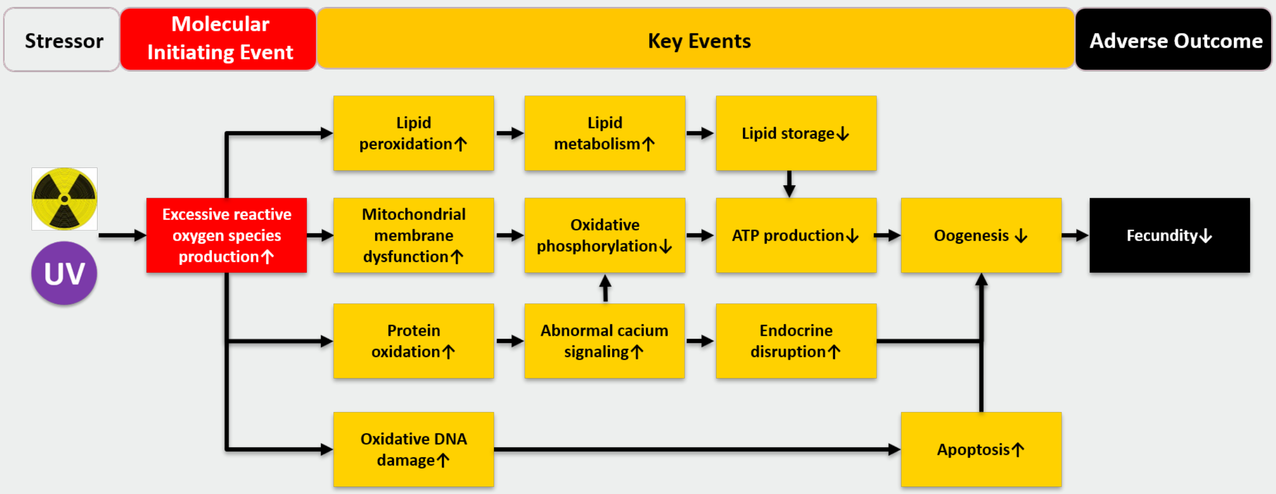

Figure 1. *Conceptual Adverse Outcome Pathway (AOP) for radiation-mediated reproductive effects in aquatic invertebrates.*

RA4: CHARACTERIZING THE MODE OF ACTION (MOA) AND ADVERSE EFFECTS OF GAMMA AND UV RADIATION AS SINGLE AND MULTIPLE STRESSORS IN THE AQUATIC PLANT *Lemna minor* EXPOSURE

NIVA: *L. Xie, Y. Song, D.A. Brede, O.C. Lind, B. Salbu, K. E. Tollefsen*
NMBU: *K.A. Solhaug, D,A. Brede, B. Salbu*

Objectives: Characterize the toxic responses in *L. minor* and develop Adverse Outcome Pathways (AOPs) to provide causal links between mode of action (MoA) and adverse effects of ionizing radiation (gamma) and UV radiation (UVR), alone and in combination (multiple stressors).

Methods: *L. minor* was exposed to gamma radiation and UVR either alone or in combination for 7 days. Toxicity endpoints such as cellular reactive oxygen species (ROS) formation, DNA damage (COMET or cyclobutene-pyrimidine dimers (CPD)), lipid peroxidation (LPO), oxidative defense mechanisms (non-photochemical quenching (NPQ) and glutathione (GSH)), pigments (chlorophylls and carotenoids), mitochondrial and chloroplast functions (CO2-uptake, PSII performance and oxidative phosphorylation (OXPHOS)) and growth parameters were measured.

Results: Gamma radiation caused a high number of dose rate dependent effects that were correlated (Fig.1). Low dose rates (14 mGy/h) induced DNA damage (COMET), inhibited frond development and reduced plant growth. Higher dose rates (>24 mGy/h) increased ROS formation, induced LPO, inhibited PSII and OXPHOS, reduced photosynthesis, induced NPQ, and reduced pigment content. UVR also displayed similar dose rate dependent effects from 0.5 w/m^2, although in this case DNA damage was measured as increase in CPD. Combined exposures to the two stressors caused a similar pattern of effects, however, enhancement and interactions between the stressors were frequently observed along the AOP continuum (Fig. 1).

Conclusion: The results demonstrate causal relationships between MoA and adversity for gamma radiation and UVR that were used to develop AOPs for *L. minor*. Combined toxicity studies revealed a combination of different interactions that, in more than half of the cases, led to enhancement of effects compared to effects observed for the single stressors.

References:

Xie et al., Mode of action and adverse effects of gamma radiation in aquatic macrophytes Lemna minor (submitted to Sci Tot Environ).

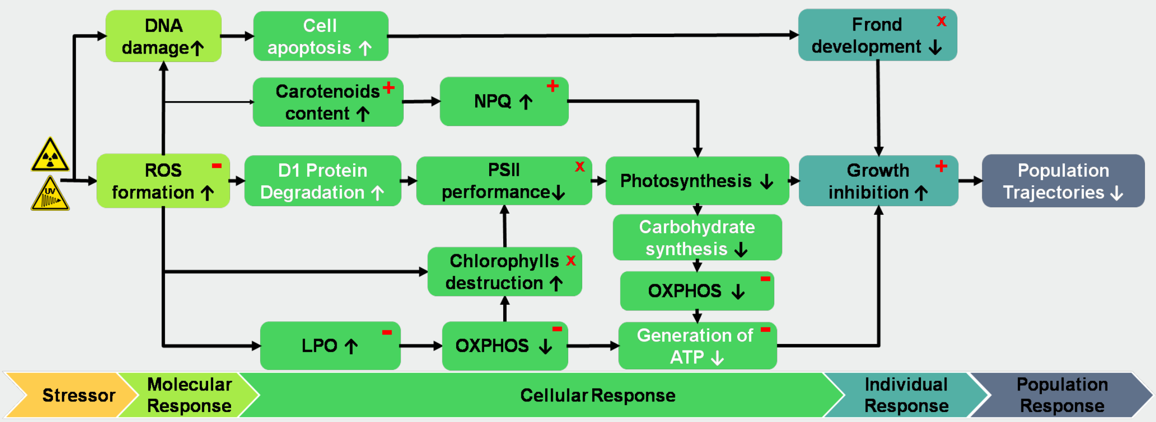

Figure 1. *Conceptual AOPs for gamma radiation and UVR exposure of Lemna minor. Black font denotes measured endpoints, whereas white font denotes endpoints requiring experimental verification. In the combined exposure, "+" denotes enhancement through interaction, "-" denotes lack of enhancement through interaction and "x" denotes enhancement without interaction.*

CERAD

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RA4: SOCIETAL CONSEQUENCES OF NUCLEAR ACCIDENTS

NRPA: *A. Liland, J. E. Brown, J. E. Dyve, M. Iosjpe, L. Skuterud, P. Strand, H. Thørring, M. A. Ytre-Eide*
NMBU: *D. Oughton, O.C. Lind, S. Navrud, E. Romstad, B. Salbu, Y. Tomkiv*
MET: *J. Bartnicki, H. Klein, M. Simonsen*
NIVA: *Y. Lin*

Objectives: 1) Model health and environmental impacts in Norway from a hypothetical accident at the Sellafield nuclear site; 2) use the modelling results to discuss challenges with a range of stakeholders to improve emergency preparedness; and 3) adapt a cost-benefit analysis (CBA) framework to radioactively contaminated sites.

Methods: Eight different models were used in a chain to calculate concentrations and dose rates to humans and biota in all ecosystems. Results were presented in a stakeholder dialogue seminar and further discussed using collaborative deliberation. Questionnaires were used to measure the degree of learning, networking, involvement and problem solving.

Results: The study showed that we could successfully link the 8 models. Key factors contributing to uncertainty were identified. Modelled concentrations in foodstuffs and dose rates to the environment showed that a fallout of this magnitude would lead to decades of problems and call for the implementation of mitigating actions. The stakeholder dialogue seminar showed that collaborative deliberation added significantly to increased learning (Fig. 1), networking, involvement and problem solving.

Conclusion: Linking all the models and discussing the results with a range of stakeholders gives a holistic view of the societal challenges. Future work will focus on model uncertainties and adaption of a CBA framework specifically to optimising mitigation of radioactively contaminated sites.

References:

- *Liland, Y. Tomkiv, D. Oughton, S. Navrud, E. Romstad & L. Skuterud (2017): The power of collaborative deliberation in stakeholder dialogue seminars, Journal of Risk Research, DOI: 10.1080/13669877.2017.1378247.*
- *Liland, O.C. Lind, J. Bartnicki, J. E. Brown, J. E. Dyve, M. Iosjpe, H. Klein, Y. Lin, M. Simonsen, P. Strand, H. Thørring, M. A. Ytre-Eide, B. Salbu. Using a chain of models to predict health and environmental impacts in Norway from a hypothetical nuclear accident at the Sellafield site. Submitted to STOTEN.*

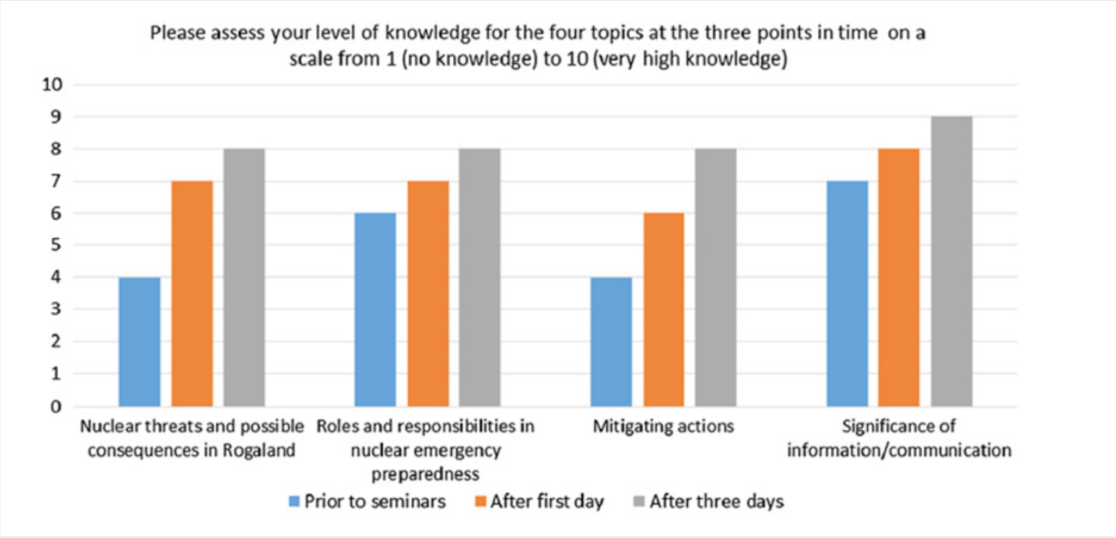


Figure 1. *Level of knowledge reported by the participants at the stakeholder dialogue seminar for four different topics prior to the seminar, after one day and after three days (median scores, n=30). Day 1 = lectures, Day 2 and 3 = collaborative deliberation.*

RA4: EMBRACING THE COMPLEXITIES: THE VALUE OF LISTENING TO PUBLIC IN NUCLEAR EMERGENCY PREPAREDNESS

NMBU: *Y. Tomkiv, D. Oughton*
Lancaster University: *B. Wynne*
Nordland Research Institute:
I. Bay-Larsen

Objectives: Aging nuclear power plants in Europe, increased transport of spent nuclear fuel along the Norwegian coast and increased risk of terrorist attacks, increase the probability of nuclear accidents with radioactive emissions affecting Norwegian territories. The objective of this study was to understand people's concerns, motivations, beliefs and value judgments that underlie individual decision-making in an emergency situation, in order to improve governance of nuclear or radiological accidents.

Methods: Six focus groups consisting of up to 10 people each were organised in Bodø in May 2018. The groups used one of the two hypothetical scenarios as a basis for discussion. The first scenario was an accident at the Sellafield reprocessing facility–based on the CERAD "Western Norway Scenario", and focused on the contamination of food chain.
The second scenario was an accident with a floating nuclear power plant, which focused on acute countermeasures like sheltering and iodine tablets. The transcripts of the discussions were analysed for prevailing topics using qualitative text analysis techniques.

Results: The results of the discussions demonstrated that the publics' relationship with emergency actors is affected by two major factors: knowledge and trust. The public knows surprisingly little about nuclear emergency preparedness, which causes them a great deal of concern. Their trust towards authorities is topic dependent and experience-based. Findings also show that there are societal and ethical factors that influence publics' perception of risk. They are generally positive about following official recommendations, but their response would depend on how effective and safe they think those actions are, their social relationships and previous experience with recommendations from authorities.

Conclusion: There are multiple publics within the Norwegian society and they differ in their concerns, information needs and expectations. Communication approaches for emergency preparedness should acknowledge these complexities and the development of such approaches should be done in collaboration with publics.

Floating Nuclear Power Plant
Photo: NRPA

International Collaboration

CERAD has during 2018 maintained and expanded upon bilateral and international collaborative initiatives. CERAD continues its Arctic Council activities, contributing to updated knowledge to the Arctic Monitoring and Assessment Programme (AMAP), reinforcing the scientific foundation with respect to radioactive contaminants and climate change. CERAD remains active within ongoing and new Nordic Nuclear Safety Research (NKS) projects, building upon its standing as an important player to the strengthening of relevant competencies in the Nordic region. CERAD maintains its prominent position within European research initiatives and activities relevant to radioecology including the European Radioecology Alliance (ALLIANCE), the Multidisciplinary European Low Dose Initiative (MELODI), the European Platform on preparedness for nuclear and radiological emergency response and recovery (NERIS), and the European Radiation Dosimetry Group (EURADOS). During 2018, CERAD contributed actively as a key partner within the EU Projects TERRITORIES (Integrated and graded risk management of humans and wildlife in long-lasting radiological exposure situations) and CONFIDENCE (Uncertainties in the area of emergency management and long-term rehabilitation) and further builds upon its position as a partner in the European Joint Programme for the Integration of Radiation Protection Research (CONCERT).

CERAD/NMBU continued in 2018 as the sole provider of a European MSc in Radioecology, a role which is supported through collaborative agreements (MoU) with a number of universities internationally. Such international collaboration serves to provide access to cutting edge experimental facilities in Germany, France, Australia and Spain as well facilitating access to contaminated sites (*e.g.*, Chernobyl, Fukushima) that enable and enhance CERADS field and research activities. CERADs broad international engagement is well represented in the list of co-authors in CERAD publications (see Publication list).

CERAD participated actively in international bodies and fora such as The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Atomic Energy Agency (IAEA), International Union of Radioecology (IUR), and the International Commission on Radiological Protection (ICRP). CERAD was represented by individual experts during the sixty-fifth session of UNSCEAR held in June of 2018 to which Norway was invited for the first time. CERAD was involved in the organisation of «The 7th International Conference on Radioactivity in The Arctic & Other Vulnerable Environments» in June 2018, CERAD scientists being well represented among the international participation.

CERAD is again well represented in IAEA activities related to radioactive particles (chair IAEA CRP), revision of technical safety guides and ongoing work on the societal impacts of Fukushima. CERAD's Deputy Director is the chairman of an IAEA/FAO/WHO Steering Group on Developing Guidance on the Control of Radioactivity in food and drinking water in Non-Emergency Situations.

CERADs close and fruitful collaboration with the IUR in ongoing developmental work related to an Ecosystem Based Approach for radioecology continued through 2018. CERAD experts work in ICRP task groups and CERADs' Research Director is a member of UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology. CERAD has cooperated with the intergovernmental OECD-Nuclear Energy Agency (NEA), in facilitating cooperation among countries with respect to advanced nuclear technology infrastructures, and the OECD NEA: Expert group on Management of Radioactive Waste After a Nuclear Power Plant Accident, both chaired by the CERAD Deputy Director. CERAD Deputy Director is also chair of the OECD/NEA Expert Group on Characterisation Methodology of Unconventional and Legacy Waste (EGCUL).

Professor Per Strand, Deputy Director

Experimental Facilities, Models and Tools

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

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

To meet the scientific requirements, the CERAD CoE has the possibility to perform cutting edge research due to access to unique experimental facilities, models and tools, both within CERAD and in collaboration with partner institutions and also internationally. Below, the experimental facilities, models and tools are listed in short. More information on each tool and infrastructure items can be found in the 2016 CERAD annual report.

Radionuclide, element and isotope ratios

CERAD is well equipped when it comes to determining radionuclides and other elements in the environment:

- At NMBU Isotope Laboratory and NRPA instrumentations and methods for determination of both gamma- beta- and alpha emitting radionuclides are available.
- At NMBU, three Agilent Triple Quadrupole ICP-MS (ICP-QQQ-MS) are utilized for the determination of long-lived radionuclides, including isotope ratios, and a large range of other elements in the periodic table (Fig. 1).
- At NMBU a Bruker M4 Tornado micro-XRF is installed.
- At very low concentration levels, the AMS facilities at Australian National University, Canberra, Australia and University of Seville, Spain are utilized.

Particles, speciation and fractionation techniques

CERAD has 30 years of experience within speciation and fractionation of radionuclides and other element in the environment. Therefore, equipments utilized for *in situ* and *in lab* speciation analysis are important tools, and include:

- At the Isotope laboratory, NMBU, CERAD has a unique particle archive containing sub-micrometer to millimetre sized radioactive particles released from different sources, varying with respect to composition, particle size, crystalline structure and oxidation states. The well characterized anthropogenic and naturally occurring particles originate from different historical sources and release scenarios such as nuclear weapon tests, conventional detonation of nuclear weapons, reactor accidents, accidental and routine releases from nuclear reprocessing facilities, different NORM sites, as well as the use of depleted uranium and particles associated with dumped waste.
- *In situ* fractionation systems such as chromatography-hollow fibre and tangential flow systems are available at NMBU Isotope Laboratory, and these are used in field expeditions all over the world where CERAD/NMBU is involved in aquatic research projects
- A FIFFF-ICP-MS (flow field flow fractionation) system is utilized for speciation work at the Isotope laboratory.
- HPLC-ICP-MS is especially utlized for determination of a series of selenium species, including GPx.

Synchrotron x-ray radiation facilities and imaging tools

Based on many years of close collaboration with scientists nationally and internationally CERAD/NMBU has access to and has utilized

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

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

CERAD experimental facilities

CERAD has access to different experimental facilities both at NMBU, but also at partner institutions. These facitlites includes:

- The NMBU low-medium dose gamma radiation exposure facility (Figaro). The NMBU constructed gamma irradiation source at Aas is the only one of its kind, provides a continuous dose rate field from 3 Gy/hr down to 400 µGy/hr, and allows simultaneous chronic exposure of samples over the whole dose-rate field. The CERAD/NMBU facility opened in 2003, and was upgraded in 2012, supported by the EU DoReMi project. The facility is utilized for a series of chronic exposure experiments (including combined gamma/alpha and multiple stressor studies) on various test organisms
- Fish Experimental Facilities - Transfer and Effects Experiments on Fish - both Freshwater and Marine Fish Species (NMBU).
- Zebrafish platform–transfer and effect studies on Zebrafish (NMBU).
- Mouse platform–transfer and effect studies on mice (NIPH).
- Greenhouses/Plant uptake and effect experiments (NMBU phytotron).
- Climate chambers for combined UV and gammma exposure (NMBU).

The CERAD biological effects toolbox

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

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

Models

At CERAD, a key focus is to link models describing radionuclides released from a source term, via dispersion, deposition, and ecosystem transfer to biological uptake and effects to estimate impact and risks for man and the environment as well as consequences for the economy and the society. Therefore, a series of models available at the CERAD partners are interphased:

- Dispersion and Transfer Models: Advanced air/marine transport models and real time/historic/future prognostic meteorological data are further developed by MET and NRPA.
- Ecosystem transport models: Advance fresh water (NIVA) and terrestial (NRPA) models, advanced models on dosimetry (NRPA), as well as human food chain and wild life food chain models (NRPA) are also utilized at

CERAD.

- Models for impact and risk assessment including the ERICA assessment tool and Cummulative Risk Assessment (CRA), are available (NRPA, NMBU, NIVA) to predict the hazard and risk of single stressors and combinations of these (multiple stressors).
- The economic modeling under CERAD covers so far two main parts linked to Potential nuclear events: 1) Scenario specific assessment of economic consequences for agriculture due to potential accidental release and radioactive contamination, 2) scenario specific assessment of economic consequences for recreational fisheries due to potential radioactive contamination.

HPLC coupled to Triple Quad ICPMS
Photo: Karl Andreas Jensen

Field Studies and Expeditions

Several expeditions and fieldwork have been performed every year within CERAD. Since the start of CERAD, fieldwork or expeditions concerning accidental release of radionuclides, nuclear test sites, naturally occurring radioactivity (NORM) sites and fieldwork concerning case studies have been performed. The CERAD fieldwork provide input to all CERAD research areas (RA), as investigations carried out relate to the speciation of radionuclides (RA1), mobility and transfer in the environment and bioavailability towards aquatic and terrestrial organisms (RA2) and also possible effects in the studied organisms from both radionuclides and other stressors (RA3). Thus, most results feed into the environmental risk assessment performed in RA4.

Field course arranged 2018

In June 2018, CERAD and the National University of Environment and Life Sciences (NUBIP), Ukraine, co-organized a successful field course within the Chernobyl exclusion zone in Ukraine. The aim of the course was to obtain practical skills of fieldwork within radioactively contaminated territories like Chernobyl exclusion zone (ChEZ), through solving actual problems within radioecology. The course participants were trained in field sampling techniques and worked within project teams on one of the following problems:

1. Forest fires in ChEZ: risk assessment and recommendations for preventive actions.
2. Nuclear power plant cooling pond drainage: environmental impact assessment and providing recommendations for further implementation.

The course will be arranged again June 2020 in Chernobyl and Kiev.

Fieldwork concerning accidental release of radionuclides to the environment

The Chernobyl exclusion zone (CEZ), Ukraine, were visited both in June, September and November 2018 to do in-field experiments. The fieldwork was performed in close collaboration with Ukraine partners at National University of Life and Environmental Sciences of Ukraine (NUBIP). The campaigns focus on aquatic environment, i.e., collection of water samples and fish species both to identify radionuclides and biomarkers. Comet assay was performed in field. Both CERAD partners (NMBU and NIPH) and NUBIP have worked with collected samples.

Fieldwork in Fukushima, Japan.
Photo: Deborah H. Oughton

Field work in the Red Forest in the Chernobyl 30-kilometer zone, Ukraine.
Photo: Brit Salbu

Fieldwork study on exposed pine and COMET assay in field

In connection with the field course in the Chernobyl Exclusion zone in June, we collected pine needles and shoots from three sites: high exposure, medium exposure, and low exposure. One sub-set of the samples were subjected to Comet assay on site, while other sub-sets were brought to NMBU for histological (microscopy) and metabolite analyses. We also brought back pine seeds for experimental purposes.

Fieldwork concerning the CERAD tracer field experiment

The third year with controlled tracer experiments with I-131 have been performed at NIBO's facilities at Apelsvoll and Furuneset, an inland and west coastal area, respectively. The transfer of I-131 in terrestrial environments with grass and potatoes was studied in July 2018. A total of 10 field works have were carried out since 2016 to study transfer of I-131 in grass and barley or potatoes, including collection of rainwater, soil profiles grass and barley.

CERAD Education Program

An essential ingredient in CERAD is researcher training and education (MSc, PhD, PostDoc) to provide an internationally attractive research environment, and to produce candidates that are internationally competitive within radioecology and ecotoxicology.
The ultimate aim of the education and training parts of CERAD is to ensure a sustainable workforce in radioecology. To do this we are dependent on interactions with the wider radioecology community, through outreach to students, teachers, employers and employees, and other stakeholders outside of our networks. Since radioecology is a multidisciplinary science, students on MSc or PhD projects in radioecology have a wide range of future carrier opportunities, and one of our goals is to put students in contact with potential employers and research projects, as well as to ensure that training and education in radioecology meets the needs of those employers.

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.
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. All courses are given in English and most courses are run intensively to make access possible for students from all over Europe. The MSc courses focus on radioecology, radiochemistry and ecotoxicology. The main courses within CERAD are listed in the table below. Every year CERAD have MSc students working on their MSc research projects associated to CERAD projects.

Phd and PostDoc education at CERAD

The MSc and PhD education at NMBU and collaborating universities are programmes given to provide the European nuclear stakeholders their future workforce. Of particular concern to the stakeholders (EU Commission, authorities, industry and professionals) are the significant and persistent needs for post-graduates with skills in radiochemistry, radioecology, radioecotoxicity, environmental modelling, radiation protection including radiobiology and dosimetry.

In 2018: Selma Hurem defended her PhD thesis February 13th, 2018 and Leonardo Martin defended his PhD thesis February 20th, 2018.

In 2018, 4 new PhD students started their work funded full or part time from CERAD 2018. This means that

- eight PhDs students have already defended their PhD work in CERAD (2 in 2014, 1 in 2015, 2 in 2016, 1 in 2017, 2 in 2018),
- seventeen students are currently working full time or associated to CERAD (per. 31st December 2018)
- two new PhD position will be filled in 2019.

In total, this is 26 PhD students associated with CERAD to date. We can therefore expect several dissertations the next coming years, and 4 dissertations already in 2019. There were also three PostDocs associated with CERAD in 2018, while the total of 9 PostDocs have been funded by CERAD since the start in 2013. One new Postdoc position will be available in 2019.

Internationally organized courses 2018

During 2013–2018, CERAD has arranged several international short courses, either at NMBU or at other host institutions. In 2018, The National University of Life and Environmental Sciences of Ukraine (NUBiP) and Ukrainian Institute of Agricultural Radiology (UIAR) in collaboration

The CERAD course portfolio within the fields of radiochemistry / environmental radioactivity / ecotoxicology

Course code	Title	ECTS	Course syllabus in short	Course responsible
KJM350	Radiation and Radiochemistry	10	http://www.nmbu.no/course/kjm350	Lindis Skipperud
KJM352	Radiation and Radiation Protection	5	http://www.nmbu.no/course/kjm352	Lindis Skipperud
KJM351	Experimental Radioecology	10	http://www.nmbu.no/course/kjm351	Ole Christian Lind
KJM353	Radioecology	5	http://www.nmbu.no/course/kjm353	Ole Christian Lind
KJM360	Assessing Risk to Man and Environment	10	http://www.nmbu.no/course/kjm360	Deborah H. Oughton / Per Strand
MINA410	Environmental Radiobiology	5	http://www.nmbu.no/course/mina410	Deborah H. Oughton
FMI309	Ecotoxicology	10	http://www.nmbu.no/course/fmi309	Hans Christian Teien
FMI310	Environmental Pollutants and Ecotoxicology	15	http://www.nmbu.no/course/fmi310	Hans Christian Teien
FMI330	Effect and biomarker methods in (eco)toxicology	5	http://www.nmbu.no/course/fmi330	Knut Erik Tollefsen

with CERAD/NMBU organised a field course ("Experimental Radioecology and Radiobiology") in Chernobyl and Kiev from the 1st to 15th of June as part of a SiU project collaboration Norway–Ukraine. The course is open to both MSc and PhD students. Similarly, seven international students including four SiU project funded students from NUBIP participated in the annual KJM351 Experimental Radioecology course in January, organized by CERAD/NMBU with contribution from NUBIP scientists.

International cooperation

CERAD is also one of the founding members of the The European Network on Nuclear and Radiochemistry (NRC) Education and Training, legally created in 2016: http://nrc-network.org/. The objective and functions of the European NRC Network are to cooperate in NRC education and training in Europe, to promote development of NRC education and training in Europe, to represent NRC education and training community towards other organizations and society, to promote and organize student and teacher exchange between partners and to organize common courses in NRC.

Memorandum of Understanding (MoU) covering both education, research and exchange of students and staff, have been signed between CERAD/NMBU and several universities and research institutes in Russia, Ukraine, Japan, Canada, Spain and Kazakhstan.

Within the CINCH-II project, Letter of intent (LoI) and ERASMUS+ Inter-institutional agreement 2014-21 has been signed with all participating universities: Czech Technical University in Prague (CTU, Czech Republic), Chalmers University of Technology (CHALMERS, Sweden), University of Helsinki (UH, Finland), Loughborough University (LU, United Kingdom), University of Leeds (UNIVLEEDS, United Kingdom), University of Oslo (UiO, Norway).

Radioecology E&T platform and link to other education and training platforms

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

- Radioecology exchange: https://wiki.ceh.ac.uk/display/radex/The+Radioecology+Exchange
- CINCH Nuclear chemistry: https://nucwik.wikispaces.com/
- DoReMi training & education: http://www.doremi-noe.net/training_and_education.html

Within the Radioecology Exchange webpage, **CERAD has developed an education and training platform**, linking education in different nuclear disciplines together. The Radioecology Education and Training Platform is a website focal point for students and professionals interested in radioecology, and it was developed as part of the EC STAR project and further developed during EC COMET project. The platform presents an overview of education and training course modules within radioecology/environmental radioactivity presently offered by the STAR and COMET consortiums, and will be further developed by the CONCERT-TERRITORIES project. The whole Radioecology Exchange, including E&T platform is now maintained by the ALLIANCE.

Professor Lindis Skipperud, Director of Education

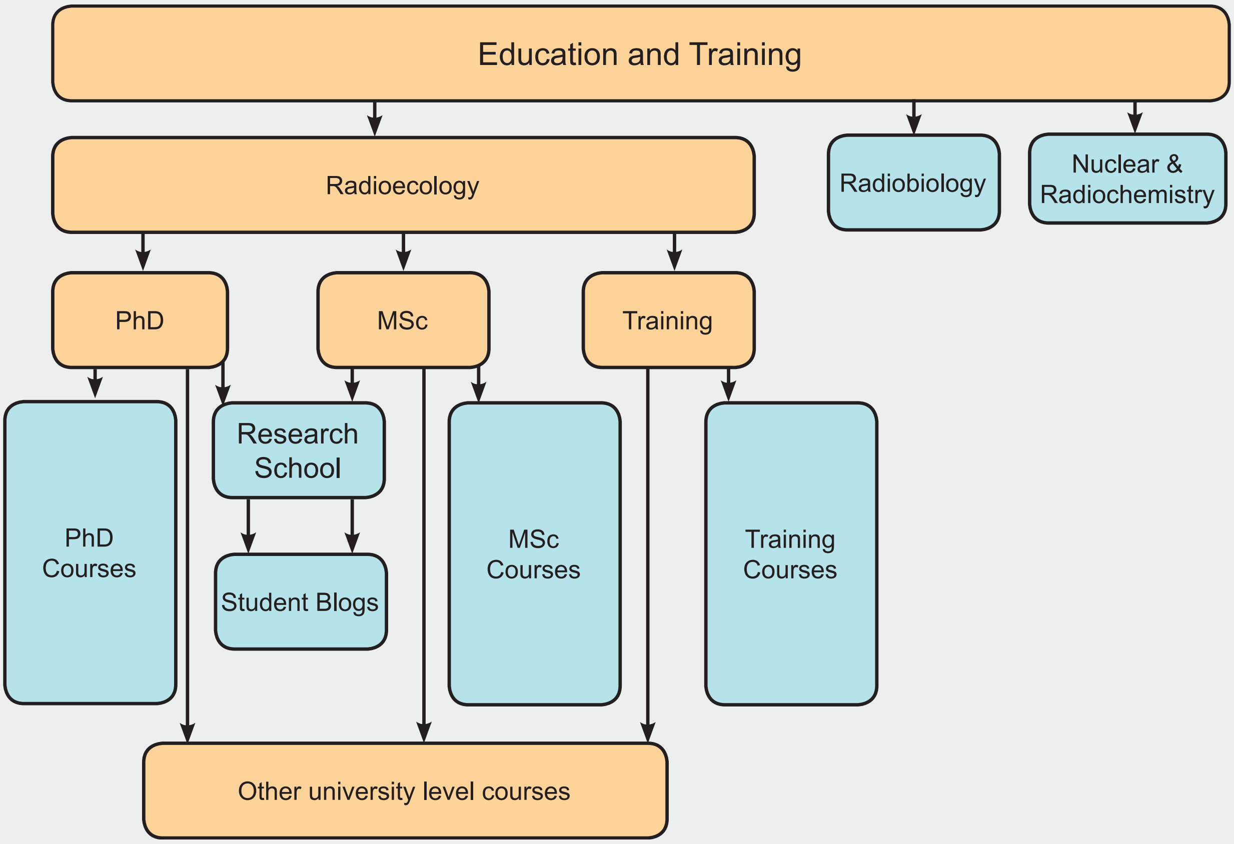
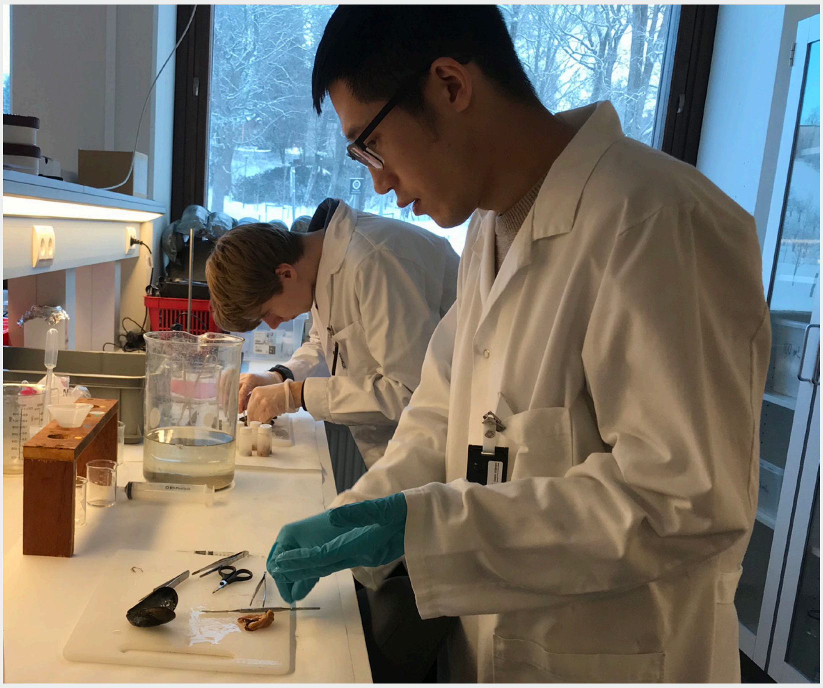
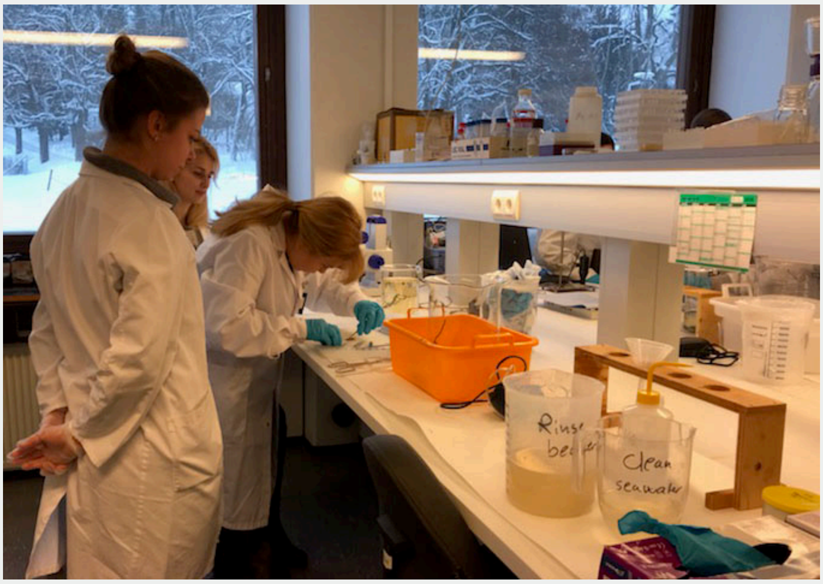


Figure 1. *The E&T platform on the Radioecology Exchange website.*





International students joining the intensive course in radioecology KJM351.
Photo: Marit Nandrup Pettersen

Funding and Expenditures

The present account reflects a high level of activity in CERAD CoE in 2018.

The CERAD CoE project financing constitutes of funding from the RCN and of a substantial in kind contribution from all CERAD partner institutions. In addition, several ongoing RCN (EU) funded projects at NMBU/Isotope Laboratory are included as a financial source for CERAD (Fig. 1).

The turnover for CERAD in the sixth operational year is MNOK 51.

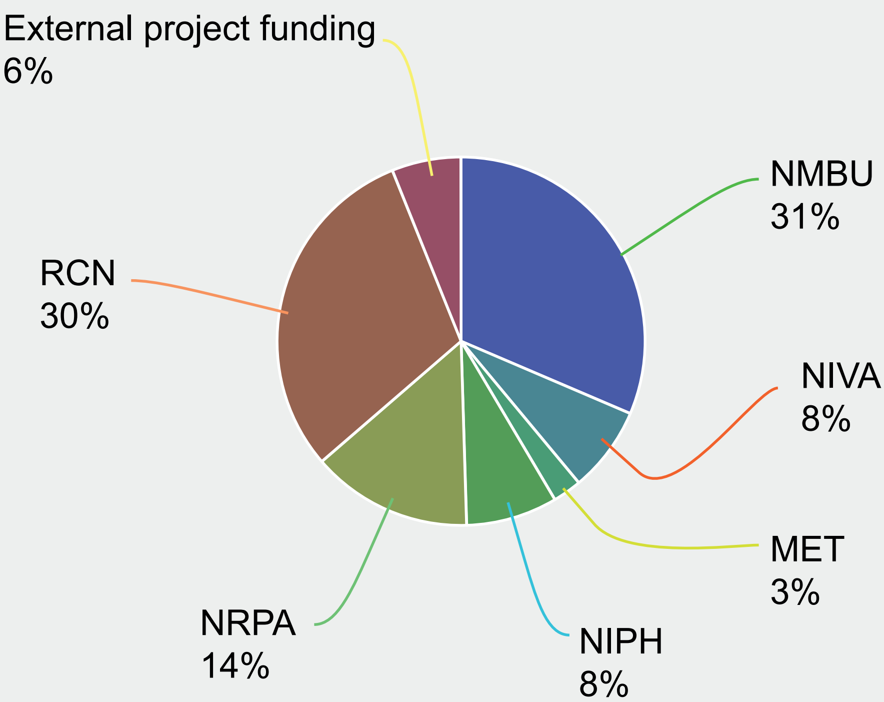
In 2018, the direct core funding contribution from RCN was MNOK 15.5. Other cash contributors (MNOK 2.3) were the Norwegian University of Life Sciences (NMBU) and The Norwegian Radiation Protection Authority (NRPA). The In kind personnel contributions from partner institutions are estimated to about MNOK 32.5.

The expenditure is primarily related to salaries amounting to MNOK 39.5, the sum also includes overhead covering indirect costs.

Other running expenses amounted to MNOK 10.

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

Jorunn Hestenes Larsen, Management Director



Relative (%) contribution to the CERAD total turnover 2018

CERAD Annual Conference

The annual CERAD conference was organized at the Norwegian Academy of Science and Letters in Oslo, Norway, January 29th–30th, 2018. The conference attracted about 80 of CERAD's scientists, including the CERAD Board, the international Scientific Advisory Committee (SAC) and the Relevance Advisory Committee (RAC).

The aims of the 2018 annual conference were to present the results obtained by the CERAD consortium since 2013, with focus on issues of relevance to the Mid-term evaluation of CERAD initiated by the Research Council of Norway. Thus, presentations included the strategic research (2017-2022) and associated Highlights, the education and training platform of CERAD and the active participation of CERAD members on the international arena. The presentations were followed by constructive discussions on priorities as well as on the way forward. The panel discussions were most useful with input from SAC members during the meeting, via e-mails or via skype from Japan.

Following the first day presentations and discussions, we all enjoyed HYBRIS, the CERAD House-band concert, prior to dinner.

Rector Mari Sundli Tveit
Photo: Yevgeniya Tomkiv

Annual conference participants gathered 2018
Photo: Yevgeniya Tomkiv

Societal Impact

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

In 2018, research has continued on the societal impacts of nuclear events. This has included work on the societal and ethical aspects of the Fukushima accident as well as health surveillance and thyroid screening in collaboration with the WHO, Fukushima Medical University and IAEA. As a follow-up to the EU SHAMISEN project (Nuclear Emergency Situations: Management and Health Surveillance), CERAD is leading work on the ethical challenges with health and dosimetry Apps, and will hold a consensus workshop in Oslo in 2019. CERAD has also participated in work on the planned rezoning of the Chernobyl Exclusion Zone (CEZ) in collaboration with the iClear project, chairing stakeholder meetings and participating in surveys of affected populations. These studies have involved participation of a wide-range of stakeholders (international and Ukrainian and Japanese authorities and scientists) including members of the affected population in Fukushima and Chernobyl, thus having a direct influence on both policymaking and society.

Work on the potential ecological impacts of Fukushima and Chernobyl continues, with follow-ups to UNSCEAR reviews of environmental effects. And CERAD has contributed to a series of workshops in collaboration with the IUR on ecosystem effects and potential confounding factors. This work includes the economic and societal consequences of environmental effects, through assessment of impacts on ecosystem services and environmental value.

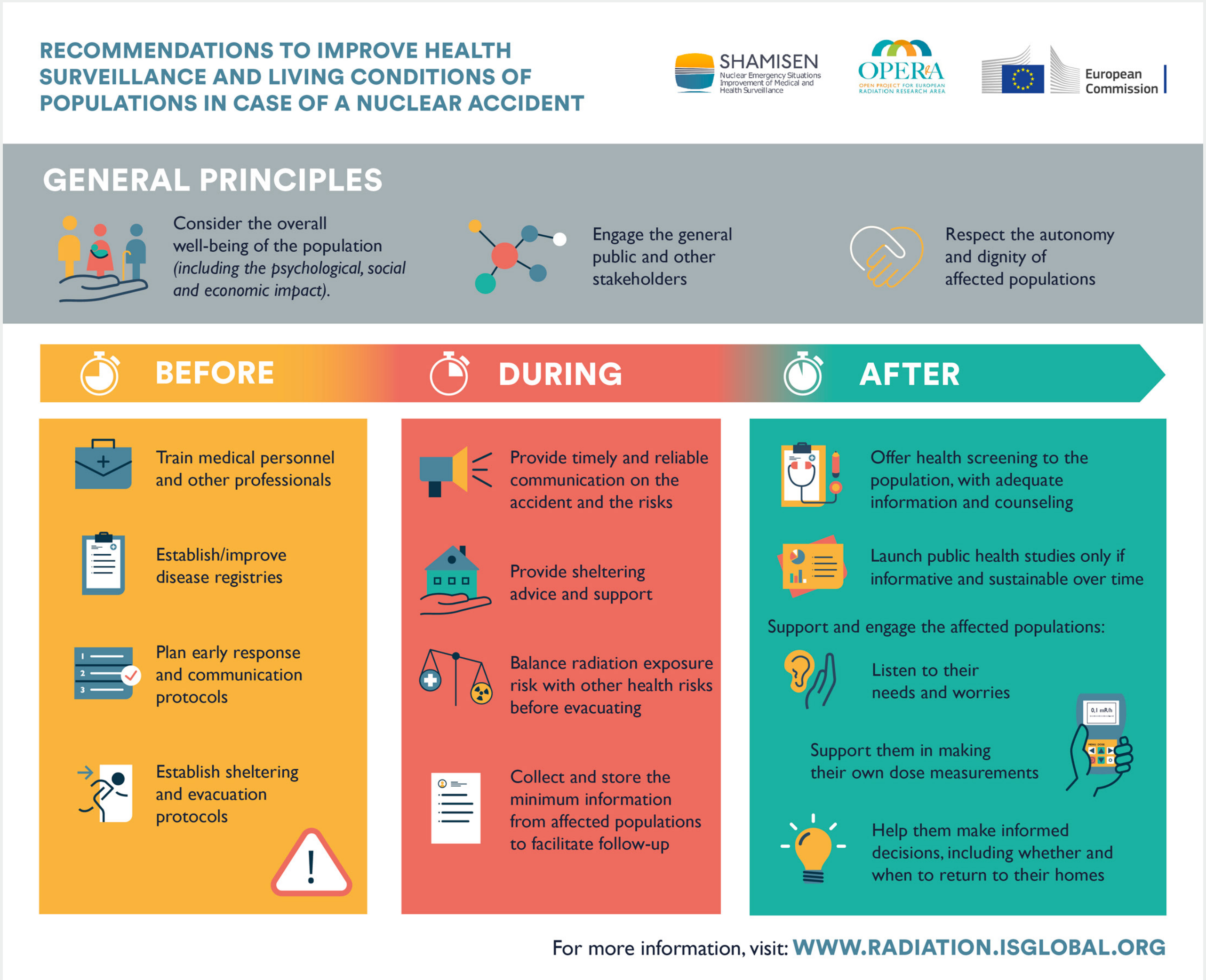
CERAD continues to cooperate with the intergovernmental OECD-Nuclear Energy Agency (NEA), in facilitating cooperation among countries with respect to advanced nuclear technology infrastructures, and the OECD NEA: Expert group on Management of Radioactive Waste After a Nuclear Power Plant Accident, both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

UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology is finalised a Declaration on Water and Ocean Ethics in collaboration with the Intergovernmental Oceanographic Commission (IOC). The Research director is a member of the Commission (nominated by the Norwegian Ministry of Education and Research), and has fronted both CERADs and Norwegian research and policy interests feature (*e.g.*, radioactive waste discharges, oil industries, OSPAR). An international water and ocean ethics seminar was held in Oslo in 2018.

CERAD continues to be involved in work on the socioeconomic aspects of accident scenarios, including the economic impacts of countermeasures. Stakeholder dialogues have the advantage of facilitating dissemination of CERAD's research as well as an increased understanding of the technical, organisational and socioeconomic challenges of radiation risks.

CERAD members participate in most of the EC H2020 EURATOM programme boards, and as such have been instrumental in formulating topics and text for the EU EURATOM calls. Through CONCERT, CERAD also participates in the new Social Sciences Platform in Radiation Protection, contributing to their SRA. EURATOM and CONCERT calls include a specific focus on uncertainties, impact and risk as well as risk communication, risk perception and societal aspects of radiological protection within EU research, which is fully in line with CERADs multidisciplinary approach and inclusion of research on social and ethical aspects in addition to its strong natural science foundation.

Professor
Deborah H. Oughton,
Director of Research



CERAD publication list 2018

Articles in international journals

Adam-Guillermin, C., Hertal-Aas, T., Blanchard, L., Alonzo, F., Armanta, O., Oughton, D.H., Horeman, N. (2018). Radiosensitivity and transgenerational effects in non-human species, *ICRP Proceedings Annals of the ICRP*, 47(3-4): s. 327-341

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CERAD in Media


Østlandets Blad

NMBU FORSKNING ÅS-MILJØET

Får 155 millioner til å fortsette forskningsprosjekt på NMBU

GLADE: Professor Lindis Skipperud (til venstre) og CERAD-prosjektleder Britt Salbu er svært fornøyde med å ha fått tildelt midler til forskningsprosjektet. Foto: Gisle Bjørneby/NMBU

Av Johanne Lund
03. juli 2018, kl. 16:10

Østlandets blad, 3 July 2018

NRK TV Folkeopplysningen, 26 September 2018:
https://tv.nrk.no/serie/folkeopplysningen/KMTE50002418/26-09-2018

NRK–Researcher Grand Prix 2018, Frøydis Meen Wærsted
25 September 2018, Latter Oslo / NRK TV: https://tv.nrk.no/serie/kunnskapskanalen/2018/MDDP17002518

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Jakub Jaroszewicz, Poland
Chloe Eastabrook, Great Britain
Mei He, China
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CERAD Conferences and Workshops

Joint US / Nordic Workshop on
Nuclear Security and Forensics in the Nordic region
Oslo 17th-19th January 2018
Organizer: NRPA, STUK and SSM in association with the U.S. Department of State, and in cooperation with CERAD

CERAD Annual Conference,
The Norwegian Academy of Science and Letters,
Oslo 29th-30th January 2018
Organizer: CERAD

UNESCO
World Commission for Ethics of Scientific Knowledge and Technology
(COMEST)
Seminar on Water Ethics:
Ocean, Freshwater and Coastal Areas
The Norwegian Academy of Science and Letters
Oslo 9th May 2018
Organizer: COMEST, NMBU/CERAD, KD

7th International Conference on Radioactivity in the Arctic & other Vulnerable Environments
Oslo 18th-20th June 2018
Organizer: NRPA and IUR, in cooperation with CERAD, IAEA, Roshydromet, Lawrence Livermore National Laboratory, European Radioecology Alliance and AMAP

UV-radiation protection and UV-risks in perspective: the UV-Sievert
Harry Slaper, RIVM, Netherlands
Oslo 1st November 2018
Organizer: NRPA and NMBU/CERAD

Research Director speaking at the International Symposium on Radiation Disaster Science, Fukushima
Photo: Fukushima Medical University

Norwegian University of Life Sciences

DSA Norwegian Radiation and Nuclear Safety Authority

Norwegian Meteorological Institute

NIPH Norwegian Institute of Public Health

NIVA Norwegian Institute for Water Research