Norwegian Centre of Excellence

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

ANNUAL REPORT 2019

Norwegian University of Life Sciences

Norwegian Centre of Excellence
The Research Council of Norway

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

CERAD Annual Report 2019 (RCN Project Number 223268)

Coverpage: Fieldwork with the Vågå Tamreinlag at Valdresflya, Jotunheimen, Norway: helicopter herding of domestic reindeer, including 3 reindeer with GPS gamma dosimeters.
Photo: Ole Christian Lind

Coverpage inside: The tower of the sunken USSR nuclear submarine «Komsomolets» at 1673 m depth south of Bear Island.
Photo: Ægir 6000, Institute of Marine Research
Design & Layout: Design idea by Signe Dahl, NMBU. Layout by Quentin Mennecart.

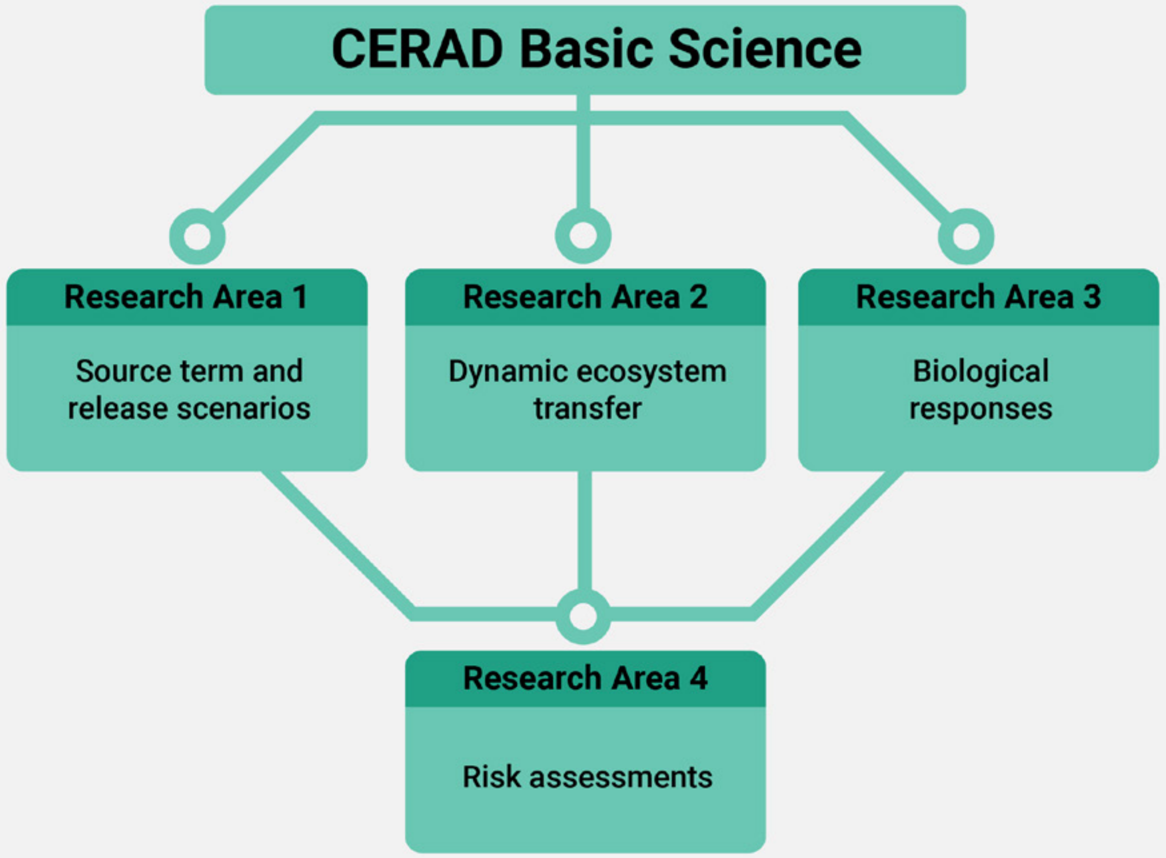
CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

WHO ARE WE?

The CERAD Centre of Excellence for Environmental Radioactivity was established in 2013 to perform long term research to improve impact and risk assessments associated with environmental radioactivity, also combined with other stressors. The scope includes man-made and naturally occurring radionuclides that were released in the past, those presently released as well as those that potentially can be released in the future. The strategic research agenda covers a broad scientific field, and the program is based on the interdisciplinary effort from scientists representing the five CERAD partners (NMBU, DSA, MET, NIPH, NIVA) as well as our network of national and international collaborators.

OUR OBJECTIVES

CERAD's core objective is to provide the scientific basis for impact and risk assessments which underpin management of radiation risks



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

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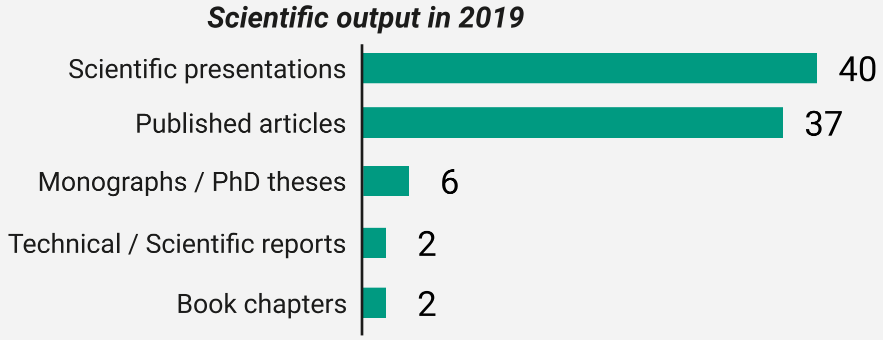
Acronyms and Abbreviations

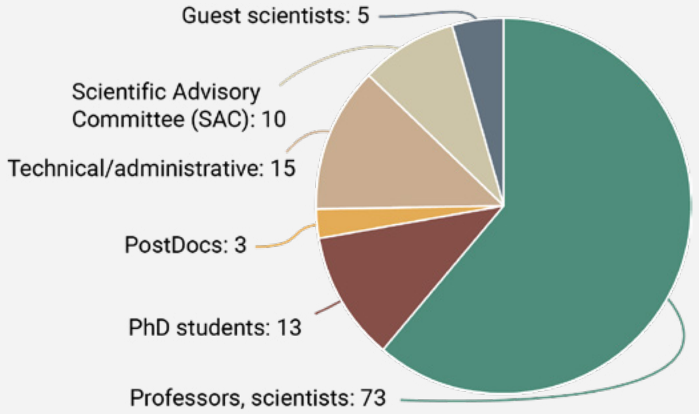
ALLIANCE	European Radioecology Alliance (European Platform in Radioecology)
AMAP	Arctic Monitoring and Assessment Programme
CERAD	Centre for Environmental Radioactivity
CoE	Centre of Excellence
COMEST	World Commission on the Ethics of Scientific Knowledge and Technology
COMET	Co-ordination and Implementation of a pan-European Instrument for Radioecology
CONCERT	European Joint Programme for the Integration of Radiation Protection Research
CONFIDENCE	Coping with uncertainties in the area of emergency management and long-term rehabilitation. Research project under CONCERT
DIKU	Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education
DoReMi	EU project Low Dose Research towards Multidisciplinary Integration
DSA	Norwegian Radiation and Nuclear Safety Authority (formerly NRPA)
EURADOS	European Radiation Dosimetry Group (European Platform in Dosimetry)
EURATOM	European Atomic Energy Community
FAO	UN Food and Agriculture Organization
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IFE	Institute for Energy Technology
IMR	Norwegian Institute of Marine Research
IUR	International Union of Radioecology
MELODI	Multidisciplinary European Low Dose Initiative (European Platform in Radiobiology)
MET	Norwegian Meteorological Institute
NEA	Nuclear Energy Agency of OECD
NERC	UK Centre for Ecology and Hydrology
NERIS	European platform on preparedness for Nuclear and Radiological Emergency Response and Recovery
NIBIO	Norwegian Institute of Bioeconomy Research
NIPH	Norwegian Institute of Public Health
NIVA	Norwegian Institute for Water Research
NKS	Nordic Nuclear Safety Research
NMBU	Norwegian University of Life Sciences
NMBU/BIOVIT	Faculty of Biosciences, NMBU
NMBU/HH	School of Economics and Business, NMBU
NMBU/MINA	Faculty of Environmental Science and Natural Resource Management, NMBU
NMBU/VET	Faculty of Veterinary Medicine, NMBU

NORM	Naturally Occurring Radioactive Materials
NRC-Network	European Network on Nuclear and Radiochemistry Education and Training
NUBIP	National University of Life and Environmental Sciences, Ukraine
OECD	Organization for Economic Co-operation and Development
RAC	Relevance Advisory Committee
RadoNorm	EU project Research on Radon and other Naturally Occurring Radioactive Materials
RCN	The Research Council of Norway
REMPAN	Radiation Emergency Medical Preparedness and Assistance Network
RPA	Russian Research and Production Association
SAC	Scientific Advisory Committee
SHAMISEN	Nuclear Emergency Situations: Management and Health Surveillance
SHARE	Social Sciences Platform in Radiation Protection
SLS	Swiss Light Source
SRA	Strategic Research Agenda
TERRITORIES	Integrated and graded risk management of humans and wildlife in long-lasting radiological exposure situations. European project under CONCERT.
UiB	University of Bergen
UNESCO	UN Educational, Scientific and Cultural Organization
UNSCEAR	UN Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organisation

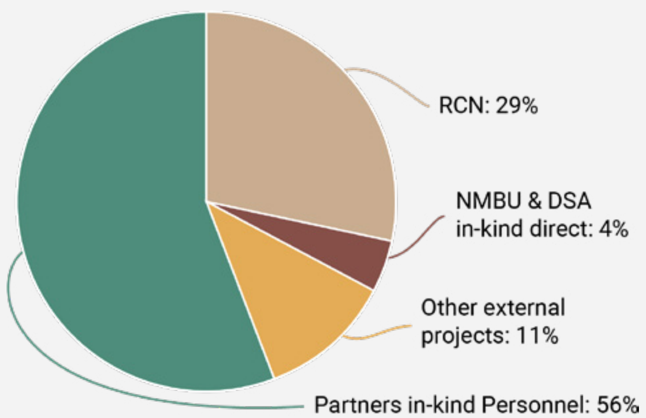
CERAD in Numbers

Norwegian University of Life Sciences
DSA Norwegian Radiation and Nuclear Safety Authority
NIVA Norwegian Institute for Water Research
NIPH Norwegian Institute of Public Health
Norwegian Meteorological Institute





Full- and part-time personnel in 2019
Total: 119



Funding 2019 in MNOK
Total: 56 MNOK

CERAD in Short

The overall objective of CERAD CoE is to improve the ability to assess the radiological impact and risks associated with environmental radioactivity. By focusing on key factors contributing to uncertainties, state-of-the-art tools and methods have been developed to better manage those risks. Since CERAD was established, about 70 part-time scientists, 30 PhDs, 10 PostDocs and 15 technical/ administrative personnel have contributed to the objectives of CERAD. Following the RCN international mid-term evaluation, CERAD was considered "a global Centre of Excellence and a flagship for Norwegian science with an agenda that is also highly relevant for society". Thus, CERAD has so far delivered what should be expected.

In 2019, new challenges have been put forward. These include decommissioning of two Norwegian research reactors in the years to come, and nuclear events such as detonation of nuclear bombs close to or in Norway, that change the scale of emergency preparedness. A series of paradigm shifts have accompanied severe nuclear events: the Three Mile Island accident demonstrated that low probability accidents could occur, the Chernobyl accident demonstrated that releases could by far exceed the 30 km zone, the Fukushima accident demonstrated that geohazards are underestimated, and the World Trade Center attack demonstrated that groups have the intention and capacity to harm. Thus, a change in CERAD priorities is expected in 2020; in addition to decommission and waste storage, focus will also be put on nuclear events (nuclear weapons, attack on nuclear installations, dirty bombs) and on nuclear forensics. As stated when CERAD was established, there are many nuclear sources out there, and competence and capacity must be in place when needed.

Management Group

Professor
Brit Salbu,
Centre Director

Professor II
Per Strand,
Deputy Director

Professor
Deborah H. Oughton,
Director of Research

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

Professor Brit Salbu, Centre Director Photo: Gisle Bjørneby

Seven years has passed since CERAD CoE was established - strange how fast time is running. During these years, the objective of CERAD still seems to be highly relevant; "The CERAD CoE is designed to improve the ability to assess the radiological risks from environmental radioactivity, combined with other stressors. By focusing on key factors contributing to the overall uncertainties, CERAD represents state-of-the-art tools needed for better assessment and management of those risks." As a series of sources potentially could release man-made and naturally occurring radionuclides into the environment, the research program has so far focused on source and release scenarios, ecosystem transfer and biological effects from ionizing radiation to assess impact and risks. Thus, about 250 scientific papers have been published by CERAD associated scientists, 30 PhD students and 10 PostDocs since 2013.

Following the very successful mid-term evaluation of CERAD, four research topics were considered very promising: 1) Potential nuclear events. Many nuclear sources could contribute to releases of radioactivity in the future. Most impact and risk assessment models are, however, associated with large uncertainties. Based on a hypothetical accident in Sellafield, UK, CERAD is for the first time linking 8 specialized and generic models in a chain, from the source to impact and risks. 2) Linking particle characteristics to sources and effects. Based on the particle research competence at CERAD, the director has acted as chair for the IAEA Coordinated research program on radioactive particles since 2013. Thus, CERAD has acted as guest editor for a Special Issue (Journal of Environmental Radioactivity) on radioactive particles released from a series of sources. 3) Comparative Radiosensitivity. Based on the unique NMBU gamma facility, 12 different test organisms have been exposed to a range of gamma radiation dose rates/doses to identify responses. Comparative studies are showing for instance large variations in responses in plants where pine and spruce are much more sensitive than Arabidopsis. 4) Differentiating Uncertainties – Variability. Field experiments in Chernobyl with caged clean fish introduced to a contaminated lake and caged contaminated fish introduced to a clean lake demonstrated that the "handbook" transfer coefficients to fish needs revision. GPS dosimetry was also performed for bear in Sweden and reindeer in Vågå, Norway.

Education is also essential to CERAD, and several international students have attended MSc course modules in Radioecology. Furthermore, CERAD plays an active scientific role on the national and international arena, such as being partner in bilateral, international and EU projects as well as contributing to international organizations such as ICRP, UNSCEAR, IAEA, OECD/NEA, and IUR.

Thus, it has been a privilege to act as director of CERAD since 2013. The research organization is in good shape, with competent scientists producing highlights in collaboration with scientists nationally and internationally. In the years to come, the key challenge is to develop an exit strategy that is sustainable, ensuring that CERAD CoE remains highly competent on the international scientific arena and highly relevant to serve the Norwegian society.

Finally, I would like to thank all my collaborators, within CERAD and outside, nationally and internationally for exciting years in science as well as all my students for inspiring company.

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Comments from the new CERAD Centre Director Deborah Oughton

Professor Deborah H. Oughton, Centre Director from 1st February, 2020 Photo: Gisle Bjørneby

It is an honour and a privilege to have been appointed as the new CERAD Centre director. It has been a fantastic journey since 2013 and I am certain that the future will be as challenging and as stimulating as the past seven years. Those challenges are made easier by the solid foundations that have been laid so far, thanks largely to an enthusiastic and committed team, but most importantly the unstinting dedication and expertise of our former director Brit Salbu.

Although grounded in solid basic research, CERAD's work has always had a high societal relevance. This is likely to become even more so in the next years, with the decommissioning of two Norwegian reactors, radioactive waste management, and an ever-changing nuclear threat. CERAD members are partners in the new 5-year EU project RadoNorm, building on our experience from NORM research.

RadoNorm will also bring new scientific topics, and new collaborators, including epidemiology, inhalation risks, microdosimetry, and the opportunity to study the way radon interacts with other environmental stressors. We will also study factors influencing public perception of radon risks, and methods of communication. Building public trust in science will be a key factor for both new and old challenges related to radiation risk in the environment.

The output of CERAD's scientists, technicians and students makes us more capable of dealing with environmental radioactivity, even if results often indicate that things are more complex than we assume. Biological and ecological responses to ionizing radiation can be both positive and negative, dosimetry needs to be better characterized, and societal, economic and ethical outcomes add a further dimension of complexity.

In recognition of new challenges, the CERAD Strategic Research Agenda (SRA) will be revised during the next period, and promising new projects are in the pipeline. These include experimental studies on uranium nanoparticles, models for predicting the dispersion of radionuclides in the environment and biological models to unravel mechanisms.

Research-based education is an important part of any university, and CERAD is no exception. CERAD scientists teach on NMBU courses at all levels: Bachelor, Masters and PhD. The overall goal is to produce graduates that have the skills, competence and enthusiasm to meet future research needs.

CERAD was conceived through the support of the RCN, but has matured significantly since then. Although there are only three years left of this phase of the project, I am confident that the CERAD family will continue past this phase due to the continuing relevance of the research. Together with partners, the management team is already working hard to establish an exit strategy, and to ensure that CERAD remains at the forefront of research in environmental radioactivity, nationally and internationally.

Comments from the Chair of the CERAD Board Øystein Johnsen

Pro-rector
Øystein Johnsen,
Chair of the Board
Photo: Gisle Bjørneby

Since 2013, CERAD has created a scientific fundament for reducing overall uncertainties in societal impact and risk assessments of radioactive exposure. The work in 2019, the output of numerous scientific reports, the analytic achievements and the collaborative approach have shown great progress, and results produced so far are state-of-the-art.

Highlights from 2019 were presented at the Annual Conference, in February 2020. We heard about uncertainties in calculations of atmospheric dispersion of radionuclides, micro-analytical characterization of Fen and Søve minerals, high resolution Al transport modelling in Sandnesfjorden estuary, impact assessments for dumped nuclear objects in the arctic, and radiocaesium containing particles in Fukushima soils and pond sediments. Presentations were given on model development for radioactive particle transformation processes, transfer of radionuclides to fish, transgenerational effects in zebrafish, and quantitative adverse outcome pathways for predicting the hazards of radionuclides. Interesting effects of ionizing radiation on the radioresistant organism *C. elegans* and mice models were presented, including impacts of dose rate on leukemia. We learned more about mechanisms behind differential radiosensitivity in plants, assessment of multiple stressors, including reflections on moving from exposure to environmental hazard and risk, and studies on Chernobyl residents' attitudes to rezoning contaminated areas.

Moreover, we heard about future nuclear challenges, the societal and ethical relevance of CERAD research, the Komsomolets expedition in 2019, challenges associated with decommissioning of the IFE reactors and handling and storage of spent nuclear fuel, nuclear weapons including potential consequences of their use, health effects of exposure to radon in combination with other stressors, and finally about reducing uncertainties. On the second day, young scientists in CERAD presented their results, and it was discussed how important it is to recruit young scientists associated to CERAD.

The director of CERAD, professor Brit Salbu, retired in February 2020. The board wants to thank her for the impressive work she has been doing, especially her international and national networking and positioning, and for her performance related to excellent science. The strong leadership as a director in CERAD has created great scientific and societal impacts, and her merits have made all of us both proud and enthusiastic. The board now looks forward to cooperating with professor Deborah Oughton, the new director of CERAD, and wishes her all the best for a successful leadership in the years to come. We also anticipate that the integration of the faculty of Veterinary Medicine at Campus Ås will be a benefit for the future cooperation within the CERAD family in the years to come.

The centre comprises experienced researchers and younger scientists. The board appraises them all for their excellent work, and we appreciate the good advices and recommendations given by the international Scientific Advisory Committee. As the chairman, I sincerely thank the board members from NMBU, the Norwegian Institute of Public Health, the Norwegian Meteorological Institute, the Norwegian Institute for Water Research and The Norwegian Radiation and Nuclear Safety Authority for all their contributions, discussions and positive interactions in 2019.

Daphnia feeding time.
Photo: Lisa Rossbach

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 the NMBU Pro-rector of Research is chair and the CERAD Management Director acts as secretary for the board. The CERAD's Deputy Centre Director, Research Director and Education Director take part as observers only. The board meets twice a year to secure cooperation within CERAD, discuss financial issues as well as effective collaboration between the partners.

The CERAD Board members 2019 have been:

- Pro-rector Øystein Johnsen, NMBU, Chair
- Director General Ole Harbitz, DSA, Deputy chair
- Dean Sjur Baardsen, NMBU/MINA; Dean Hans Frederik Hoen NMBU/MINA (from November 2019)
- Division Director Toril Attramadal, NIPH
- Deputy Managing Director Tor-Petter Johnsen, NIVA
- Research Director Lars-Anders Breivik, MET
- Scientist Dag Anders Brede, CERAD/NMBU
- Centre Director Brit Salbu, CERAD/NMBU

CERAD Scientific Advisory Committee

The CERAD Scientific Advisory Committee (SAC) is headed by the CERAD Research Director and includes 10 internationally well-merited scientists from 9 countries (USA, Ukraine, Slovenia, Belgium, Sweden, Canada, Australia, Japan, and Finland). 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 2019 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
- Dr. Clare Bradshaw, Stockholm University, Sweden
- Professor Janet Bornman, Curtin University, Australia
- Professor Sisko Salomaa, University of Eastern Finland, Finland

CERAD Relevance Advisory Committee

The CERAD Relevance Advisory Committee (RAC) is headed by the CERAD Deputy Director and includes representatives from key Norwegian stakeholders.
The RAC meets once a year at the CERAD conference. In 2019 the RAC included 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
- Torild Agnalt Østmo, Norwegian Food Safety Authority

CERAD Research Management

The CERAD Management Group (MG) is responsible for running the research management of 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 RA 1 and 2, while Deborah Oughton is in charge of RA 3 and 4. In addition, Anne Marie T. Frøvig, DSA, is adviser to the 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, DSA / Professor II, NMBU
- Education Director: Lindis Skipperud, Professor, NMBU
- Research Directors: Deborah H. Oughton, Professor, and Ole Christian Lind, 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 Director.

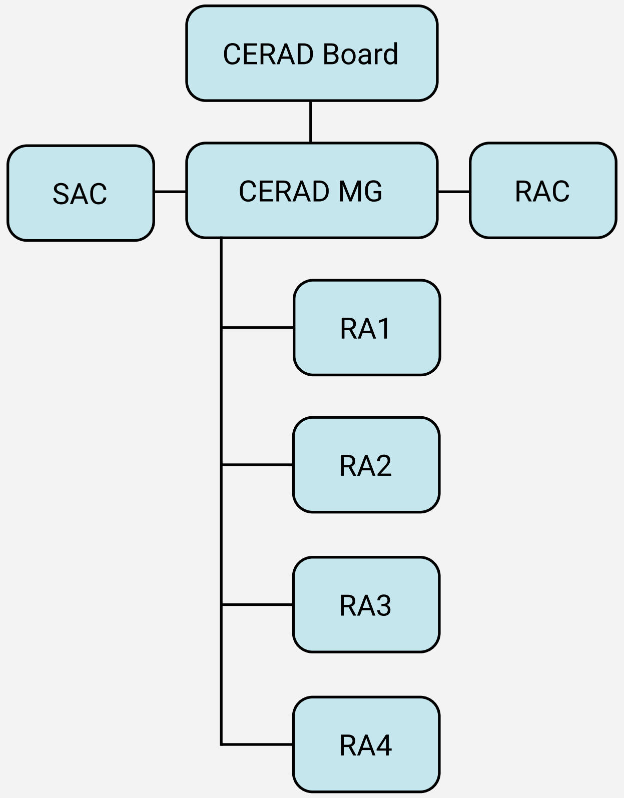

Figure 1. *The CERAD research organization*

The CERAD research area leaders in 2019 were:

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

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.

Research and Strategic Research Agenda

CERAD's research is organized around four Research Areas (RA) outlined in the CERAD Strategic Research Agenda (SRA). These research areas are defined by scientific questions and foster collaboration between institutes as well as disciplines. In each RA, at least three CERAD partners participate. The current SRA (2017-2021) presents CERAD's activities and achievements, hypotheses, approaches, and priorities (see https://cerad.nmbu.no for full details). The SRA also forms the basis for decisions regarding personnel, experiments and equipment within CERAD.

Research Area 1 - Source Term and Release Scenarios

Ole Christian Lind and Erik Berge

A series of natural and man-made nuclear/radiological and non-nuclear sources have contributed, are contributing or may contribute in the future to the release radionuclides into 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 ecosystem transfer, uptake, accumulation and effects. In 2019, the focus areas (umbrellas) of RA1 have been:

- Umbrella 1A: Particle Sources (Ole Christian Lind)
- Umbrella 1B: Dispersion Modelling: Atmospheric and Marine (Erik Berge)
- Umbrella 1C: UV/Ionising Radiation and Dosimetry (Elisabeth Lindbo Hansen)

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 and 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 into the underlying mechanisms influencing transfer. Thus, RA2 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. Improved knowledge about responses has implications for risk assessment and radioprotection of humans and the environment, and would reduce existing uncertainties. In this respect a major data-gap exists on effects following exposure of low doses and low dose rates of ionizing radiation to both humans and wildlife. Such effects cover apical endpoints like reproduction, embryonal development,

behaviour, as well as transcriptomics, epigenetics and transgenerational effects. In 2019, the focus areas of RA3 have been:

- Umbrella 3A: Radiosensitivity (Dag Anders Brede).
- Umbrella 3B: Combined Toxicity and Cumulative Risk (Knut-Erik Tollefsen).
- 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

CERAD's aim is to reduce overall uncertainties in impact and risk assessments and thus increase the protection of man and the environment from harmful effects of ionizing radiation, alone and in combination with other stressors. Firstly, the overall uncertainties associated with model predictions will be assessed by interfacing models that link source and release scenarios via ecosystems to impact and risk assessments (Fig. 1). Predicting power should improve by better understanding the factors that contribute most to uncertainties. Secondly, there is an increasing focus on effects of low radiation doses at the community or ecosystem level, and to link observations in the field to results obtained from laboratory experiments. Finally, there is an increasing recognition that radiation protection needs to address socioeconomic impacts. In 2019, the focus areas of RA4 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 contain research highlights from 2019, as presented during CERAD's Annual Conference in February 2020. An overview of the major achievements over the first five years of the centre can be found in the full SRA as well as the Midterm report from 2017. Further references can be found in the publication list.

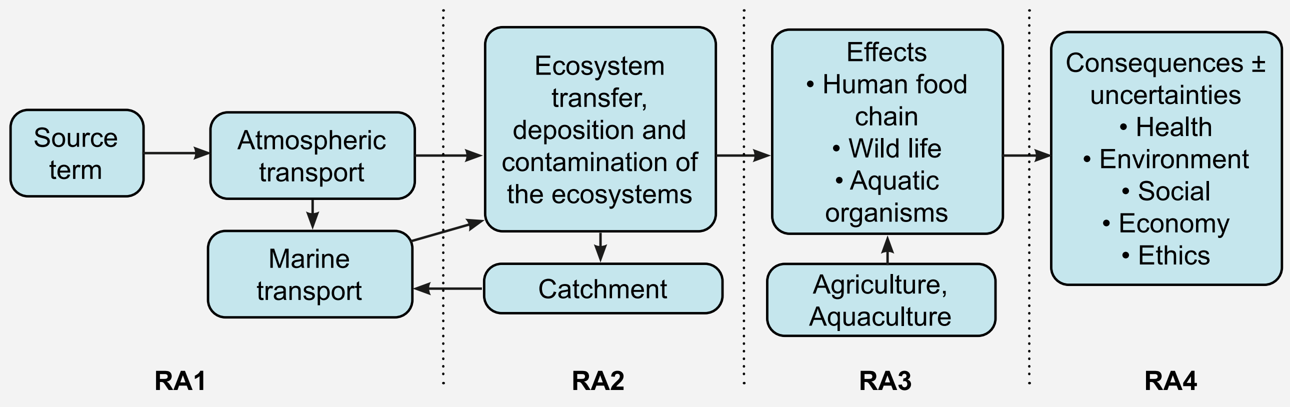

Figure 1. *Linking models from source term via an ecosystem transfer to the impact for humans and the environment, for the society, economy and ethics. The research within RA1 to RA4 should reduce the overall uncertainties associated with modelling the impact and risk.*

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RA1: UNCERTAINTIES IN THE DISPERSION MODELLING OF RADIONUCLIDES.

MET: *M. Ulimoen, E. Berge, H. Klein*
NCSRD: *S. Andronopoulos*
NMBU: *B. Salbu, O.C. Lind*
DSA: *N. Syed*

Objectives: To understand and quantify uncertainties of dispersion models following nuclear events.

Methods: Develop ensembles of concentrations and depositions of radionuclides by combining meteorological ensembles and emission scenarios.

Results: In the early phase of a nuclear event, when measurements are not yet available, the atmospheric transport of radionuclides must be calculated by dispersion models. One important uncertainty in the transport of the radionuclides stems from uncertainties in the meteorological fields characterized by an ensemble of meteorological runs. Another important uncertainty factor is the source term. The dispersion model approximations also give rise to uncertainties. In this study we assess the uncertainties associated with two different cases: the Fukushima Daiichi accident (Korsakissok et al., 2019) and a hypothetical nuclear reactor accident on board a marine vessel outside the coast of Norway and fallout in Western Norway (Berge et al., 2019).

In the Fukushima study, nine source terms from the scientific literature were combined with 51 meteorological ensembles. This gave a total of 459 members of the dispersion ensemble, showing large variation in concentrations. In Figure 1, results of the SNAP model are compared with measurements at the Koga Hokenjyo site southwest of Fukushima. The total ensemble (min to max values) agrees well with the measurements. However, we also see that the measurements lie outside the 25th to 75th percentile range during parts of the simulation period. The large spread in the ensembles reflects the uncertainties in the meteorological

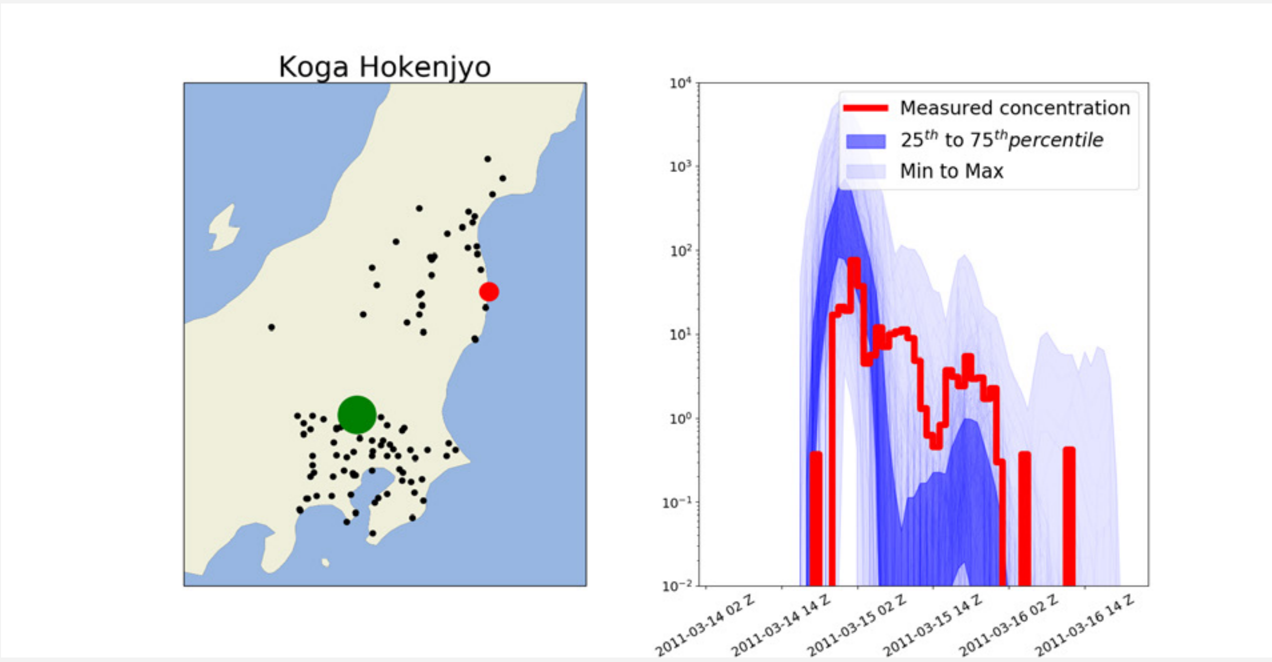

Figure 1. Observed (red line) and ensemble predictions (blue) of concentrations (Bq/m³) at Koga Hokenjyo for a period of 4 ½ days after the Fukushima accident. 25th to 75th percentile is dark blue, minimum to maximum values in light blue.

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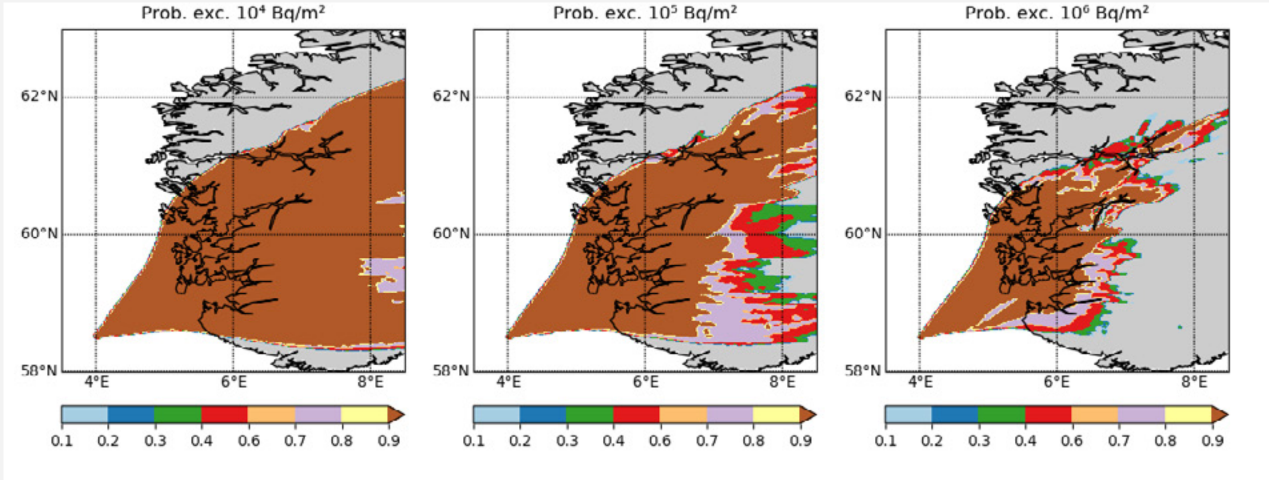


***Figure 2.** Probability of exceeding 10^4 Bq/m² (left), 10^5 Bq/m² (middle) and 10^6 Bq/m² (right) of accumulated total deposition for a 24 hours forecast period during the western Norway case.*

conditions and the source term during the Fukushima accident, and shows the need for ensemble calculations for this scenario.

For the Western Norway case, ten meteorological ensembles and five emission scenarios were applied, resulting in 50 dispersion ensembles.

Figure 2 shows the probability maps of total deposition exceeding the selected threshold values of 10^4 Bq/m², 10^5 Bq/m², 10^6 Bq/m². The simulation was performed using the SNAP model, modelling a 24h simulation starting on 2017-03-16 09 UTC. From figure 2 we note that the affected area can be divided into high probability (> 90%), and low probability (<10%) areas of exceeding the given threshold value. This is related to the low spread of the meteorological ensembles for this case, yielding small variations in the transport directions and precipitation fields between ensemble members (see Berge et al., 2019).

Conclusion: The two studies of Fukushima and Western Norway clearly show the importance of ensemble runs to assess uncertainties, especially in an early phase of a nuclear event when little or no observations are available. The studies also show that the uncertainties can lead to large differences in predicted concentrations and depositions of radionuclides, with the differences ranging from a factor of 2 to a factor of 100. Uncertainties related to weather conditions are larger for the Fukushima case than for the Western Norway case. Further studies regarding uncertainties in atmospheric dispersion and how these should be dealt with in further modelling of radionuclides and decision making are recommended.

References:

- *Berge, E., Klein, H., Ulimoen, M., Andronopoulos, S., Lind, O.C., Salbu, B., Syed, N. 2019. D 9.5.2 Ensemble calculation for hypothetical accident scenarios in Europe: the Norway case study. European Joint Program for the Integration of Radiation Protection Research CONCERT - CONFIDENCE project.*
- *Korsakissok, I., Périllat, R., Tomas, J.M., Andronopoulos, S., Bedwell, P., Klein, H., Leadbetter, S.J., Sogachev, A., Ulimoen, M., 2019. D 9.5.3 Ensemble calculation for a past accident scenario: the Fukushima case study. European Joint Program for the Integration of Radiation Protection Research CONCERT - CONFIDENCE project.*
- *Korsakissok, I., Périllat, R., Andronopoulos, S., Bedwell, P., Berge, E., Charnock, T., Geertsema, G., Gering, F., Hamburger, T., Klein, H., Leadbetter, S., Lind, O.C., Pázmándi,T., Rudas, C., Salbu, B., Sogachev, A., Syed, N., Tomas, J., Ulimoen, M., de Vries, H. and Wellings, J. Uncertainty propagation in atmospheric dispersion models for radiological emergencies in the pre- and early release phase: Summary of case studies. Radioprotection, In press.*

RA1: CHARACTERIZATION OF DOUNREAY FUEL FRAGMENTS

NMBU: *I. Byrnes, O.C. Lind, B. Salbu*
DSA: *E.L. Hansen*
University of Antwerp: *K. Janssens*

Objectives: Highly enriched (~75 %) uranium (U) containing fuel fragments recovered from the environment near the Dounreay reprocessing facility was characterized for structure, morphology, elemental composition, oxidation state of U, and contact dosimetry.

Methods: Structure and elemental composition of particles sourced to the Dounreay Fast Reactor (DFR) and the Materials Test Reactor (MTR) were investigated by laboratory-based µ-XRF and SEM-XRMA. Subsamples of the particles were subjected to synchrotron- based U L_{III} µ-XANES and U enrichment was examined by ICP-MS. Finally, contact dosimetry was evaluated using gamma spectrometry, beta probe measurements, and the VARSKIN6 code from the USNRC.

Results: Characterization showed that DFR particles (not pictured) were small and prone to fragmentation and indicated the presence of UNb_2O_7 in the particles, which was likely formed during high-temperature dissolution events during the fuel reprocessing. Particles from the MTR (Fig. 1) were sturdier and exhibited an inhomogeneous distribution of U and Al within the particle, indicative of shavings removed from the original UAl_4 assemblies. Dose assessment of contact with Dounreay fuel fragments, based on beta measurements, was commensurate with previous assessments.

Conclusion: Novel data on characteristics of DFR and MTR particles obtained in the present work reflect differences in fuel design, release scenarios, and subsequent environmental influence. The present work should contribute to reducing uncertainties in the risk assessment of Dounreay particles.

Reference:
- *Byrnes I., Lind O.C., Hansen E.L., Janssens K., Salbu B. et al., Characterization of radioactive particles from the Dounreay Nuclear Reprocessing Facility, Science of the Total Environment, in press.*

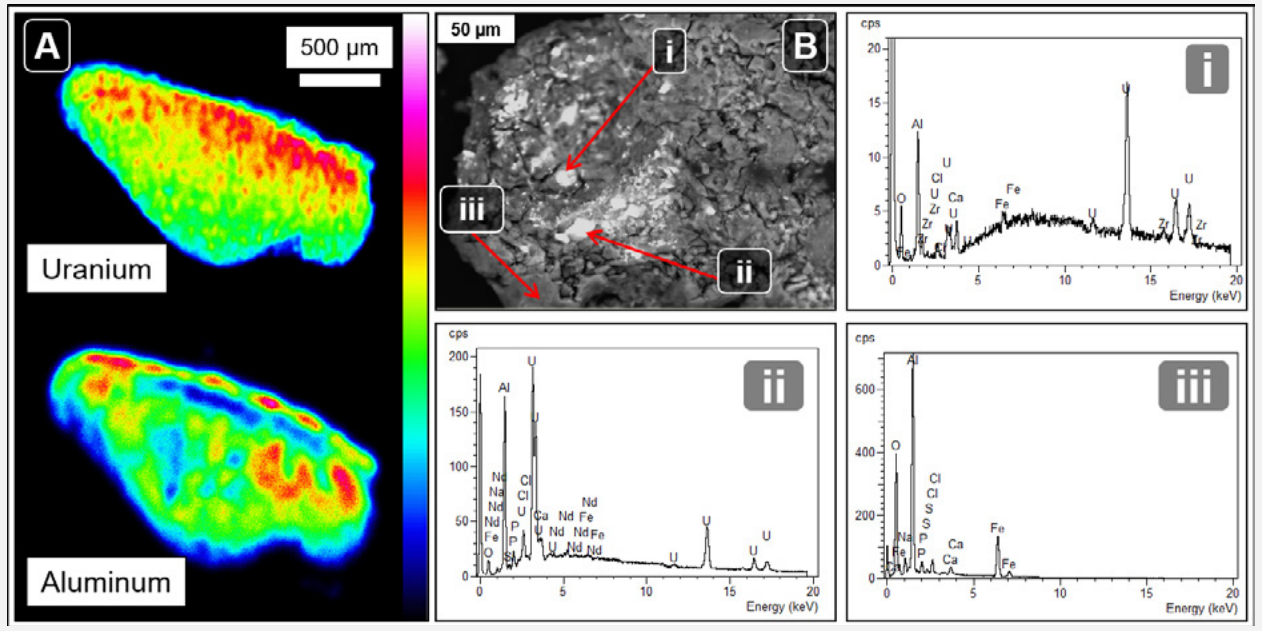


Figure 1. *(A) µ-XRF elemental mapping of a Dounreay Materials Test Reactor particle showing the inhomogeneous distributions of U and Al. (B) Electron microscopy of the particle with dense, U and Al containing areas shown at points i and ii.*

RA1: MOBILITY AND POTENTIAL BIOAVAILABILITY OF RADIOCAESIUM-CONTAINING PARTICLES IN FUKUSHIMA SOILS AND POND SEDIMENTS

NMBU: *E. Reinoso-Maset, M.N. Pettersen, A. Tetteh, B. Salbu, O.C. Lind*
DSA: *J. Brown*
University of Groningen: *F. Steenhuisen*
Fukushima University: *T. Wada, T.G. Hinton*

Objectives: Radioactive particles deposited after a severe nuclear event, such as the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident in March 2011, are usually considered inert under environmental conditions. They can be retained in soils and sediments, delaying ecosystem transfer until particle weathering and/or remobilization occur. In this study, we aimed to elucidate the role of radioactive particles on the mobility and potential bioavailability of radiocaesium in soils and sediments from the FDNPP's near field (<30 km) by determining radiocaesium distribution and reversible/irreversible interactions with soil and sediment components, and by studying the link between inhomogeneous distributions and inert fractions in soils and sediments.

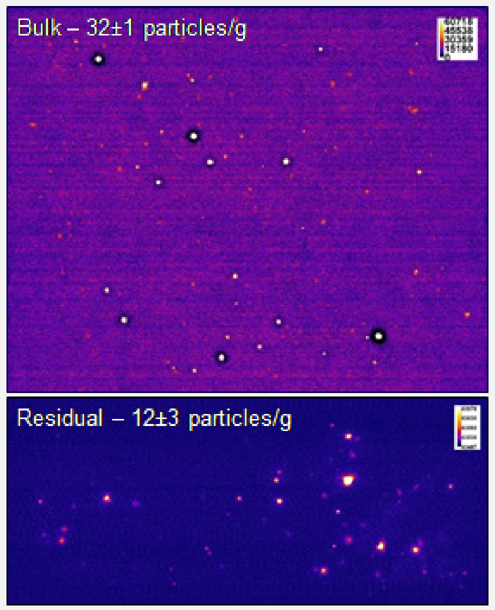


Figure 1. *Autoradiography images of a Fukushima pond sediment before (bulk) and after (residual) sequential chemical extraction. Colour scale represents photo-stimulated luminescence signal intensity. Frequency of particles is per gram of dried mass.*

Methods: Soil and sediment samples collected in Sept. 2016 from highly contaminated locations within 11 km of the FDNPP were characterised (pH, organic content, size fractions, activity concentration) and subjected to leaching with simulated gastrointestinal fluid and sequential chemical extractions. The presence, distribution and frequency of radiocaesium containing particles was studied by digital autoradiography. Additionally, radiocaesium activity concentration was evaluated relative to ambient equivalent dose rates measured *in situ* during sampling and reported radiocaesium deposition plumes.

Results: Total ^{137}Cs activity concentration varied with site location, but was predominately present in the top 5-6 cm layer and distributed between sand and silt fractions (<5 % was associated with clay). Simulated gastrointestinal fluid extracted <3 % of the total ^{137}Cs activity, which agrees with the minimal reversibly bound fraction (0.1-11 %) obtained by chemical extractions. Most ^{137}Cs activity was irreversibly bound to soils (44-90 %) and sediments (23 %) or present in an inert form (10-66 % residuals). Autoradiography images showed heterogeneities as particles, even after chemical extraction (Fig. 1). Estimated particle frequency was positively correlated with total ^{137}Cs activity concentration and associated with direction and distance from the FDNPP reactors, matching *in situ* air dose rates and the main release and deposition plumes.

Conclusion: Radioactive contamination in Fukushima soils and sediments is dominated by radiocaesium containing particles of relatively low mobility and bioavailability under environmental conditions. Yet, they might still represent a radiation hazard following accumulation and remobilization.

Reference:
- Reinoso-Maset et al. 2020, J. Environ. Radioact., 211, 106080.

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, L. Xie, K.E. Tollefsen*
DSA: *H. Thørring*
NUBIP: *V. Kashparov, S. Levchuk, V. Protsak, E. Kashparov*
Fukushima University: *T. Wada, T. Hinton*
CNA: *R. Garcia-Tenorio, J.M. Lopez-Gutierrez*

Objectives: In order to reduce uncertainties in impact assessment models, we aim to improve the characterisation of radionuclide transfer to fish and to link exposure to biological responses (Fig. 1). Furthermore, we compared data from laboratory studies with those from the field.
Hypothesis 1: The transfer of radionuclides is dynamic and takes place through waterborne exposure and through diet.
Hypothesis 2: The biological effects of radionuclides are correlated with radioactivity concentrations in biota and depend on exposure pathways.

Methods: Controlled exposure experiments were performed to identify the transfer of radionuclides directly from water and via diet. Prussian carp juveniles (*Carassius gibelio*) and embryos and juveniles of Atlantic salmon (*Salmo salar L.*) were exposed, and effects analysed using either bioaccumulation tests (OECD 305), 96 hrs acute toxicity tests (OECD 203) or chronic toxicity tests (OECD 210). In addition, uptake and toxicity were studied separately and in combination with gamma radiation or Cd for both juveniles and embryos, and as a function of varying water ion concentrations (H^+, Ca^{2+}, Mg^{2+}, Na^+, K^+) in juveniles.

Field campaigns were performed to collect water and fish from contaminated ponds in Fukushima and from lakes in Chernobyl (Fig. 2).

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.

The analytical program included determination of ^{238}U, ^{137}Cs, ^{90}Sr and ^{129}I. Speciation of radionuclides in water, accumulation of radionuclides in tissues (gill, liver, eggs) and induced response endpoints based on the CERAD Toolbox were determined. Toxic mechanisms were explored by combining gene expression, metabolomics profiling, histopathology, DNA-damage, ROS-defence enzyme activity.

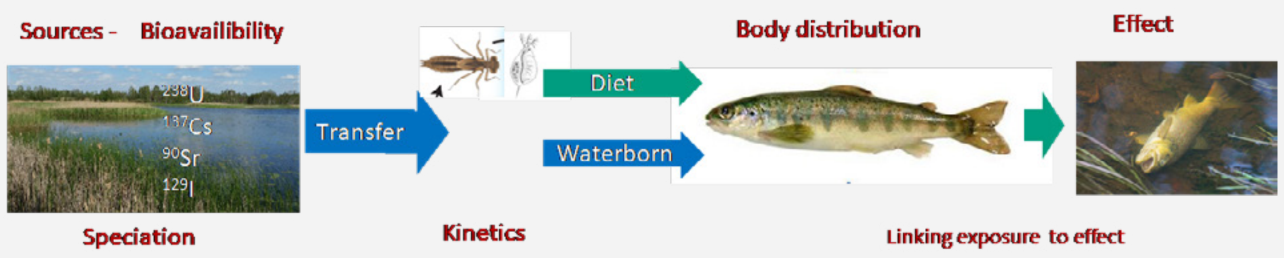


Figure 1. *Transfer of radionuclides to fish, including key influencing factors.*

Figure 2. *Field experiments during summer and winter. Photo: H-C Teien*

Results: Our data demonstrated that the bioavailability of radionuclides was dependent on speciation and that pH, DOC and UV are key influencing factors. Furthermore, the uptake of radionuclides is dynamic and the body distribution depends on uptake pathways. ^{238}U and ^{90}Sr accumulate primarily through waterborne exposure, while ^{129}I and ^{137}Cs are dependent on dietary uptake. Terrestrial insects and aquatic organisms are the key food sources for transfer of radionuclides.

Results from fieldwork indicate that the internal doses of ^{129}I, ^{137}Cs and ^{90}Sr in fish are higher than external doses from water. Furthermore, seasonal variation in transfer of radionuclides to fish was observed, with higher rates of uptake and depuration during June - October (water temperature >15 °C) and lower transfer in October - December (water temperature <10 °C).

Results also demonstrate that the transfer of radionuclides depends upon life stage, as transfer rates differed between embryos and juveniles, and that the presence of competing ions influences the uptake.

Laboratory studies showed that radionuclide concentrations in juvenile gills and as eggs were independent of water quality, but were correlated with effect endpoints such as genotoxicity (Comet assay) and the oxidative stress defense system (CAT and GPx enzyme activities), as well as ionoregulatory disruption in juveniles following waterborne exposure.

No significant toxic effects were identified in chronically exposed fish in Fukushima and Chernobyl. In the latter, ^{90}Sr was the main dose contributor to fish. The radionuclide and associated doses were, however, unevenly distributed.

Conclusion: We have obtained radionuclide transfer rates that differ significantly from those given in the IAEA handbook. Uptake of radionuclides is speciation dependent, is dynamic and can occur by both waterborne and dietary exposure. Metabolism and competing effects from stable analogues are key also influencing factors.

RA2: ADAPTATION OF FDMT AND INCLUSION OF FUEL PARTICLES

DSA: *A. Hosseini, J. Brown*
NMBU: *O.C. Lind, B. Salbu*
UIAR: *V. Kashparov*
CEH: *N. Beresford*

Objectives: To update, adapt and improve the FDMT (Food chain and Dose Module for Terrestrial pathways), an integrated module within the ARGOS decision support system for emergency preparedness that deals with food chain transfer and dose estimation.

Methods: The FDMT model has been transferred to a probabilistic-enabled and flexible modelling platform. This provides easier access to underlying parameters and sub-models and allows the possibility of updating and adapting FDMT to better fit the purpose of application under various circumstances.

Results: The default soil model used by FDMT does not consider the presence of fuel particles (FP) in soil. An adaptation of the model would require us to consider how to include FP composition, their weathering and the associated mobilisation of radionuclides (RN) over time. To account for the distribution of RN in soil systems with respect to different physico-chemical forms of radioactive fallout, and their relative uptake by plants, a new soil model was set up. The new soil model incorporates three compartments related to U-Zr-Oxides, UO_2 and UO_{2+x}. Each FP structure has a specific weathering rate that changes as a function of soil pH. The new soil model has been tested by employing scenarios developed to be compatible with available empirical data for Ukrainian soil and grain (2011-2018). The results have been compared with the outputs from FDMT.

Conclusion: Accounting explicitly for the presence of FP makes a difference to the long-term predictions of activity concentrations of ^{137}Cs and ^{90}Sr in crops and ^{137}Cs in soil. This is reflected in the prediction of food-chain activity concentrations as the model indicates a maximum occurring many years after deposition (Fig. 1).

Reference:
- *Lind et al. 2019 D 9.16. Evaluation of the importance of radioactive particles in radioecological models. EJP-CONCERT.* http://concert-h2020.eu/en/Publications

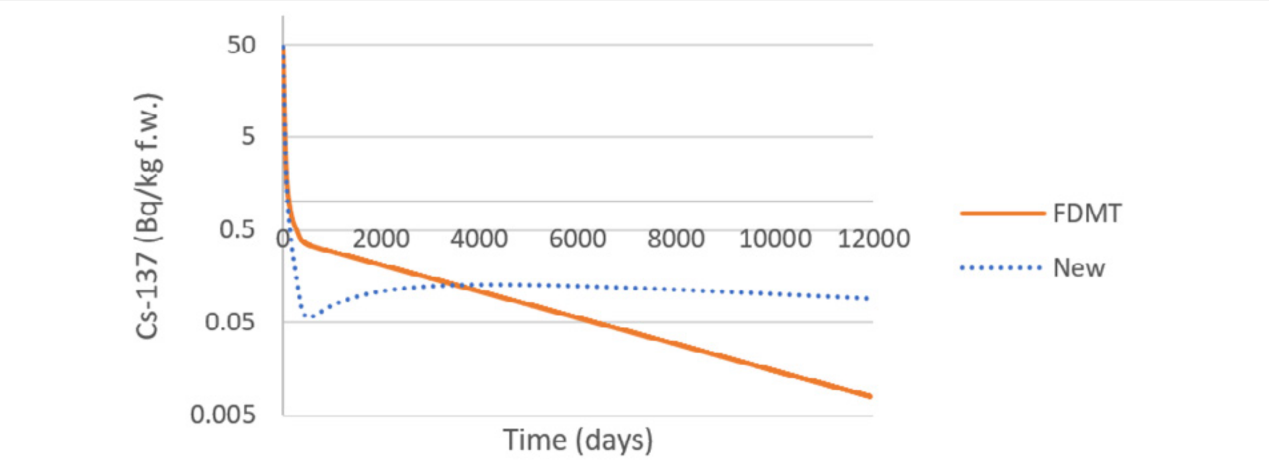


Figure 1. *Activity concentrations of ^{137}Cs (Bq/kg fresh weight) in grass with time (days) simulated using 2 models: 'New' fuel-particle soil model (dashed blue line) and FDMT (solid orange line). Deposition ^{137}Cs = 1 kBq/m² to soil, 50 kBq/m² to vegetation.*

RA2: COMPARING URANIUM EXPOSURE ROUTE (WATERBORNE VS. DIETARY) TOXICOKINETICS IN A FRESHWATER FOOD CHAIN

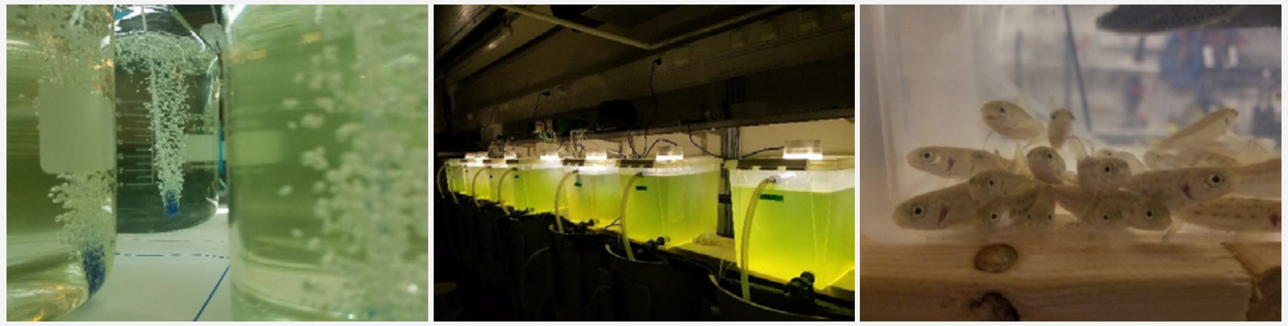
NMBU: *S. Scheibener, H-C. Teien, T. Storbakken, B. Salbu*
NIVA: *Y. Song, L. Xie, K.E. Tollefsen*

Objectives: Compare waterborne and dietary transfer of uranium (U) across a freshwater food chain from primary producer to primary consumer and further to secondary consumer.

Methods: We studied time-dependent transfer of U from water to algae (*Raphidocelis subcapitata*), from algae to a primary consumer (*Daphnia magna*) and the subsequent transfer into juvenile Atlantic salmon (*Salmo salar*). Observations took place in controlled laboratory experiments, and food chain transfer was compared to waterborne uptake. Algae were exposed for 4 hrs, daphnia for 48 hrs and Atlantic salmon for 28 days across a range of U concentrations (50-500 µg/L, 10-250 µg/L and 10-100 µg/L). To study dietary exposure, daphnia were continuously fed U-contaminated algae in 7 bulk tanks (5,000-10,000 daphnia individuals/tank). U-contaminated daphnia were transferred twice daily to tanks containing juvenile Atlantic salmon for 28 days. Salmon were dissected and internalized U was determined for different tissues.

Results: At low environmental concentrations in solution, U is directly taken up in algae, daphnia and fish. Our dietary transfer data show that U is transferred from contaminated algae to daphnia and further to juvenile salmon, but that biodilution occurs from daphnia into salmon. Dietary transfer rates are low and the distribution of U in daphnia and salmon differs depending on exposure route. For example, salmon exposed to waterborne U have concentration-dependent uptake in most tissues (primarily in gills and skin), whereas the majority of U from dietary exposure is localized to the stomach. In daphnia, alterations in calcium homeostasis and differentially expressed genes correlate with internalized U concentration from waterborne exposures only.

Conclusion: The difference in exposure pathways for radionuclides must be better understood to improve predictions of their risk to aquatic life and human health. In addition, U redistribution occurs between tissues and information about dynamics and internalized concentrations is essential to understand the mechanism and risks of toxic effects.



Experimental setup for the study of dietary U transfer in a freshwater food chain. Algae were grown in tanks (left), contaminated with U and continuously fed to Daphnia (middle). The contaminated Daphnia were subsequently fed to juvenile salmon (right) for 28 days.
Photos: Shane Scheibener

RA3: *IN VIVO* ASSESSMENT OF OXIDATIVE STRESS EFFECTS INDUCED BY CHRONIC EXPOSURE TO GAMMA RADIATION IN *CAENORHABDITIS ELEGANS*

NMBU: *E. Maremonti, L.M. Rossbach, O.C. Lind, B. Salbu, D.A. Brede*
NIPH: *D.M. Eide*

Objectives: To assess whether antioxidant defences (AODs) could ameliorate radiation-induced reactive oxygen species (ROS) or if the increase in ROS would cause oxidative damage in the radioresistant nematode *C. elegans* when chronically exposed to gamma radiation.

Methods: Determination of total brood size and growth effects as phenotypical endpoints. *In vivo* measurements of spatiotemporal patterns in hydrogen peroxide (H_2O_2) levels, superoxide dismutase 1 (sod-1) expression and glutathione redox potential, using a GFP reporter strain (sod1::gfp) and two ratiometric biosensors (*HyPer* and *Grx1-roGFP2*). Global gene expression analysis via RNA sequencing on young adult nematodes exposed for 72 hours from L1 stage.

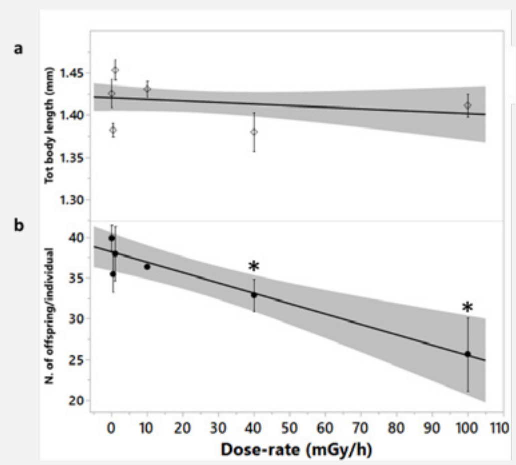


Figure 1. Effects on (a) somatic growth and (b) reproduction on wild-type Caenorhabditis elegans exposed to increasing dose rates of gamma radiation for 96 hours, in 24-well plates containing OP50 re-suspended in MHRW. Data represent Mean ± SE (n = 15). Asterisks indicate significant difference to control treatment (Tukey post hoc, p-value < 0.01). Dose rates are given as nominal values.

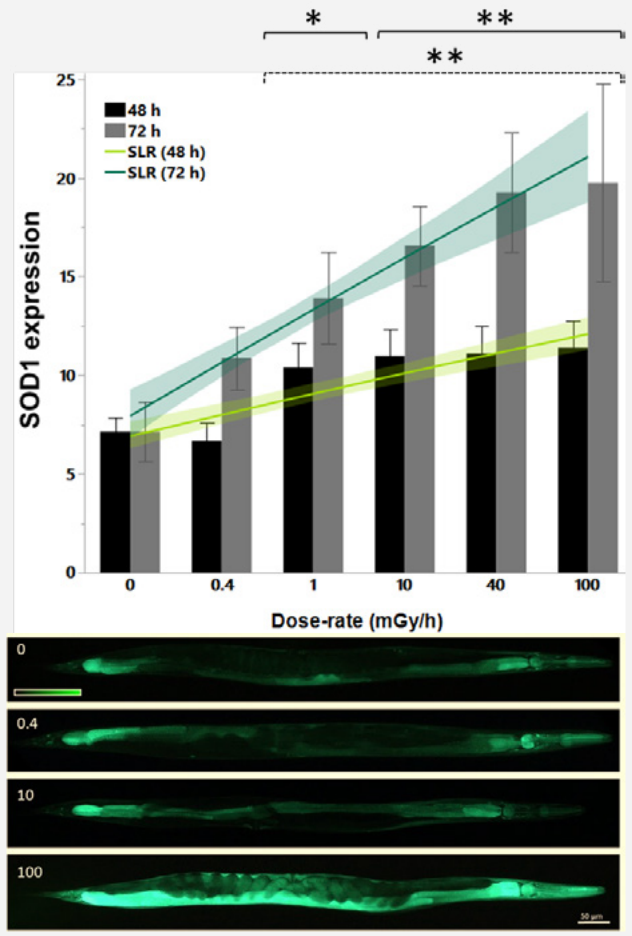


Figure 2. (top) Sod-1 expression assessed in vivo in C. elegans reporter strain (sod1::gfp), after 48 and 72 hours of exposure to increasing dose-rates of gamma radiation, in MHRW containing OP50. Data represent Mean ± 95% CI (n = 10). Dashed or continuous line with asterisk indicates significant difference to control treatment at 48 and 72 hours, respectively (Tukey post hoc, p-value < 0.001 and < 0.0001). Values are normalized to somatic growth. Dose rates are given as nominal values. (bottom) Relative epifluorescence images of the expression pattern at different exposure dose rates (mGy/hr) after 48 hours of irradiation. Scale bar: 50 µm.

Results: Reprotoxic effects, but no effects of somatic growth, were shown at dose rates ≥40 mGy/hr (total dose ≥ 3.9 Gy) (Fig. 1). These effects were accompanied by dose-dependent and time-dependent increase of *sod-1* expression, H_2O_2 levels and a temporary

redox imbalance. The data showed that at dose rates ≤10 mGy/hr (total dose ≤1 Gy) defence mechanisms were able to prevent the manifestation of oxidative stress response, whereas at dose rates ≥40 mGy/hr (total dose ≥1.9 Gy) the continuous formation of radicals caused a redox shift, leading to oxidative stress transcriptomic response (Fig. 2). RNA-sequencing analysis indicated differential expression of genes related to programmed cell death, oxidative stress, reproduction and essential mitochondrial functions (Fig. 3). In particular, essential pathways involved in protein degradation, lipid metabolism, cuticle morphology and mitochondrial respiratory chain were affected by chronic exposure to 100 mGy·hr-1 (total dose ≥7.2 Gy) of gamma radiation. Moreover, genotoxic effects were among the most over-represented functions affected by chronic gamma irradiation, as indicated by differential regulation of genes involved in DNA damage, DNA repair, cell-cycle checkpoints, chromosome segregation and chromatin modification.

Conclusion: In the radioresistant nematode *C. elegans*, chronic exposure to ionizing gamma radiation during larval development significantly enhances the levels of ROS and induces activation of AODs. At doses ≤10 mGy/hr (total doses ≤0.8 Gy) nematodes appear to tolerate chronic gamma irradiation, while at doses ≥40 mGy/hr (total doses ≥2.9 Gy), the observed redox shift in the cell induces oxidative damage and changes in the redox signalling functions, modulating a cascade of molecular and cellular processes in the entire organism with adverse consequences for its reproductive system.

Reference:

- *Maremonti, E., Eide, D.M., Rossbach, L.M., Lind, O.C., Salbu, B., & Brede, D.A. (2019). In vivo assessment of reactive oxygen species production and oxidative stress effects induced by chronic exposure to gamma radiation in Caenorhabditis elegans. Free Radical Biology and Medicine.*

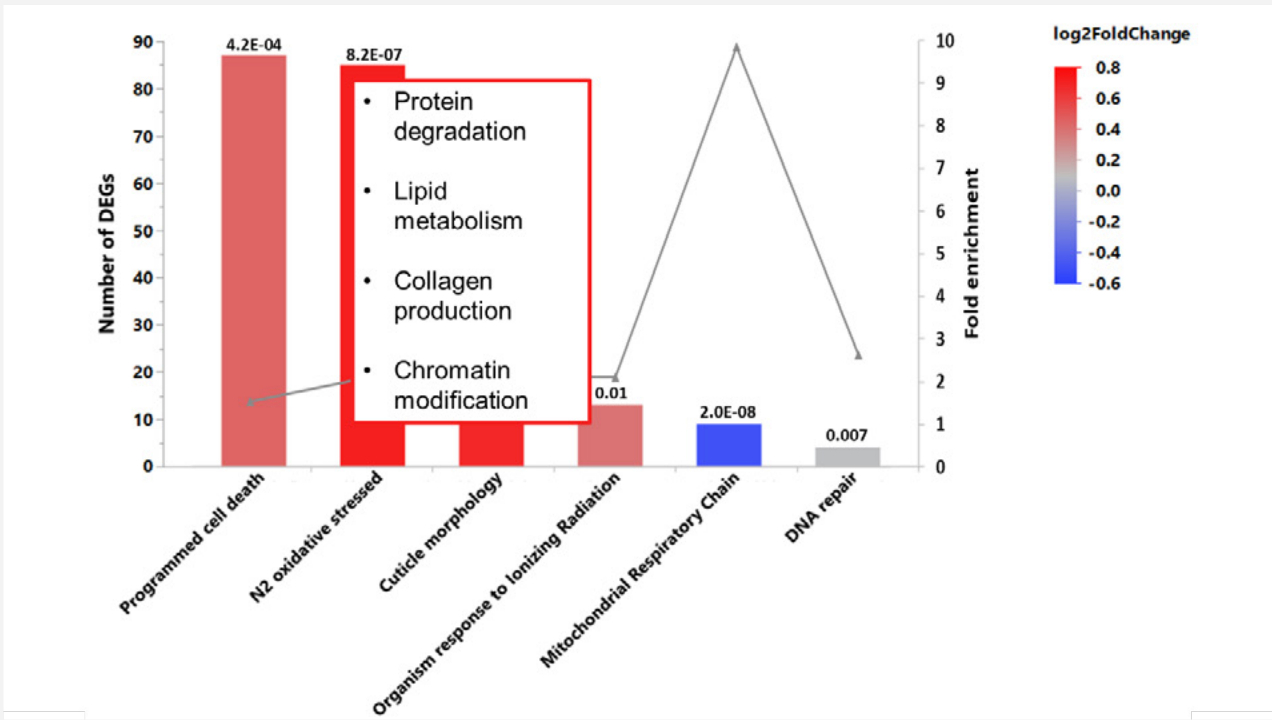


Figure 3. Over-represented categories modulated by ionizing radiation-induced oxidative damage resulting from 72 hours exposure to 100 mGy/hr of gamma radiation in the nematode C. elegans. (Data labels indicate total number of genes from each selected category of comparison).

RA3: DIRECT AND HERITABLE EFFECTS IN ZEBRAFISH AND COMPARATIVE MODELS

NMBU: *P. Aleström, J. Ballangby, V. Berg, D.A. Brede, S. Hurem, J.H. Kamstra, Y.A. Kassaye, O.C. Lind, L.C. Lindeman, Y. Lee, O.C. Lind, J.L. Lyche, L.M. Martin, I Mayer, D. Oughton, E.M.K. Rasmussen, B. Salbu, H.C. Teien*
NIPH: *A-K.H. Olsen, J. Ballangby*
NIVA: *J. Asselman, Y. Song, J. Thaulow, K.E. Tollefsen, L. Xie*
DSA: *T. Christensen*
Utrecht University: *J. Kamstra*
Camaguey University: *L.M. Martin*

Objectives: To study effects of gamma radiation during two sensitive life stages of zebrafish (*Danio rerio*) development, embryogenesis (*blastula-early gastrula*) and germline development using two lines of zebrafish: a transgenic (vas:egfp) with fluorescent label of germline-specific primordial germ cells (PGC) and an AB wild type (wt) strain.
Subgoal 1. To determine how germline development is affected in: (i) F0 embryos exposed between 2.5- 5.5 hpf and adult F0 fish exposed between 0-21 dpf; and (ii) F1-F3 offspring from exposed parental fish. The transgenic line allows imaging of migrating PGCs during germline development and isolation of the PGC population for single cell type analyses after FACS mediated cell sorting of homogenized embryos and larvae. Analyses of 5.5 hpf embryos and information on the early programming of the zygotic epigenome give insights into mechanisms behind later phenotypic observations.
Subgoal 2. Comparative epigenomics to: (i) compare how salmon (*Salmo salar*) and zebrafish (AB wt) early development (blastula up to 50 % epiboly in early gastrula) are affected by environmentally relevant doses of gamma radiation; (ii) correlate chromosome-associated histone proteins post-translational modifications (PTM) with exposures of chemical stressors 5-azacytidine (5AC) and gamma radiation in Daphnia magna.
Subgoal 3. Analyses of fertility and environmental exposure related effects from field samples from Northern pike (*Esox lucius*) collected in Chernobyl.

Methods: Zebrafish (*Danio rerio*) embryos from the 2.5 hpf (blastula stage) were exposed to gamma radiation in multiple well plates with doses of 1 to 40 mGy/h (^{60}Co, Figaro facility, NMBU) for either 3h or for 21 days. Macro/microscopic endpoints included fluorometric (ROS), colorimetric (LPO), Comet assay and histopathology. Omics studies include transcriptomics, by mRNA-seq; chromatin structure analysis with locus specific histone modification (ChIP-PCR) and chromatin accessibility profiling (ATAC-seq).

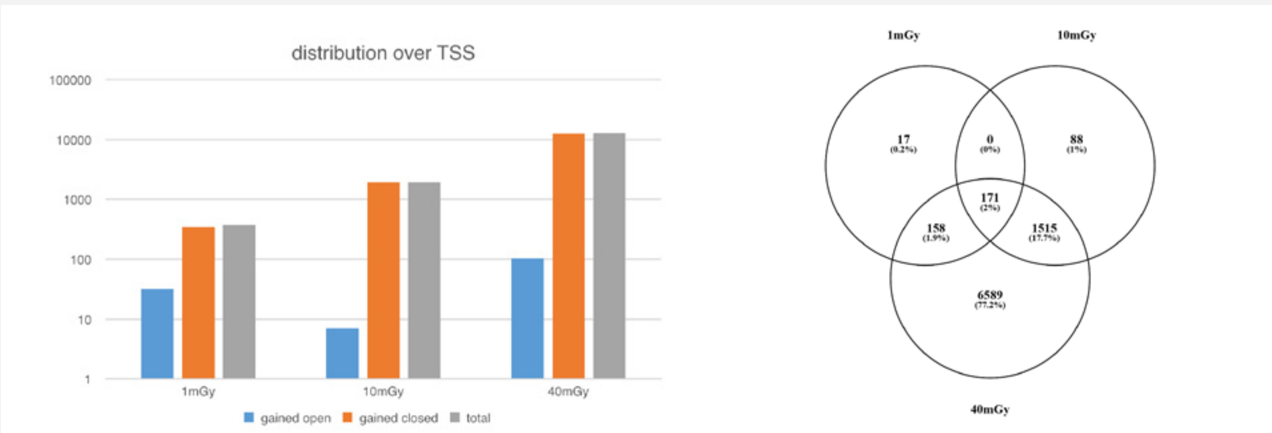


Figure 1. *ATAC-seq data, changes in open-closed chromatin regions relative to control for embryos exposed during 2.5-5.5 hpf. The results are shown as bar graph and Venn diagram.*

Results:
Subgoal 1. The ATAC-seq analysis of embryos from F0 exposed parents revealed a dose-response effect with 346, 1774 and 8483 loci showing altered access in chromatin structure after 1, 10 and 40 mGy/h (Fig. 1). 1-2 % of fish developed distinct phenotypes with tumors and pigment disorganization, and GFP fluorescence was decreased in offspring embryos from both groups of exposed parental fish (Fig. 2).
Subgoal 2. (i) The salmon-zebrafish study revealed an induced hyper-enrichment of H3K4me3 at the hnf4a loci for early gastrula embryos. F1 embryos of the exposed zebrafish parents showed similar hyper-trimethylation of H3K4 on the same locus, while this mark was not inherited to F2 generation embryos. (ii) Results from Daphnia exposed to 5AC show a decrease in global DNA methylation for the F0 generation, but no significant changes on H3K4me3 or H3K27me3. In the F1 offspring, the reduction in DNA methylation is inherited together with changes in histone trimethylation and in the transcriptome.
Subgoal 3. Preliminary results showed increased blood biochemical markers indicating liver disorders, increased numbers of monocytes and lymphocytes, including lower motility and lower number of spermatids in fish from the contaminated lake.

Conclusion: In general, exposure of zebrafish at sensitive stages of development generates a wide range of results, further demonstrating the value of this model organism in radiobiology assessments. Results are currently being evaluated using the adverse outcome pathway (AOP) approach, to identify the common molecular initiating events. The next step will be to increase complexity and produce multi-species AOPs.

The finding that gamma radiation affects chromatin accessibility towards more closed regions in a dose relationship manner, suggests a model wherein chromatin compaction as a stress response protects the DNA against damage.

References:
• *Lindeman et al. 2019. Gamma radiation induces locus specific changes to histone modification enrichment in zebrafish and Atlantic salmon. PLoS ONE 14, e0212123.*
• *Alestrom, P. et al. 2019. Zebrafish: Housing and husbandry recommendations. Laboratory Animals 51, 002367721986903–12.*
• *Lindeman et al. 2019. Gamma radiation induces locus specific changes to histone modification enrichment in zebrafish and Atlantic salmon. PLoS ONE 14, e0212123.*
• *Lindeman et al. 2019. Epigenetic, transcriptional and phenotypic responses in two generations of Daphnia magna exposed to the DNA methylation inhibitor 5-Azacytidine. Environmental Epigenetics. doi: 10.1093/eep/dvz016.*
• *Ballangby, J. Chromatin Accessibility after Inhibition of Enhancer of Zeste Homolog 2 (Ezh2) in Zebrafish Embryos. MSc Thesis, NMBU, MINA.*

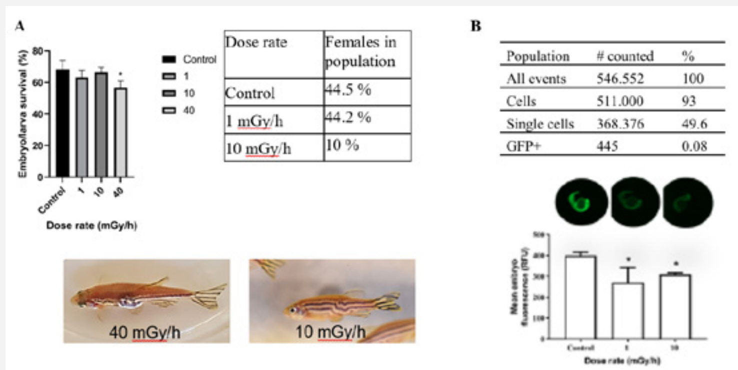


Figure 2. *Transgenic tg(vas:egfp) A) F0 exposed fish. Top left: Survival after 1 week of exposure. Top right: Sex ratios at 6 months (mpf). Below: Phenotypes with tumors and pigment disorganization. B) F1 zebrafish embryos from parental (F0) fish exposed to 0 (control), 1 and 10 mGy/h. On top: FACS sorting results. Below: GFP fluorescence.*

RA3: EFFECTS OF LOW DOSE/DOSE RATE IONIZING RADIATION IN MOUSE MODELS MIMICKING HUMANS

NIPH: *D. Eide, N. Duale, H. Dahl, T. Tengs, J. Ballangby, E.S. Berg, M. Amberger, B. Lindeman, K.B. Gutzkow, J. Andersen, L. Sareisian, A. Ihksani, C. Instanes, H. Dirven, A-K. Olsen*
NMBU: *D.A. Brede, P. Aleström, J.H. Kamstra, O.C. Lind, L. Lindeman, D. Oughton, B. Salbu, H.C. Teien*
DSA: *T. Christensen*
PHE, UK: *C. Badie, M. Ellender, S. Bouffler*

Objectives: While there is extensive knowledge regarding biological effects of **high** dose/dose rate ionizing radiation, we still know little about the effects of **low** dose/dose rate ionizing radiation. Our overall objective is to contribute to this knowledge by studying how exposure to low dose/dose rate ionizing radiation affects mice.
For 2019, we report on three of several research aims, regarding cancer and reproduction.

1. Generate novel data on the risk of cancer following low dose rates or low doses ionizing radiation in a tailored, sensitive mouse model.
2. Investigate the genotoxic, epigenetic and transcriptional response of γ-irradiation in a dose-rate related perspective.
3. Identify a molecular biomarker signature for exposure to ionizing radiation using prediction models on expression profiles of microRNAs.

Results:
Aim 1. We generated a mouse model that harbours a point mutation in one allele of a cancer-gene, and thus is significantly more sensitive to development of cancer (acute myeloid leukemia, AML) compared to alternative mouse models. Mice were exposed to dose rates from 2.5 to 100 mGy/h for 1 hr up to 3 months in the NMBU Figaro facility. Mice were kept alive until they showed symptoms of AML, and were then culled and analysed. The mouse model demonstrated its suitability for predicting AML from radiation; mice acquire AML at an early age, before age-associated conditions occur. Correct identification of radiation-induced AML had been hampered by such conditions in previous studies using wild type mice. The CBA-Spm model is highly sensitive in discerning between doses in the low-to-intermediate range, whereas dose-rate differences were not specifically detected (Fig. 1). New experiments are now designed to investigate this further.

Aim 2. Effects of ionizing radiation is likely to depend on the dose rate applied; we hypothesize that chronic exposure to low dose rate may be less harmful than acute exposure to identical total doses. We addressed this by exposing male mice of two strains (CBA/CaOlaHsd and C57BL/6NHsd) to 0, 2.5, 10 and 100 mGy/h γ-radiation, to a total dose of 3 Gy. We investigated

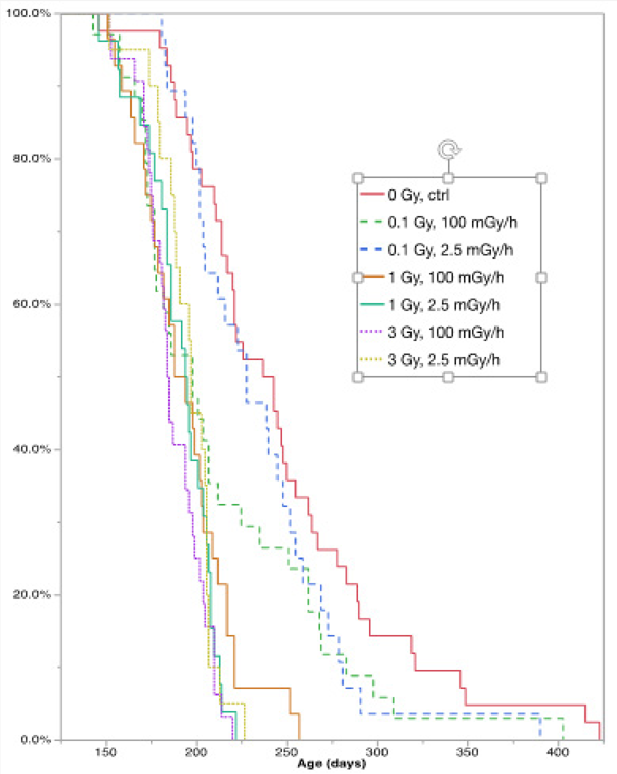


***Figure 1.** Survival analyses of CBA-Spm mice exposed to ionizing radiation. Age in days at the x-axis and percentage surviving mice at the y-axis.*

the genotoxic effects, and measured epigenetic changes leading to a differentially expressed genome. Genotoxicity was measured using the flow cytometry-based micronucleus assay, whereas epigenetic regulation was assessed by Assay for Transposase-Accessible Chromatin (ATAC)-sequencing and transcriptomics by mRNA-sequencing. We observed a statistically significant dose-rate related increase in genotoxicity that was accompanied by increase in differentially expressed genes (Fig. 2). Initial analysis of open chromatin by ATAC sequencing was performed for the highest dose rate (100 mGy/h) and shows differentially open regions of the genome. Our results support the working hypothesis that the biological effects of ionizing radiation indeed depend on the dose rate.

Aim 3. Robust biomarkers of exposure to chronic low dose/dose rate ionizing radiation are urgently needed. MicroRNAs (miRNA) have emerged as promising markers. Our objective was to identify miRNA-signatures that can discriminate between exposure to γ-radiation or not, including chronic low dose rates. We exposed male CBA/CaOlaHsd and C57BL/6NHsd wild-type mice to 0, 2.5, 10 and 100 mGy/h γ-irradiation (3 Gy total-dose). A

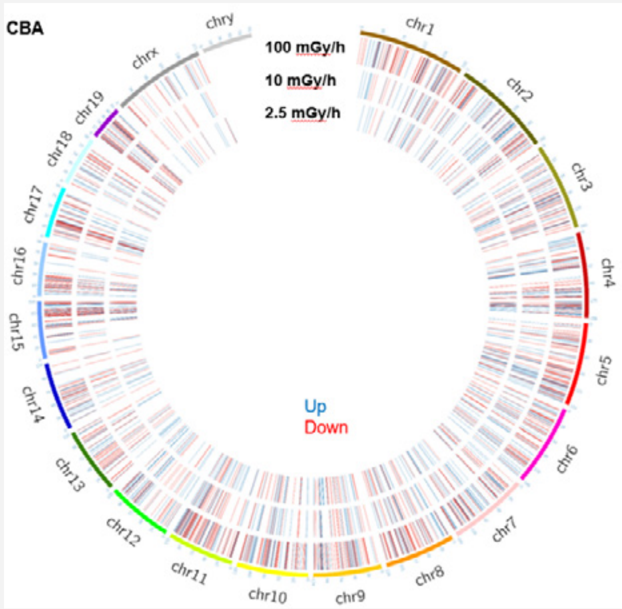


***Figure 2.** Dose-rate related changes in differentially expressed genes (DEGs) in each chromosome in CBA-mice.*

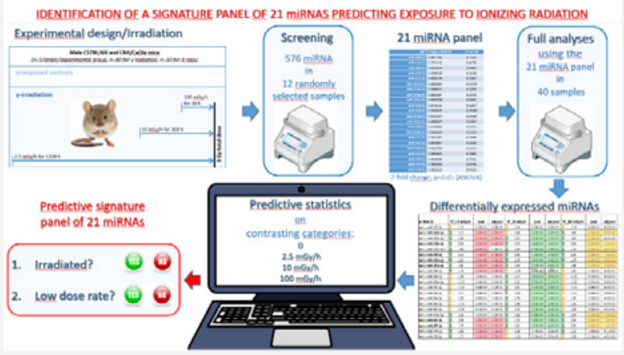


***Figure 3.** Using prediction models to identify miRNA-based markers of stress from chronic low dose rate.*

set of 21 miRNA- signatures was identified based on differential expression (>± 2-fold or $p < 0.05$), screening 576 miRNAs in 12 samples. Expression analyses of the 21-signature miRNA panel was performed in all samples (40).

To identify miRNAs that distinguished exposed from unexposed mice, nine prediction methods were employed; i.e., six variants of generalized regression models, random-forest, boosted-tree and nearest-shrunken-centroid (PAM). Using the 21-miRNA panel in the prediction models, we identified sets of candidate miRNA markers that correctly predicted exposure to γ-radiation, also for a low dose rate of 2.5 mGy/h (Fig. 3). Similarly, exposure to high dose rates was correctly predicted, including for X-rays.

Our approach with miRNA-based signature panels may also be useful for classification of exposure to environmental, nutritional and lifestyle-related stressors, including chronic low-stress scenarios.

Reference:
• *Duale, N., Eide, D.M., Amberger, M.L., Graupner, A., Brede, D.A., Olsen, A-K. Sci Total Environ. 2020 Feb 4;717:137068.*

RA3: MOLECULAR MECHANISMS BEHIND DIFFERENTIAL RADIOSENSITIVITY AND EFFECTS OF GAMMA RADIATION IN PLANTS

NMBU: *J.E. Olsen, Y.K. Lee, P. Bhattacharjee, D. Blagojevic, M. Viejo, G.B. Gillard, L. Grønvold, T.R. Hvidsten, S.R. Sandve, O.C. Lind, B. Salbu, D.A. Brede*

Objectives: Our previous studies showed dose-dependent DNA damage, growth inhibition and mortality in seedlings of the radiosensitive conifers Norway spruce and Scots pine after 6 days of gamma irradiation at ≥ 40 mGy/h, while the radioresistant herbaceous plant *Arabidopsis thaliana* showed DNA damage, but no mortality, and only slightly delayed reproductive development at ≥ 400 mGy/h (Blagojevic et al 2019a, b) (Fig. 1). The objectives of the current study were 1) to elucidate the molecular mechanisms behind differential radiosensitivity among plant species, 2) to assess early molecular events in response to gamma radiation and establish a dose-response connection to phenotypic effects and 3) to assess radiosensitivity of embryogenic conifer cells as compared to seedlings.

Methods: Seedlings of Norway spruce and *Arabidopsis thaliana* were exposed to 48 h of gamma radiation at 1 to 290 mGy/h from the NMBU ^{60}Co source. RNA sequencing (RNA-seq) was then performed (1, 10, 40, 100 mGy/h) and DNA damage (COMET assay), histology (light microscopy) and phenotypic effects were evaluated post-irradiation. Embryogenic cells of Norway spruce were also exposed to gamma radiation at 1 to 100 mGy/h, and subjected to RNA-seq. Analyses of DNA damage, histology, cytology (with transmission electron microscopy) and programmed cell death (Tunel assay) were conducted directly after irradiation and during post-irradiation cell proliferation and embryo development.

Results: In Norway spruce, reduced shoot length was already observed after 48 h of gamma irradiation at dose rates from 100 mGy/h. Two months post-irradiation, growth was still significantly reduced. In contrast, *A. thaliana* did not show reduction in growth at any of the applied dose rates. Both species exhibited significantly increased DNA damage from 1 mGy/h, but with slightly higher levels in Norway spruce than in *A. thaliana*. Although reduced, DNA damage was still present in both species 2.5 months post-irradiation.

In Norway spruce, there were a few differentially expressed genes (DEGs) after 48 h exposure to 1 and 10 mGy/h (about 40 DEGs). However, 40 and 100 mGy/h resulted in a progressive increase in the number of DEGs (about 800 and 5,000 DEGs, respectively).

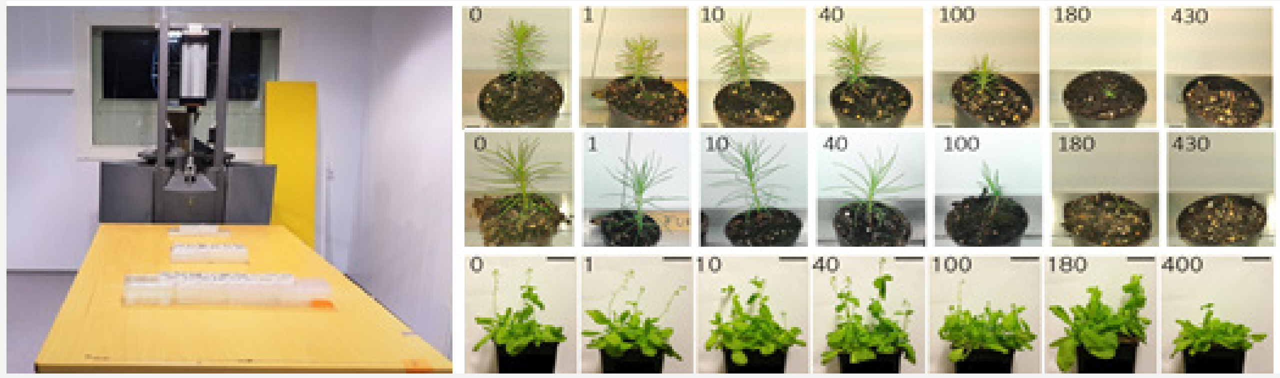


Figure 1. *(Left) Exposure of young seedlings in petri dishes to gamma radiation from a ^{60}Co source. (Right) Plants 1.5 months post-irradiation (mGy/h). Norway spruce (upper panel), Scots pine (middle panel) and Arabidopsis thaliana (lower panel). (Blagojevic et al. 2019a).*

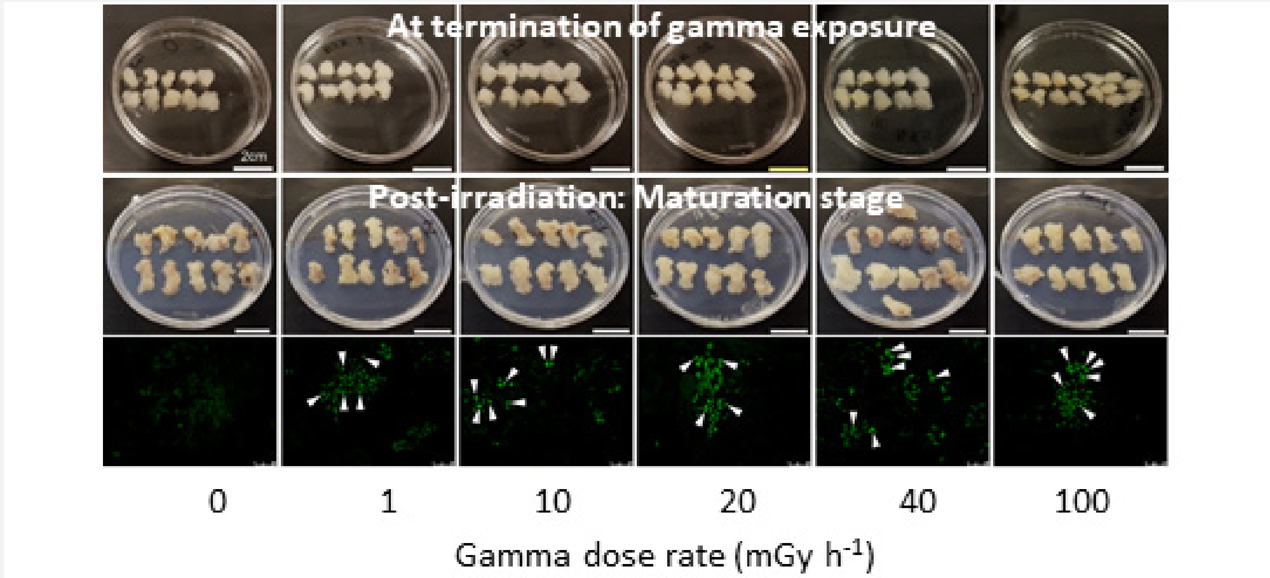


Figure 2. *Aggregates of embryogenic cells of the radiosensitive conifer Norway spruce after 6 days gamma irradiation (upper panel), and post-irradiation cultures for induction of embryo development at maturation media following cell proliferation (middle panel). Programmed cell death at the embryo induction stage analysed by Tunel assay (lower panel).*

In comparison, *A. thaliana* exhibited a massive shift in gene expression even at the lowest dose rates applied; with the number of DEGs ranging from about 3400 to 5000 at 1 and 100 mGy/h, respectively. Consistent with reduced growth in Norway spruce, genes involved in growth hormone biosynthesis, transport and signalling, cell wall organisation and photosynthesis were down-regulated at ≥ 40 mGy/h, and protein catabolism genes were upregulated. By contrast, in *A. thaliana*, genes related to growth hormone biosynthesis and signalling as well as cell wall organisation were upregulated, and protein catabolism genes downregulated. More genes related to protection towards oxidative stress and endoreduplication appeared upregulated in A. *thaliana* than in Norway spruce, whereas genes related to DNA repair were upregulated in both species, but with onset at higher dose rates in Norway spruce.

Gamma-irradiated embryogenic cells of Norway spruce showed similar dose-dependent DNA damage levels as seedlings exposed to equal gamma doses. For all dose rates applied, cell proliferation was observed during the post-irradiation culture (Fig. 2) and embryos grew, although all appeared malformed. At the end of the gamma irradiation as well as post-irradiation, cell damage and programmed cell death prevailed at all dose rates, with clearly damaged nuclei and accumulation of amorphous materials in the vacuoles (Fig. 2). Like in Norway spruce seedlings, genes related to protein degradation were massively upregulated, and cell-division related genes were downregulated.

Conclusion: The radioresistant *A. thaliana* showed a massive shift in gene expression even at 1 mGy/h, but in the radiosensitive conifer Norway spruce such a shift was observed only at higher dose rates and resulted in substantial DNA damage and impaired growth. Embryogenic cells of Norway spruce shared a wide range of DEGs with the seedlings and showed similar dose-dependent DNA damage.

References:

- *Blagojevic, D., Lee, Y.K., Brede, D.A., Lind, O.C., Yakovlev, I., Solhaug, K.A., Fossdal, C.G., Salbu, B., Olsen, J.E. 2019a. Comparative sensitivity to gamma radiation at the organismal, cell and DNA level in Norway spruce, Scots pine and Arabidopsis thaliana. Planta 250: 1567-1590.*
- *Blagojevic, D., Lee, Y.K., Xie, L., Brede, D.A., Lind, O.C., Tollefsen, K.E., Solhaug, K.A., Nybakken, L., Olsen, J.E. 2019b. Interactive effects of UV-B-gamma exposure on plant development, DNA damage and antioxidants in Scots pine seedlings. Photochem Photobiol Sci 18: 1945-1962.*

RA3: QUANTITATIVE ADVERSE OUTCOME PATHWAYS (qAOPs) TO PREDICT THE HAZARDS OF RADIATION AND RADIONUCLIDES

NIVA: *Y. Song, K.E. Tollefsen, L. Xie, S.J. Moe, R. Wolf*
NMBU: *D.A. Brede, Y. Kassaye, Y. Lee, J. Olsen, K.A. Solhaug*

Objectives: The main goal is to develop novel computational/mathematical models (qAOPs) for predicting the adverse effects of radiation and radionuclides on aquatic organisms.

Methods: A quantitative Adverse Outcome Pathways model (qAOP) is an evolved form of AOP that captures the quantitative Key Event (KE) Relationship (KER) in a causal pathway. This makes it feasible to predict Adverse Outcome (AO) based on the Molecular Initiating Event (MIE) and KEs measured at lower levels of biological organization (e.g. molecular, cellular) (Fig.1). With existing data from *Daphnia* (crustacean) and *Lemna* (aquatic macrophyte) studies, modular response-response (RR) relationship models were developed using basic statistical modelling approaches (benchmark dose analysis and generalized additive model), based on previously submitted AOPs (https://aopwiki.org/, AOP#216, 238, 311). A complete qAOP was constructed based on the modular models using a Bayesian Network (BN) approach. The BN modelling allows identification of a threshold value for an upstream KE to trigger a downstream KE, as well as to provide quantitative understanding of change as a function of radiation dose-rate in an AOP. Uncertainties related to the model were assessed using Monte Carlo simulations and the performance of the model was evaluated through Mean Squared Prediction Error (MSPE) and Area Under the Curve (AUC) measures. The NIVA Risk Assessment Database (RAdb) was used to organize and visualize data.

Results: An initial qAOP model was constructed based on the *Daphnia*-UV data using the BN approach. At least three more qAOPs for ionizing radiation are currently under development, including a plant-specific qAOP, an invertebrate-specific qAOP and a common qAOP for both.

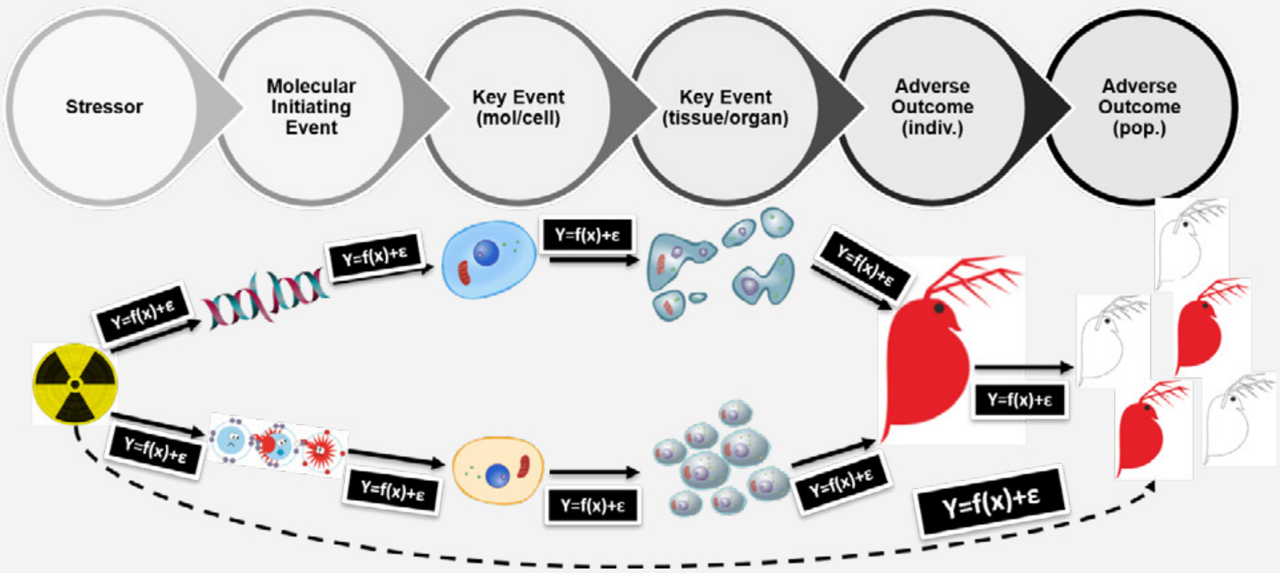


Figure 1. *Quantitative Adverse Outcome Pathways.*

RA4: IMPACT ASSESSMENTS FOR DUMPED NUCLEAR OBJECTS IN THE ARCTIC

DSA: *J. Brown, A. Hosseini*
MET: *H. Klein*

Objectives: To map and assess the most hazardous dumped or sunken radioactive objects in the Russian Arctic, calculate their radiation doses for three hypothetical release scenarios and assess the risk to humans and the environment.

Methods: An Environmental Impact Assessment was carried out to cover three scenarios: i) "Zero-intervention", ii) removing the objects (i.e., lifting) and iii) transporting them. Radioactivity dispersion in the atmosphere and in marine environments was simulated with the MET–SNAP model and the model of the Institute of Oceanology, respectively. Biokinetic models were employed to assess potential transfer through food-chains. The ICRP's IAEA and ERICA models predicted radiological impacts to man and to the environment.

Results: The six most hazardous objects were submarines B-159 (Barents Sea) and K27 (Stepovogo), reactor compartments K-11 and K-19 (Abrosimov), the Lenin Shielding Assembly (Tsivolky) and reactor K-140 (Novaya Zemlya Trench). Source terms were specified according to up-to-date knowledge concerning the objects.

The spread of contamination in seawater and soil was mapped as activity concentrations of ^{137}Cs. We derived time series of ^{137}Cs activity concentrations in selected plants and animals (Fig. 1), and assessed doses to humans (representative person – up to 1.8 mSv/a) and to selected reference organisms (<1.5 μGy/h).

Conclusion: Highest activity concentrations in terrestrial and marine food-chains are associated with (hypothetical) release from submarine B-159. For this source, ingestion doses and doses from terrestrial deposition would dominate (for all scenarios considered), despite the fact that representative persons live more than 150 km away from the release point.

Reference:
- *Hosseini et al. (2017). J. Environ. Rad. 167, 170-179.*

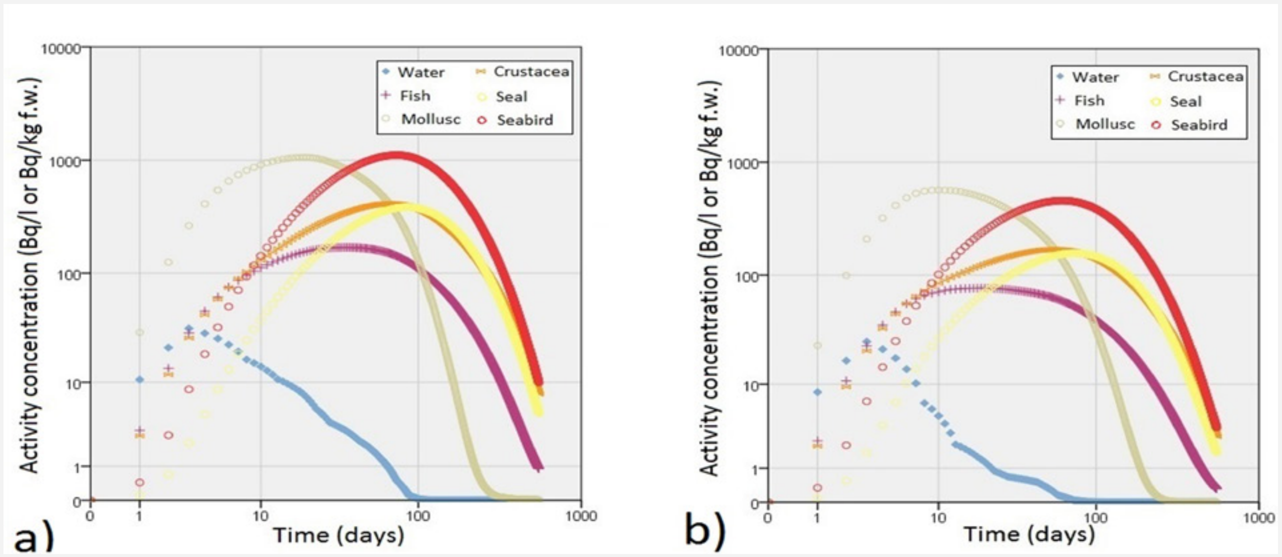


Figure 1. *Maximum activity concentrations of ^{137}Cs in sea water (Bq l^{-1}), fish, molluscs, crustaceans, seals and seabirds (Bq kg^{-1} fresh weight). These were associated with instantaneous releases to the marine environment at a) the seabed (NS B-159 burst at the bottom) and b) the surface (NS B-159 burst at the surface).*

RA4: COMPUTATIONAL AND EXPERIMENTAL ASSESSMENT OF MULTIPLE STRESSORS

NIVA: *K.E. Tollefsen, K. Petersen, Y. Song, L. Xie*
NMBU: *L. Skipperud, H.C. Teien, L.C. Lindeman, P. Alestrøm, D.B. Blagojevic, J. Olsen, K.A. Solhaug, B. Salbu*
DSA: *J. Brown, B. Johnsen*
Newcastle university: *C. Eastabrook, G. Caldwell*

Objectives: Develop and calibrate computational models to handle combined toxicity and cumulative risk of multiple stressors.

Methods: A database tool (NIVA RAdb™, www.niva.no/radb) was developed to predict the cumulative (combined) effect of chemical and non-chemical stressors. The tool, which is organised according to the principles of Adverse Outcome Pathways (AOPs), performs hazard (CHA) and risk (CRA) assessments and identifies total pressure, sensitive species groups (taxa), toxicity drivers, the most relevant modes of action (MoA) and risk drivers for complex assemblies of multiple stressors. A comprehensive set of analytical, visualisation and simulation tools have been developed to accommodate typical user needs (www.niva.no/nctp). Data from several CERAD studies using biomarker and effect methods (Blagojevic et al., 2019, Song et al., In press, Xie et al., 2019, Lindemann et al., 2019) were used to predict multiple stressor effects, following principles suggested by Beyer, et al. (2014) and Salbu et al. (2019).

Results: We predicted the cumulative risk of multiple stressors (radionuclides, UV, trace metals and organic chemicals) in several freshwater and marine exposure scenarios. The results typically demonstrate spatio-temporal patterns in potential impact, where susceptible species and risk drivers could be identified in most cases (Fig. 1). Combined toxicity studies with the most relevant risk drivers will be performed in 2020 to evaluate predictions and calibrate the models.

Conclusion: Computational studies have demonstrated the usefulness of the CRA approach and is envisioned to assist multiple stressor impact predictions and experimental verifications of new case studies in 2020.

Reference:

- *Xie, L., Solhaug, K.A., Song, Y., Brede, D.A., Lind, O.C., Salbu, B., Tollefsen, K.E. (2019). Modes of action and adverse effects of gamma radiation in an aquatic macrophyte Lemna minor. Sci Total Environ. 680: 23-34.*

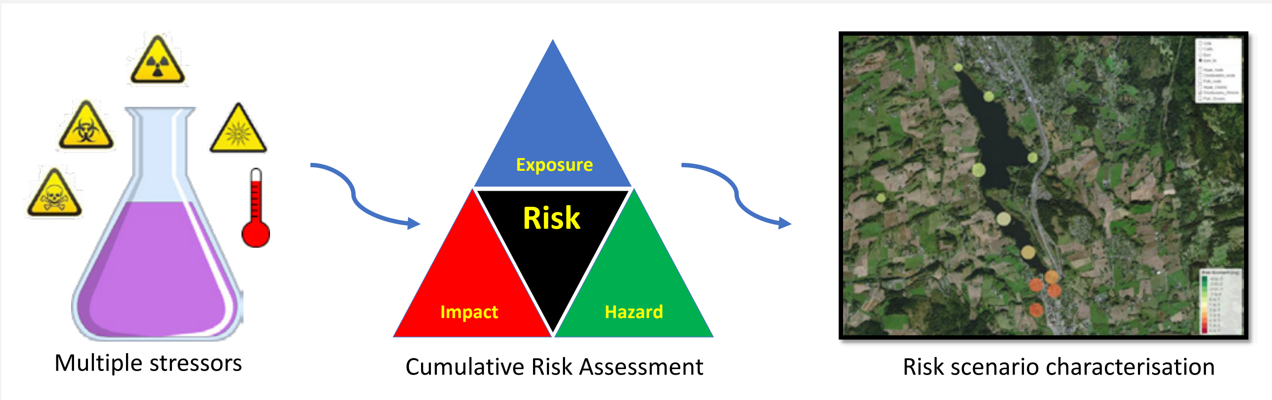


Figure 1. *Schematic illustration of cumulative risk assessment of multiple stressors in a simulated accidental spill of nuclear and chemical waste at Jarenvannet, Hadeland, Norway.*

RA4: REALISM AND USEFULNESS OF MULTISPECIES EXPERIMENTS IN RADIOECOLOGY. LITERATURE REVIEW

DSA: *H. Haanes, E.L. Hansen, T.H. Hevrøy, L.K. Jensen, R. Gjelsvik, A. Jaworska*
Stockholm University: *C. Bradshaw*

Objectives: Evaluating the design and properties of multispecies experiments using micro- and mesocosms (<100L, >2 species), to assess their suitability for radioecology.

Methods: Literature review of 406 articles in ISI Web of Science.

Results: Cosms ranged from standardized types in a laboratory setting to excised parts of natural environments. Multispecies cosms, even those <100 L, allow testing of ecological parameters like structure, function, interactions and indirect effects (Fig. 1). Even the smaller/"simpler" cosms showed to be ecologically complex, stable and long lasting (Fig. 2). Only 4 studies assessed ionizing radiation effects; the knowledge gap is clear.

Conclusion: We encourage cosm studies in radioecology using environmentally- relevant dose rates. Studies need to explain conditions of exposures/methods for dosimetry. More experimental units increase statistical power and smaller volumes are recommended when using radionuclides, due to waste concern or size limitations (in gamma exposures). Experiments should include a stabilization period, lasting as long as possible to ensure that effects manifests and asses variation in effects between replicates before the start of the experiment.

Choice of experimental design should depend on the specific scientific question. Ecologically complex designs are more representative of a natural situation and may therefore be better to assess effects in site-specific ecosystems, whereas standardized cosms increase the potential for replicability and are better to test a particular process or pathway, for example when testing relative toxicity of radiation and/or radionuclides.

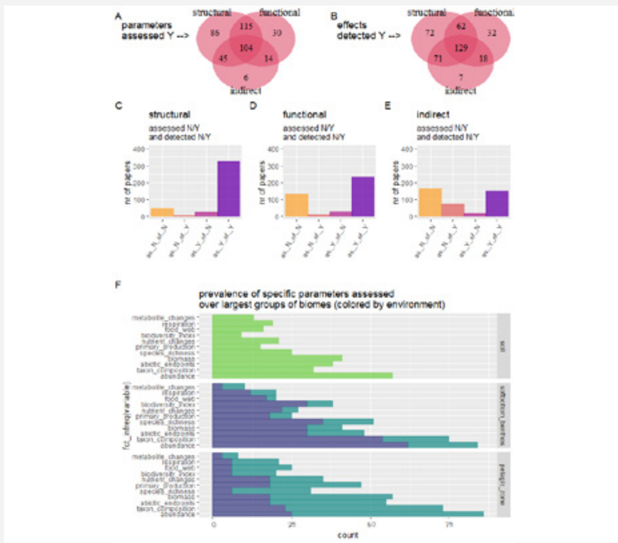


Figure 1. *A,B,C: Counts of reviewed papers that assess and/or detect effects in structural/functional/indirect effects along with prevalence of specified effects over largest groups of mimicked biomes.*

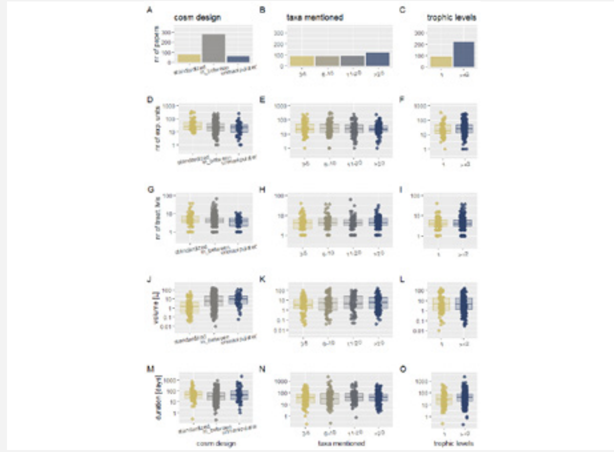


Figure 2. *Counts of review papers per category and distribution of numeric variables.*

Reference:

- *Haanes, H., et al., Realism and usefulness of multispecies experiment designs with regard to application in radioecology: A review. (2019) Science of The Total Environment, 2019: p. 134485. https://doi.org/10.1016/j.scitotenv.2019.134485.*

RA4: REHABILITATION OF THE CHERNOBYL AFFECTED AREAS: EXPLORING ATTITUDES OF LOCAL RESIDENTS

NMBU: *Y. Tomkiv, D. Oughton*
University of Portsmouth: *J. Smith*
University of Salford: *M. Wood*
NERC: *N. Beresford*
NUBIP: *N. Tverezovska*

More than 300,000 people were evacuated or relocated, and over 6,000 km² of land in Ukraine was abandoned because of the Chernobyl accident. Narodychi region is one of the areas within the zone of obligatory resettlement that for a variety of reasons remained inhabited. The special status of this area puts limitations on its development: it is forbidden to build, grow crops, or own private property. Today, more than thirty years after the accident, the Ukrainian authorities are evaluating a change in the status of Narodychi and other evacuated and relocated areas, and rezoning might allow for resettlement and agricultural production. This change could offer significant economic opportunities for the local regions but may also be a source of concern. Therefore, it is important that such proposed changes in land management are not only based on the best available scientific evidence, but also involve residents and other local stakeholders.

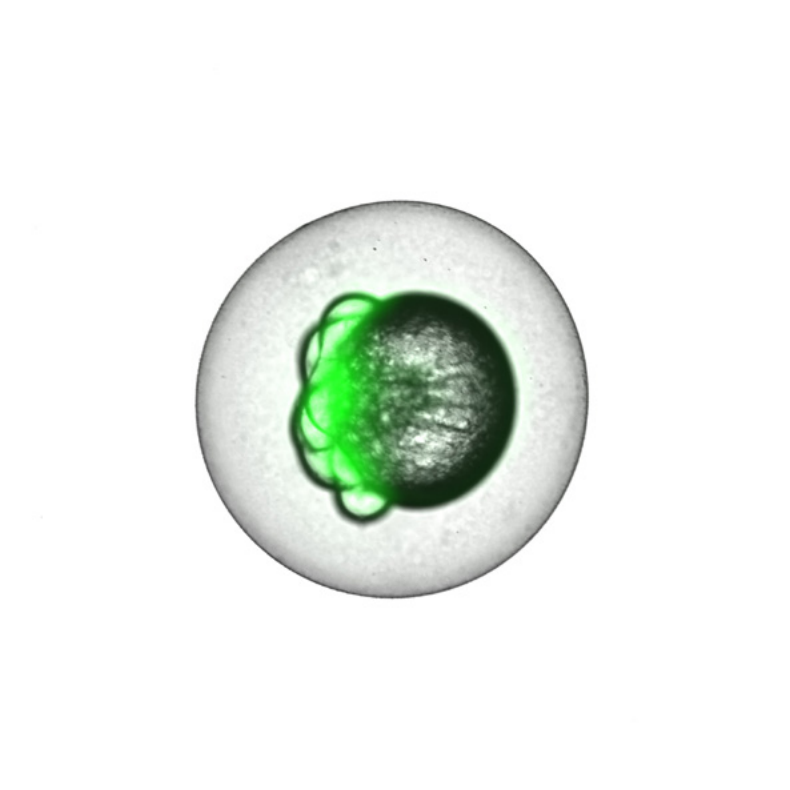
Abandoned houses are common in the Narodychi region.
Photo: Yevgeniya Tomkiv

Objectives: The purpose of this study was to get an understanding of the various perspectives residents have concerning the potential rezoning and change of land use of the Chernobyl affected territories.

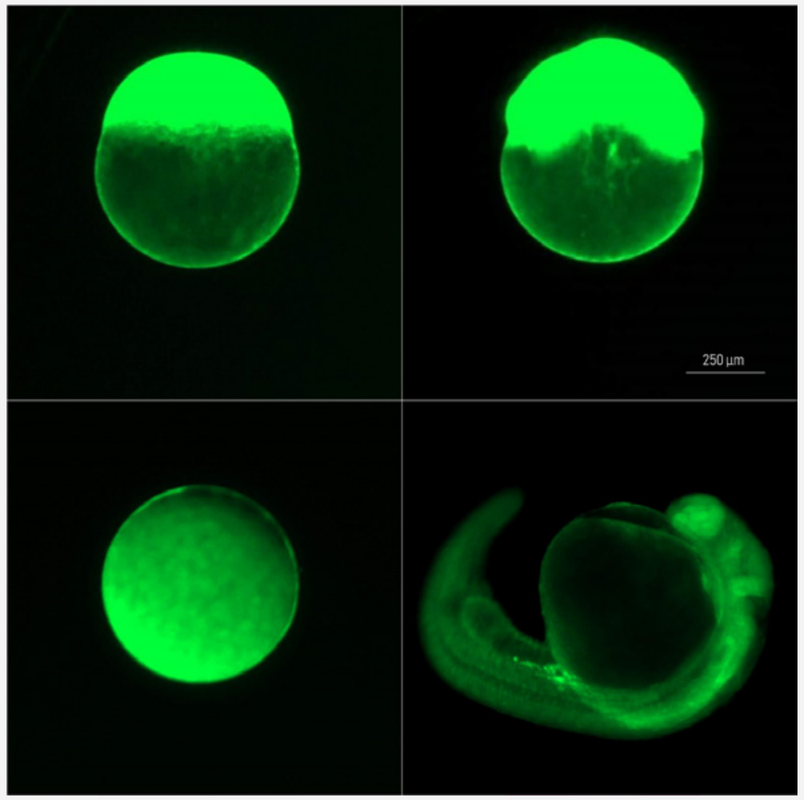
Methods: In October 2018, a round of interviews was held with residents of the Narodychi region, Ukraine (N=40). The survey aimed at exploring the views, experiences, knowledge, beliefs and/or motivations of people.

Results: The survey revealed a wide range of factors that influence the attitudes of the local population towards potential rezoning and change of land use of the Chernobyl affected territories. The residents of Narodychi region recognized the potential benefits of the rezoning and change of land use, such as an increase in number of working places and potential investors and opportunities for further development of the area. However, they were also concerned about the potential loss of social benefits and opportunities to receive alternative housing. Also, the findings of the survey highlighted the lack of information about the radiological situation in the region, about how the rezoning and land use change would be carried out and what it would imply for the residents.

Conclusion: Opinions and attitudes of residents must be understood and responded to when developing new land use plans for Chernobyl affected areas. The information gaps revealed by this study will be addressed by organizing public meetings where residents can communicate with international researchers and other relevant stakeholders, such as authorities and NGOs.



Transgenic vas::EGFP Zebrafish: from egg to embryo.
Photos: Selma Hurem



International Collaboration

Professor Per Strand, Deputy Director

During 2019, CERAD has maintained and expanded its bilateral and international collaboration. CERAD is actively engaged in Arctic Council activities and contributes updated knowledge to the Arctic Monitoring and Assessment Programme (AMAP). CERAD still works on Nordic Nuclear Safety Research (NKS) projects and has started new ones. CERAD has maintained 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). CERAD has been a key partner in the EU Projects TERRITORIES (To Enhance Uncertainties, Reduction and Stakeholders Involvement Towards Integrated and Graded Risk Management of Humans and Wildlife in Long-Lasting Radiological Exposure Situations), CONFIDENCE (Coping With Uncertainties For Improved Modelling And Decision Making In Nuclear Emergencies and further building upon its position as a partner in the European Joint Programme for the Integration of Radiation Protection Research (CONCERT).

CERAD/NMBU is still the sole provider of a European MSc in Radioecology, a role which is supported through collaborative agreements (MoU) between NMBU and several universities abroad. Such international collaboration serves to provide access to cutting-edge experimental facilities in Germany, France, Australia and Spain as well as facilitating access to contaminated sites (e.g., Chernobyl, Fukushima). This enables and enriches CERAD's field and research activities and CERAD's publication list is testimony to its broad international engagement.

CERAD participated actively in international bodies and fora such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Atomic Energy Agency (IAEA), the International Union of Radioecology (IUR), and the International Commission on Radiological Protection (ICRP).

CERAD maintained its representation in IAEA activities related to radioactive particles (chairing IAEA's Coordinated Research Projects CRP), revising technical safety guides and continuing work on the societal impacts of the Fukushima accident. CERAD's Deputy Director is the chairperson of an IAEA/FAO/WHO Steering Group on Developing Guidance on the Control of Radioactivity in food and drinking water in Non-Emergency Situations.

CERAD's close and fruitful collaboration with the IUR to develop an ecosystem-based approach for radioecology continued through 2019. Our experts work in ICRP task groups and CERAD's Research Director is a member of UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology (COMEST). CERAD has cooperated with the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD), in facilitating cooperation among countries concerning advanced nuclear technology infrastructures. NEA's Expert groups on Management of Radioactive Waste After a Nuclear Power Plant Accident and on Characterisation Methodology of Unconventional and Legacy Waste (EGCUL) are chaired by CERAD's Deputy Director.

Experimental Facilities, Models and Tools

Professor Ole Christian Lind, Director of Research

CERAD is performing cutting-edge research thanks to unique experimental facilities, models and tools within CERAD/NMBU's own premises and through collaboration with Norwegian partners and international institutions. Below, we briefly list these tools and facilities.

Radionuclides, elements, isotope ratios
CERAD is well equipped for qualitative and quantitative analysis of radionuclides and stable elements:

- At the NMBU Isotope Laboratory and at DSA, instruments and methods for determination of gamma-, beta- and alpha-emitting radionuclides are available.
- At NMBU, three Agilent Triple Quadrupole ICP-MS (ICP-QQQ-MS) are available for the determination of long-lived radionuclides, including isotope ratios, and a large range of other elements in the periodic table.
- A Bruker M4 Tornado micro-XRF is installed at NMBU to provide fast, non-destructive analysis of elemental composition and 2D distribution in a wide range of samples at microscopic spatial resolution.
- For determinations at very low concentration levels, the AMS facilities at the Australian National University in Canberra and the Centro Acceleradores at the University of Seville in Spain may be utilized.

Particles, speciation and fractionation techniques
CERAD has 30 years of experience with speciation and fractionation of radionuclides and other elements in the environment. Equipment available at NMBU for *in situ* and in lab speciation analysis include the following:

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

Synchrotron x-ray radiation facilities and imaging tools
Through collaboration with Norwegian and international research institutes, CERAD has access to the following:

- ESEM-EDX, TEM, TOF-SIMS, nano-CT, synchrotron radiation nano-and microscopic techniques. A combination of SR techniques (i.e., 2D/3D μ-XRF – elemental distributions, μ-XRD - structure, μ-XANES – oxidation state) has been developed by NMBU and the University of Antwerp in collaboration with synchrotron beamline scientists. These

techniques are utilized for particle research at facilities such as PETRA in Germany, ESRF in France and SLS in Switzerland.
- The Imaging Centre of NMBU is developing a state-of-the-art facility for microscopy (ESEM-EDX, TEM, confocal laser SEM, light microscopy, live cell imaging and spectroscopy (x-ray, RAMAN micro imaging etc). CERAD acts as an important node for the further development of expertise and instrumentation (stereo microscope with micromanipulation, micro-XRF, micro-XRD).

Experimental facilities

CERAD has access to experimental facilities at NMBU, and at partner institutions. These facilities include:

- The NMBU low-medium dose gamma radiation exposure facility (Figaro). This unique facility provides a continuous dose-rate field from 3 Gy/hr down to 400 μGy/hr, and allows for simultaneous chronic exposure of samples of various test organisms over the whole dose-rate field. It opened in 2003, and was upgraded in 2012, with support from the EU DoReMi project.
- The NMBU Fish laboratory - temperature controlled transfer and effects experiments can be performed on both freshwater and marine fish species.
- The Zebrafish platform at NMBU - for transfer and effect studies on Zebrafish.
- The Mouse platform at NIPH - for transfer and effect studies on mice.
- NMBU's phytotron: Greenhouses, for experiments on plant uptake and effects.
- NMBU's Climate chambers for combined UV and gamma exposure.

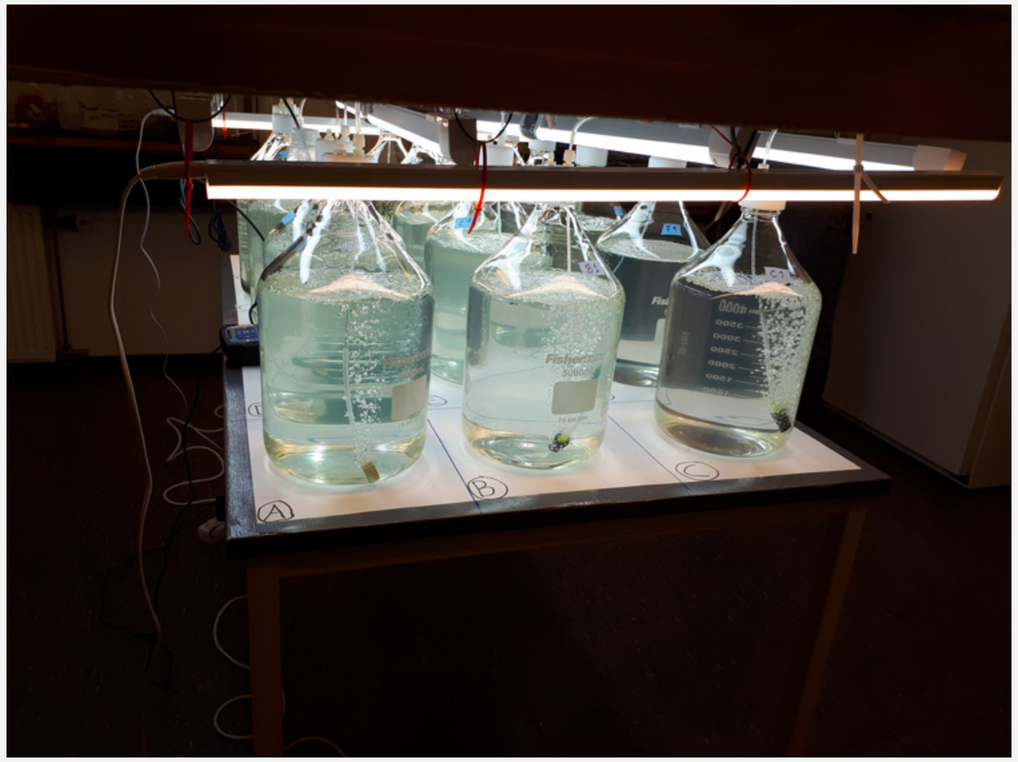
Biological effects toolbox

As part of Research Area 3, the CERAD consortium has created a toolbox for the systematic interspecies comparison of the harmful effects of chronic exposure to radioactivity. We aim to identify mechanisms at the molecular level that determine species' sensitivity to chronic low/medium dose-rate gamma radiation, but the toolbox also allows for additional stressors such as radionuclides, toxic metals and UV. Model species selected so far include 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

A key focus of CERAD is to link models describing radionuclides released from a source term, via dispersion, deposition, and ecosystem transfer to biological uptake and effects, in order to estimate impact and risks for man and environment as well as consequences for our economy and society. To that effect, several models of CERAD's partners were interfaced:

- Dispersion and Transfer Models: Advanced models of air/marine transport and real time/historic/future prognostic meteorological data are further developed by MET and DSA.
- Ecosystem transport models: Advanced fresh water (NIVA) and terrestrial (DSA) models, advanced models on dosimetry (DSA), as well as the Food chain and Dose Module for Terrestrial pathways (FDMT) module on food chain transfer and dose estimation for terrestrial pathways.
- The tools for Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) and Cumulative Risk Assessment (CRA) are employed (by DSA, NMBU and NIVA) to predict the hazard and risk of single stressors as well as of combinations of them (multiple stressors).
- CERAD has so far created two parts of an economic model for potential nuclear events: 1) a scenario-specific assessment of economic consequences for agriculture due to accidental release and radioactive contamination, 2) a scenario-specific assessment of economic consequences for recreational fisheries due to radioactive contamination.



Algea cultures.
Photo: Lisa Rossbach

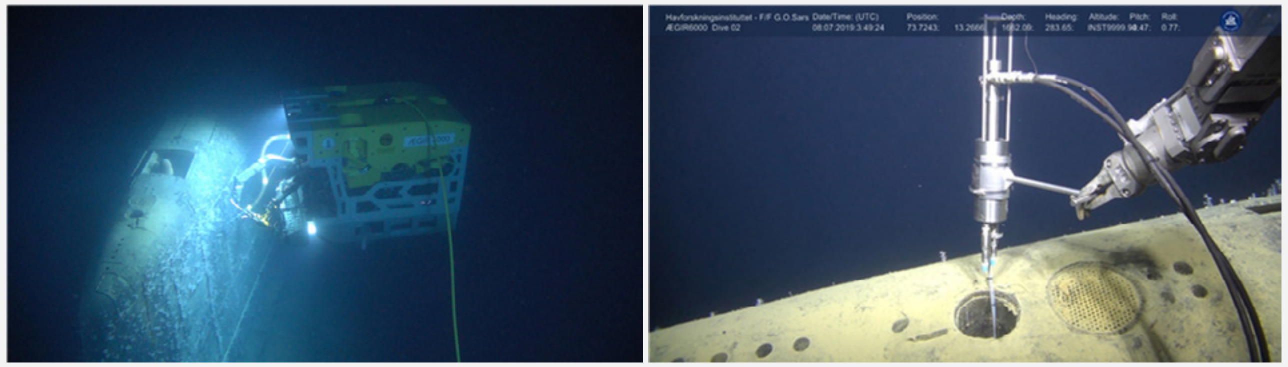
Bird's eye view of Paul Scherrer Institut (PSI) in Villigen, Switzerland, with the Swiss Light Source (SLS) 3rd generation synchrotron facility in front.
Photo: Paul Scherrer Institut, Markus Fischer.

Field Studies and Expeditions

Several expeditions and fieldwork are performed each year by CERAD. Since 2013, fieldwork and expeditions associated with accidental releases of radionuclides from nuclear test sites, naturally occurring radioactivity (NORM) sites and fieldwork concerning case studies have been carried out. CERAD fieldwork provides input to all research areas, as investigations carried out relate to the speciation of radionuclides (RA1), mobility and transfer in the environment, bioavailability for 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.

Komsomolets Expedition

In July 2019, CERAD took part in a research cruise to investigate the condition of the former Soviet Union nuclear submarine "Komsomolets", which is located at 1673 meters depth in the Norwegian sea. The cruise was carried out using the research vessel G.O. Sars from the Norwegian Institute of Marine Research (IMR) and the advanced Remotely Operated Vehicle (ROV) Ægir 6000. The expedition was performed under the auspices of the Joint Norwegian Russian Expert Group for investigation of radioactive contamination in Northern Areas. Scientific personnel included participants from IMR, DSA and CERAD/NMBU as well as one observer from the Russian institute Research and Production Association (RPA) «Typhoon». Three journalists from the Norwegian television companies TV2 and Screen Story participated to produce news stories and documentaries from the cruise. A crew of seven people from the University of Bergen (UiB) and IMR was responsible for operations with the ROV Ægir 6000, which was used to visually document the condition of "Komsomolets", and take samples of seawater, sediment and biota at specific locations around the submarine. Onboard analyses of seawater sampled directly from the ventilation pipe showed activity concentrations of ^{137}Cs between <8.0 and 857 Bq/l, indicating that previously documented releases from the reactor are still occurring, 30 years after "Komsomolets" sank. Both IMR, DSA and CERAD/NMBU are working with collected samples to further understand the nature of the releases and to determine if any Pu from the submarine or from the two nuclear warheads has been released into the marine environment.



The Remotely Operated Vehicle (ROV) Ægir 6000 used for investigating "Komsomolets" at 1763 meters depths and collection of seawater inside the ventilation pipe by a biosyringe connected to the ROV.
Photos: Ægir 6000/Institute of Marine Research

CERAD fieldwork in Valdresflya, in connection with the annual herding and slaughter of reindeer in Vågå Tamreinslag.
Photos: Ole Christian Lind (left), Marit Nandrup Pettersen (right)

Chernobyl Fieldwork

The Chernobyl exclusion zone (CEZ), Ukraine, was visited by CERAD scientists in March. Fieldwork was performed in close collaboration with Ukraine partners at National University of Life and Environmental Sciences of Ukraine (NUBIP). The 2019 campaign focused on the aquatic environment, and included collection of water samples and pike to identify uptake of radionuclides, to use selected biomarkers in the field and to study reproductive effects of long-term radionuclide exposure including sperm motility.

Fieldwork in Jotunheimen

In September CERAD including close collaborators conducted field work in Valdreflya, the Jotunheimen Mountains of Central Norway, in connection with the seasonal gathering and slaughter of domestic reindeer belonging to Vågå Tamreinslag. Two helicopters were employed to herd about 3000 animals of which 3 were tagged with GPS and electronic dosimeter equipped collars that provided us with information on variation in external gamma exposure for each animal over time, as well as variation in external exposure among the three animals across their feeding grounds. The activity concentrations of Naturally occurring and anthropogenic radionuclides in all organs of these 3 reindeers are now being determined and will provide unique and detailed biodistribution data of radionuclides and doses to reindeer from natural radioactivity (e.g. ^{210}Po) and Chernobyl fallout derived ^{137}Cs.

CERAD tracer field experiments: For the past four years, CERAD has carried out a series of controlled tracer experiments with ^{131}I at NIBIO's facilities at Apelsvoll and Furuneset, an inland and west coastal area, respectively. In July 2019, we studied the transfer of ^{131}I from rain to grass and strawberries, and the uptake of ^{131}I and ^{84}Sr by potatoes. A total of 11 field visits have been carried out since 2016, looking at transfer of ^{131}I to various crops, as well as collections of rainwater, and studies of the distribution between grass and barley and soil profiles.

Key scientists joining the Vågå fieldwork; Prof E. Knut Hove, CERAD director Brit Salbu, Prof E. Tom Hinton, USA and Lavrans Skuterud, DSA.

CERAD
CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

Education Program

Professor Lindis Skipperud,
Director of Education

An essential component of CERAD is training and education (MSc, PhD, PostDoc) in an attractive research environment. We aim to train and deliver internationally competitive candidates within radioecology and ecotoxicology. Part of the education is networking, and to achieve this we interact with the wider radioecology community, through outreach to students, teachers, employers and employees, and other stakeholders outside of our networks. Radioecology is a multidisciplinary field, and our MSc and PhD students have a wide range of carrier opportunities. We therefore bring students in contact with potential employers, and ensure that our training and education meet their needs.

European MSc program in radioecology

The MSc in Radioecology that CERAD has established at NMBU is the only one in Europe. Students from inside and outside of the continent have attended individual course modules or completed the whole MSc program. The EU MSc in Radioecology is a two-year, Bologna accredited MSc program (120 ECTS) and consists of compulsory and optional course modules and a research topic. Apart from our own staff, experts from other national and international institutions teach on our courses. All courses are taught in English and most are run as intensive blocks, to make it easier for students from abroad to attend specific ones. The main MSc courses are listed in the table below, and focus on radioecology, radiochemistry and ecotoxicology. In the second year, MSc students work on research questions that are associated with CERAD's projects.

Phd and PostDoc program at CERAD

The PhD education at CERAD should provide Europe's nuclear stakeholders (e.c. EU Commission, nuclear authorities, industry and other professionals) with the required experts. Of particular concern to these stakeholders, is the need for post-graduates with skills in radiochemistry, radioecology, radioecotoxicity, environmental modelling, radiation protection including radiobiology and dosimetry.

In total, 14 PhD students have defended their PhD thesis within CERAD. Of these, 6 PhD students defended their theses in. 2019:

- Blagojevic D. 2019. Sensitivity of plants exposed to gamma radiation. A physiological and molecular study. PhD thesis, Norwegian University of Life Sciences, Aas, Norway. Thesis number 2019: 100. ISSN 1894-6402, ISBN 978-82-575-1664-2.

CERAD scientists and students from NUBIP and NMBU in front of the Chernobyl sarcophagus. During a joint DIKU/NUBIP/CERAD young scientist seminar in Ukraine, June 2019.
Photo: Ole Christian Lind

NMBU Norwegian University of Life Sciences
Norwegian Centre of Excellence
The Research Council of Norway

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

- Kleiven, M. 2019. Silver nanomaterials in aquatic systems - linking uptake and effects in biota to exposure characterization. Norwegian University of Life Sciences, Aas, Norway. Thesis number 2019: 10. ISSN: 1894-6402, ISBN: 978-82-575-1527-0.
- Rossbach, L. 2019. Single and multigenerational studies of silver nanoparticle toxicity and adaptive mechanisms in the nematode Caenorhabditis elegans. Norwegian University of Life Sciences, Aas, Norway. Thesis number 2019: 37. ISSN: 1894-6402, ISBN: 978-82-575-1596-6.
- Simonsen, M. 2019. Marine transport modeling of radionuclides using a dynamic speciation approach. Norwegian University of Life Sciences, Aas, Norway. Thesis number 2019: 42. ISSN: 1896-6402, ISBN: 978-82-575-1602-4.
- Tomkiv, Y. 2019. Risk communication in nuclear emergency preparedness: Embracing the complexity. Norwegian University of Life Sciences, Aas, Norway. Thesis number 2019: 39. ISSN: 1894-6402, ISBN: 978-82-575-1598-0.
- Wærsted, F. 2019. Mobility of naturally occurring radionuclides and stable elements in alum shale: A case study of Gran, Highway 4, Norway. Norwegian University of Life Sciences, Aas, Norway. Thesis number 2019: 72. ISSN: 1894-6402, ISBN: 978-82-575-1632-1.

There will be 16 PhD defences coming in the later years of CERAD, and in total, this will amount to 30 PhD students associated with CERAD during the 10 year period.

CERAD also consist of Post Doc positions, and to date, 11 Post Docs have been or still are part of the CERAD Post Doc program.

International cooperation in education

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

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

CERAD/NMBU and NUBIP closely collaborate in a DIKU-funded project (2016-2020) “Joint Ukrainian-Norwegian education and training program in Environmental Radioactivity”. The project supports mobility of MSc and PhD students as well as teachers between Ukraine and Norway.

Education and training platforms

The Radioecology MSc program and courses at CERAD can also be found on several websites of EU projects and training platforms. CERAD has developed an education and training platform within the Radioecology Exchange website https://radioecology-exchange.org/. It was set up as part of the EC STAR project and was further developed under EC COMET. The Radioecology Education and Training Platform is a focal point for students and professionals interested in radioecology. It presents all education and training opportunities within radioecology and environmental radioactivity offered by members of the STAR and COMET consortiums and was further developed by the CONCERT-TERRITORIES project. The Radioecology Exchange website, including the Education and Training Platform is now maintained by the Radioecology ALLIANCE.

CERAD scientists and students at work in the NMBU fish laboratory.
Photo: Shane Scheibener

Funding and Expenditures

Jorunn Hestenes Larsen,
Management Director

The turnover for CERAD in the sixth operational year was MNOK 56.

The CERAD CoE project financing constitutes of funding from the RCN together with a substantial contribution from all CERAD partner institutions, as well as from international projects.

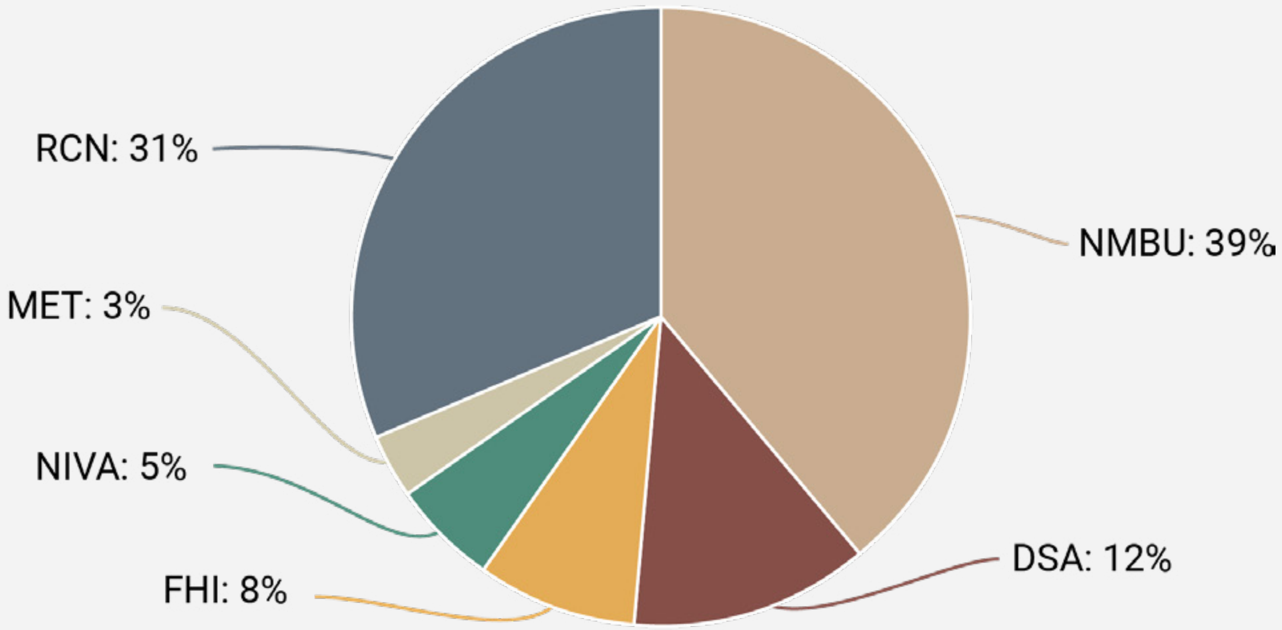
The direct core funding contribution from RCN was MNOK 15.5 in 2019. Cash funding contributions (MNOK 2.3) were received from the Norwegian University of Life Sciences (NMBU) and Norwegian Radiation and Nuclear Safety Authority (DSA). The in-kind personnel contributions from partner institutions are estimated to MNOK 30.

In addition, several ongoing RCN (EU) funded projects at NMBU/Isotope Laboratory are included as a financial source for CERAD (MNOK 6).

The expenditure is primarily connected to salaries, amounting to MNOK 36, which includes overheads covering indirect costs.

Other running expenses amounted to MNOK 15.

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



Partners’ contribution to CERAD’s total turnover in 2019

Annual Conference

The annual CERAD conference was organized at the Norwegian Academy of Science and Letters in Oslo, Norway, February 4th–5th, 2019. Furthermore, one pre - and two post- conference workshops with invited guests were organized.

The conference attracted about 80 participants, including CERAD's scientists, the Board, the Scientific Advisory Committee (SAC), the Relevance Advisory Committee (RAC) and a series of invited speakers and guests. The aim of the conference was to present highlights from research in 2018, as well as the outcome of the Mid-term evaluation of CERAD by the Research Council of Norway (RCN). Invited guest presentations focused on nuclear events such as those at Chernobyl, Fukushima and Semipalatinsk, as well as challenges associated with NORM. Attention was then focused on knowledge gaps, also identified in the EU CONCERT project, and on new challenges that CERAD has to face in the years to come. The presentations were followed by constructive discussions on priorities and the way forward. Young scientist presentations were as usual given on Day 2.

Following the program of the first day, we all enjoyed the concert by HYBRIS, the CERAD House-band, prior to dinner.

One pre-conference and two post-conference CERAD workshops were organized in connection with the Annual Conference.

*Annual conference participants gathered in 2019.
Photo: Yevgeniya Tomkiv*

*Invited lecturers (from left Sergei Tolmachev, Valery Kaspharov, Mikhail Balonov, Sergey Lukashenko) with CERAD Director Brit Salbu.
Photo: Brit Salbu*

*Participants of the post-conference workshop on Multiple stressor exposure.
Photo: Brit Salbu*

*Participants of the pre-conference workshop on Health effects following severe nuclear events.
Photo: Brit Salbu*

Societal Impact

Professor Deborah H. Oughton, Director of Research

As detailed in the International Collaboration section, CERAD's output is of importance to a large number of national and international policy makers. CERAD also carries out social science research on the impacts of nuclear events, and participates in the new EU Social Sciences Platform in Radiation Protection, SHARE. We have studied the societal and ethical aspects of the Fukushima and Chernobyl accidents, in collaboration with WHO, Fukushima Medical University and the IAEA. Research into emergency preparedness and risk communication made use of public surveys, observation exercises and focus group studies, as well as other stakeholder engagement activities, and has been used to develop recommendations given by the EU CONFIDENCE project. Our results have also been applied by NEA in its work on Integration of Non-Radiological Aspects of Emergency Planning and by WHO in its Radiation Emergency Medical Preparedness and Assistance Network (REMPAN). Both have increased attention for the psychosocial aspects of nuclear emergencies. In collaboration with the iClear project, CERAD has also participated in the rezoning of the Chernobyl Exclusion Zone, chairing stakeholder meetings and carrying out surveys of affected populations. These studies and meetings have involved a wide range of stakeholders, including members of the affected population in Fukushima and Chernobyl as well as authorities and experts. Thus, our work had a direct influence on policies and society.

CERAD has addressed ethical aspects of radiation protection and looked into challenges with health surveillance and thyroid screening, implications of radiosensitivity tests (in collaboration with MELODI), and the increased application of personal health and dosimetry tools as part of the EU SHAMISEN project (Nuclear Emergency Situations: Management and Health Surveillance). In 2019, CERAD organised a consensus workshop on Ethical Aspects of Health and Dosimetry apps in Oslo, addressing emerging challenges from Artificial Intelligence, Big Data and the Internet of Things. Results from the workshop have fed into a report on ethical challenges of artificial intelligence and machine learning by UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology. CERAD's Research director is a member of the Commission.

In addition to assessments of the ecological impacts of the Fukushima and Chernobyl accidents, our research also considers the economic and societal consequences, through assessment of impacts on ecosystem services. CERAD has contributed to a series of workshops in collaboration with the IUR on ecosystem effects, including co-arranging the "Radiobiology meets Radioecology" workshop at the International Congress of Radiation Research, in Manchester (August 2019).

CERAD continues to be involved in work on socioeconomic aspects of nuclear accident remediation, including the economic impact of countermeasures. We organised stakeholder dialogues and surveys of public opinion to assess compliance with recommendations. Stakeholder dialogues have the added advantage of facilitating dissemination of CERAD's research results and may lead to an increased public understanding of the technical, organisational and socioeconomic challenges of radiation risk assessment and governance.

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CERAD in Media

A documentary about the research cruise to the Norwegian sea

Photo: Havforskningsinstituttet/ «Ægir 6000»

Researchers from CERAD and NMBU went on a research cruise in July 2019 and uncovered a leak of radioactive material from the sunken submarine "Komsomolets", which is at the bottom of the Norwegian Sea. TV2 has made a documentary about the cruise, which will be available at TV2 Sumo

There was broad media coverage when staff of Havforskningsinstituttet, DSA and NMBU / CERAD went on a cruise to the sunken Komsomolets nuclear submarine this summer (see Field Studies and Expeditions for more details).

TV2, NRK, VG and NTB, Aftenposten, Klassekampen, and Vesterålen Online, covered the event. In addition, more than 22 Norwegian newspapers made news stories about the cruise.

Leading international news agencies such as American Press, Reuters, and AFP as well as BBC World Service (https://www.bbc.com/news/world-europe-48949113) and Fox News covered the cruise.

The following are links to stories about the cruise in national newspaper and partners' websites

https://www.tv2.no/nyheter/10712201/
https://www.tv2.no/a/10713685/
https://www.tv2.no/nyheter/10709168/
https://www.kystogfjord.no/nyheter/forsiden/30-aar-siden-Komsomolets-sank
https://www.kystogfjord.no/nyheter/forsiden/Skal-finne-ut-om-atomubaatvrak-lekker
https://www.kystogfjord.no/nyheter/forsiden/Paaviste-radioaktiv-lekkasje
https://www.dsa.no/nyheter/94831/skal-finne-ut-om-atomubaatvrak-i-norskehavet-lekker
https://www.dsa.no/nyheter/94838/forskerne-avdekket-radioaktiv-lekkasje-fra-komsomolets
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https://www.nmbu.no/en/services/centers/cerad/news/node/37910
https://www.nmbu.no/en/services/centers/cerad/news/node/37888
https://www.nmbu.no/en/services/centers/cerad/news/node/38213
https://www.svt.se/nyheter/utrikes/rysk-ubat-utanfor-norge-fortfarande-radioaktiv?

– Lav selvforsyningsgrad av norsk korn «reddet» lenge selenstatus til den norske befolkningen. Fra rundt år 1880 skyllet amerikansk korn fra områder med selenrikt jordsmonn inn over det europeiske markedet og utkonkurrerte mange europeiske produsenter, skriver artikkelforfatterne. (Foto: Terje Bendiksby / NTB scanpix)

Kan lavt inntak av selen fra mat og dyrefôr gi dårligere helse hos mennesker og husdyr?

POPULÆRVITENSKAP: Historisk sett har inntaket av selen vært svært lavt i store deler av befolkningen og husdyra i Norge – særlig i innlandet. Etter en periode med bedring er det nå lavt igjen.

In March, Forskning.no published two stories, with contributions by several CERAD partners:

- the first one discussing the health effects of low selenium in food and animal feed on people and farm animals.
https://forskning.no/forskeren-forteller-helse-mat/kan-lavt-inntak-av-selen-fra-mat-og-dyrefr-gi-darligere-helse-hos-mennesker-og-husdyr/1306202

– Et jod-inntak hos mor lavere enn ca. 150 mikrogram pr dag er assosiert med dårligere prestasjon og mer atferdsproblemer, skriver artikkelforfatterne. (Foto: Dima Sidelnikov / Shutterstock / NTB scanpix)

Moderat mangel på jod kan gi store helseskader

POPULÆRVITENSKAP: Jod er nødvendig for både mennesker og husdyr. Struma på grunn av jodmangel hos folk og dyr var et stort helseproblem, men er ikke lenger vanlig. Men fortsatt er jod-inntaket hos mennesker lavere enn ønskelig i Norge og store deler av Europa. Mild til moderat jodmangel hos kvinner i fruktbar alder, kan være kritisk for fostre og spebarn.

- the second on the health effects of low iodine intake by people.
https://forskning.no/barn-og-ungdom-helse-mat/moderat-mangel-pa-jod-kan-gi-store-helseskader/1311074

In September, NRK covered CERAD's field work in the Vågå Tamreinslag, when reindeer were tagged with collars containing GPS and dosimeters. This will provide CERAD with valuable information on the animals' year-around exposure to naturally occurring radiation (see Field studies and Expeditions for more details).
https://tv.nrk.no/serie/distriktsnyheter-oestnytt/201909/DKOP99092019/avspiller

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Christina Søyland Hassfjell, Senior Scientist, Oslo University Hospital
Chloe Eastabrook, PhD student, Great Britain
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Conferences and Workshops

CERAD Annual Conference,
The Norwegian Academy of Science and Letters,
Oslo 4th-5th February 2019
Organizer: CERAD

Pre-Conference CERAD Workshop - HUMAN HEALTH EFFECTS FOLLOWING SEVERE NUCLEAR EVENTS
Thon Hotell Vika Atrium, Oslo, February 3rd 2019
Organizer: CERAD

Post-Conference CERAD Workshop - PARTICLE CHARACTERISTICS AND NUCLEAR FORENSIC
The Norwegian Academy of Science and Letters, Oslo, February 5th 2019
Organizer: CERAD

Post-Conference CERAD Workshop - MULTIPLE STRESSOR EXPOSURE
Norwegian University of Life Sciences, Ås, February 6th 2019
Organizer: CERAD

SHAMISEN-SINGS
Consensus Workshop on Ethical Aspects of Dosimetry Tools and Apps
The Norwegian Academy of Science and Letters
Oslo 23-24th May 2019
Organizer: SHAMISEN-SINGS, CERAD

4th European Radiation Protection Week
Stockholm 14th-18th October 2019
Organizer: Stockholm University, MELODI, NERIS, CONCERT, ALLIANCE
in cooperation with CERAD, NKS and SSM

CERAD Workshop on ATAC-seq
NMBU campus Adamstuen 24th -25th September 2019
Organizer: CERAD

CERAD Workshop - CHERNOBYL EXCLUSION ZONE (CEZ)
Norwegian University of Life Sciences, Ås, December 10th 2019
Organizer: CERAD

Norwegian Centre of Excellence

Norwegian University of Life Sciences

DSA Norwegian Radiation and Nuclear Safety Authority

Norwegian Meteorological Institute

Norwegian Institute of Public Health

NIVA Norwegian Institute for Water Research