Norwegian Centre of Excellence

The Research Council of Norway

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

ANNUAL REPORT 2020

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

CERAD Annual Report 2020 (RCN Project Number 223268)

Coverpage:
Fieldwork on River Vefsna, Nordland county, Norway
Photo:
Magne Simonsen

Coverpage inside:
Preparation of water fractionation samples from fish experiment in Solbergstrand
Photos:
Håkon Sparre

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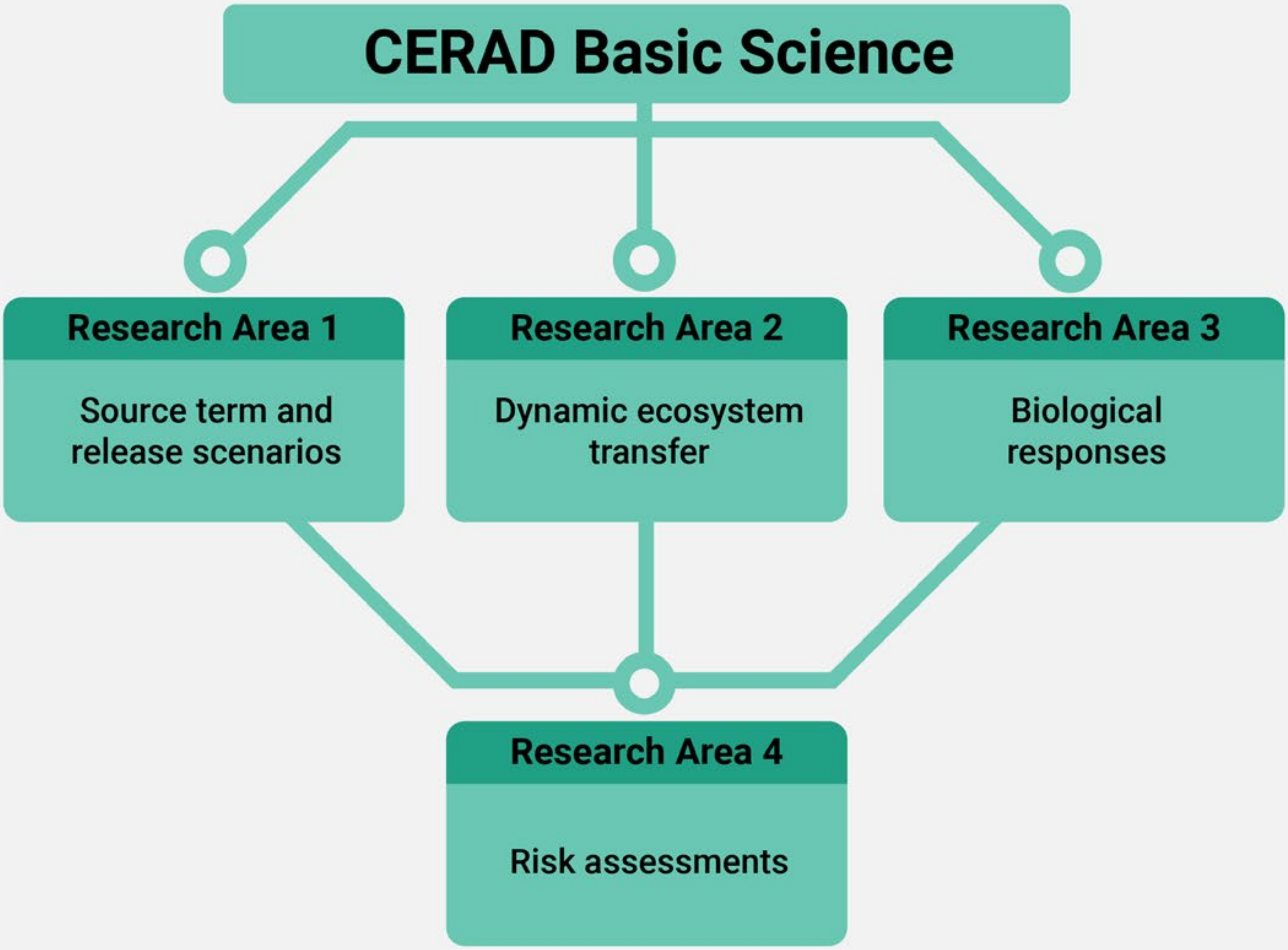
Quentin Mennecart

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

Acronyms and Abbreviations

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 and Humanities 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

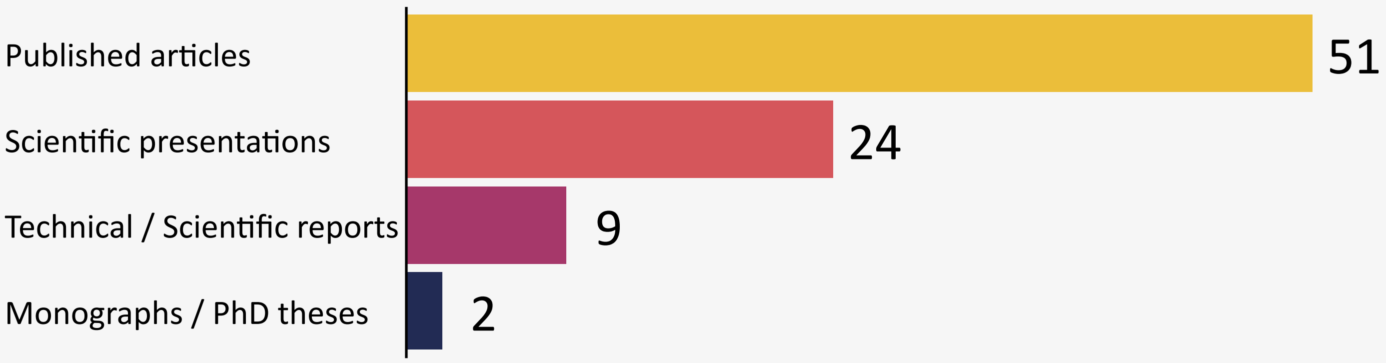
DSA Norwegian Radiation and Nuclear Safety Authority

NIVA Norwegian Institute for Water Research

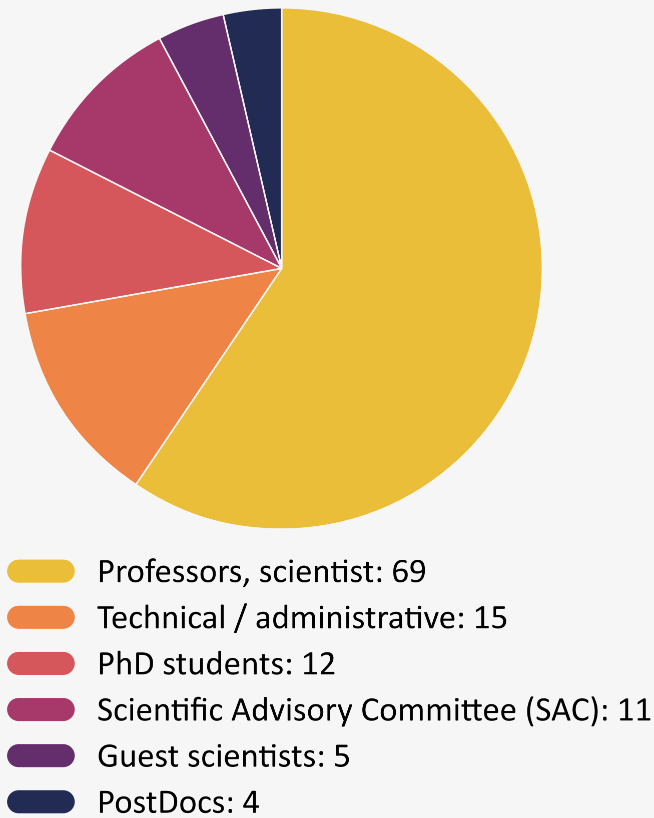
NIPH Norwegian Institute of Public Health

Norwegian Meteorological Institute

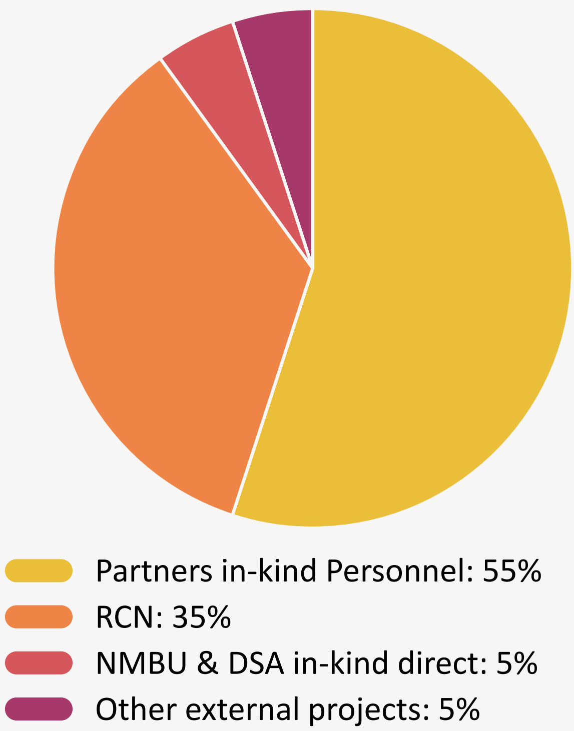
Scientific output in 2019



Full- and part-time personnel in 2020
Total: 116



Funding in 2020
Total: 45 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 75 part-time scientists, 30 PhDs, 12 PostDocs and 17 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 2020, CERAD has faced new challenges, both from the Covid-19 pandemic as well as new areas of research. Decommissioning of the two Norwegian research reactors has started, which requires a range of scientific skills, from waste characterisation and nuclear forensics, to impact assessment and stakeholder engagement. Emergency preparedness has expanded to include nuclear events such as detonation of nuclear bombs close to or in Norway. Finally, the new EU project RadoNorm has increased the focus on human and environmental effects of naturally occurring radioactive materials, including the interaction of radon with other environmental stressors. Despite the impact of Covid-19 on CERAD research plans, and especially on fieldwork and PhD projects, CERAD has risen to many of the challenges, co-organising international webinars, running online and laboratory MSc courses, and supporting PhD students who have experienced delays in their project progress.

Management Group

*Professor
Deborah H. Oughton,
Centre Director*

*Anne Liv Rudjord,
Deputy Director*

*Professor
Ole Christian Lind,
Director of Research*

*Professor
Lindis Skipperud,
Director of Education*

*Hans Christoffer Tyldum,
Management Director*

Comments from the Director
Deborah Oughton

"*Same, same, but different*". Anyone who has travelled in south east Asia will be familiar with that phrase and the variety of situations it can cover. It is what springs to mind when I look back on my past 12 months as the new CERAD director. "*Same, same*": CERAD has the same fundamental research aims, the same research agenda and research areas, and largely the same scientists and researchers. The solid foundation laid by Brit Salbu as director during the first seven years of CERAD's journey has fostered fruitful collaboration between CERAD partners, a recognition and appreciation of the different skills and knowledge that lead to successful multidisciplinary research, as well as understanding the importance of the basic research underpinning our understanding of the impacts of ionising radiation on humans and the environment. This strong foundation has also helped CERAD to meet the multitude of challenges faced by all researchers because of the Covid-19 pandemic.

Over the past 12 months CERADs research programme has evolved to meet some of the new challenges society faces in assessment and management of radiation risks. The centre has started work to assess the research needs for decommissioning Norway's two research reactors, for nuclear waste management and for expanding emergency preparedness to cover new nuclear events, such as deployment of nuclear weapons and accidents from spent fuel transportation. The new EU project RadoNorm, in which NMBU, NIVA, DSA and NIPH are partners has bought new projects linked to radon and naturally occurring radioactive materials (NORM), meaning that the CERAD research portfolio has expanded to cover epidemiology and experiments on inhalation risks from radon and other stressors. This also includes implementation of CERAD's work on Adverse Outcome Pathways (AOP) in assessing risks of multiple stressors. Interactions between radon and cigarette smoke being one of the few internationally acknowledged example of synergistic effects for human health risk.

But the biggest difference for CERAD has come from the challenges of the Covid-90 pandemic. These have been particularly hard for our early career scientists, PhD and MSc students, especially those at the end or start of their project, who have experiences delays in access to laboratory facilities and fieldwork. CERAD has prioritised support for these students, and I would like to express particular thanks to CERAD technicians and administrative staff who have done their utmost to ensure that students have access to the laboratories and reduced delays in project progress. CERAD staff involved in teaching have seen almost all courses being moved online, but we managed to hold the majority of courses from the CERAD portfolio, mostly as digital courses, but also managing to carry out some laboratory teaching during the summer. We are also grateful to CERADs many international collaborators who participated in online teaching. With respect to dissemination, since the start of the pandemic, CERAD has been involved in arranging large international webinars (200-700 participants) in collaboration with the European research platforms (SHARE, NERIS, ALLIANCE). This first of these, on 23rd April 2020, was hosted by NMBU/CERAD, and made possible by the rapid learning curve our scientists experienced in being forced to move courses online.

I thank everyone in CERAD for their support, dedication and adaptability in this exceptional year, and hope that 2021 will see a return to international fieldwork, meetings and students back in our laboratories and classrooms.

Comments from the chair of the board
Siri Fjellheim

CERAD was established to perform long-term basic research to improve the assessment of radiological risks. The Centre is founded on a strong partnership between academia, research institutes and regulators, with the support of international collaborators. The interdisciplinary nature of the research carried out is well highlighted by the number and breath of the publications from the Centre, since 2013 nearly 300 articles have been published in international peer review journals, many of which are co-authored by multiple CERAD partners. Research spans from source term characterisation, through modelling and transfer of radionuclides in terrestrial and aquatic ecosystems, to biological responses in exposed organisms, and assessments of overall environmental impact and risks. Hence, the research programme is well-suited to the core values of NMBU, and especially relevant for our focus on sustainability. The importance and societal impact of CERADs research is shown by the participation of the centre researchers in the major international organisations working with radioecology and radiation risk.

At NMBU, CERAD currently involves the participation of four faculties - Environmental Sciences and Natural Resource Management, Biosciences, Veterinary Medicine, and the School of Economics and Business - with the faculty of Landscape and Society joining as part of the new EU project RadoNorm. CERAD's research has a high profile in education throughout the university, with scientists from both NMBU and partner institutions participating in teaching, as well as MSc and PhD student supervision. This is an important part of the university's recruitment and training of candidates for society's needs.

The board recognises the work of all CERAD participants during this past year, and as chair I would like to sincerely thank the board members from NMBU, the Norwegian Radiation and Nuclear Safety Authority (DSA), the Norwegian Institute for Public Health (NIPH), the Norwegian Meteorological Institute (MET) and the Norwegian Institute for Water Research (NIVA) for all their contributions, discussions and positive interactions in 2020.

Management and Administration

The CERAD Board

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

The CERAD Board members 2020 have been:

- Pro-rector Siri Fjellheim, NMBU, Chair (from August 2020)
- Deputy Chair Per Strand, DSA, Deputy chair
- Dean Hans Frederik Hoen NMBU/MINA
- Division Director Toril Attramadal, NIPH
- Deputy Managing Director Tor-Petter Johnsen, NIVA
- Research Director Lars-Anders Breivik, MET
- Scientist Dag Anders Brede, NMBU
- Centre Director Brit Salbu, CERAD;
- Centre Director Deborah Oughton (from February 2020)

CERAD Scientific Advisory Committee

The CERAD Scientific Advisory Committee (SAC) is headed by the CERAD Research Director and includes 11 internationally well–merited scientists from 9 countries (USA, Ukraine, Slovenia, Belgium, Sweden, Canada, Australia, Japan, Finland and UK). 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 2020 have been:

- Dr. David L. Clark, National Security Education Center, Los Alamos National Laboratory, USA
- Professor Valery Kashparov, National University of Life and Environmental Sciences of Ukraine, Ukraine / Professor II, NMBU
- Professor Koen Janssens, University of Antwerp, Belgium
- Professor Peter Stegnar, Jožef Stefan Institute, Slovenia
- Professor Carmel Mothersill, McMaster University, Canada
- Professor Colin Seymour, McMaster University, Canada
- Professor Tom Hinton, Fukushima University, Japan / Professor II, NMBU
- Dr. Clare Bradshaw, Stockholm University, Sweden
- Professor Janet Bornman, Curtin University, Australia
- Professor Sisko Salomaa, University of Eastern Finland, Finland
- Professor Emerita Brit Salbu, NMBU
- Mr Graham Smith, GMS Abingdon Ltd, UK, and Adjunct Research Professor Clemson University, USA

CERAD Relevance Advisory Committee

The CERAD Relevance Advisory Committee (RAC) is headed by the CERAD Deputy Director and includes representatives from key

Norwegian stakeholders/end-users
The RAC meets once a year at the CERAD conference. In 2020 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

CERAD Research Management

The CERAD Management Group (MG) is responsible for running the research management of the Center and consists of the CERAD principal investigators, headed by the CERAD Director (Fig.1). In addition, Anne Marie T. Frøvig, DSA, is adviser to MG, and Jorunn Hestenes Larsen has retained a part time position as administrative advisor. The CERAD MG reports to the CERAD Board, and includes:

- CERAD Director: Deborah Oughton, Professor, NMBU
- Deputy Centre Director: Anne Liv Rudjord, Department of Research and Development, DSA
- Education Director: Lindis Skipperud, Professor, NMBU
- Research Director: Ole Christian Lind, Professor, NMBU
- Administration Support: Miriam van Heist, NMBU

The Extended MG includes the MG and the Research Area (RA) leaders, representing all CERAD partners. The RA leaders report to the CERAD MG and CERAD Research Director. The CERAD research area leaders in 2020 were:

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

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. Throughout 2020, these meetings were extended to include all Umbrella leaders, in order to enhance communication in Covid times.

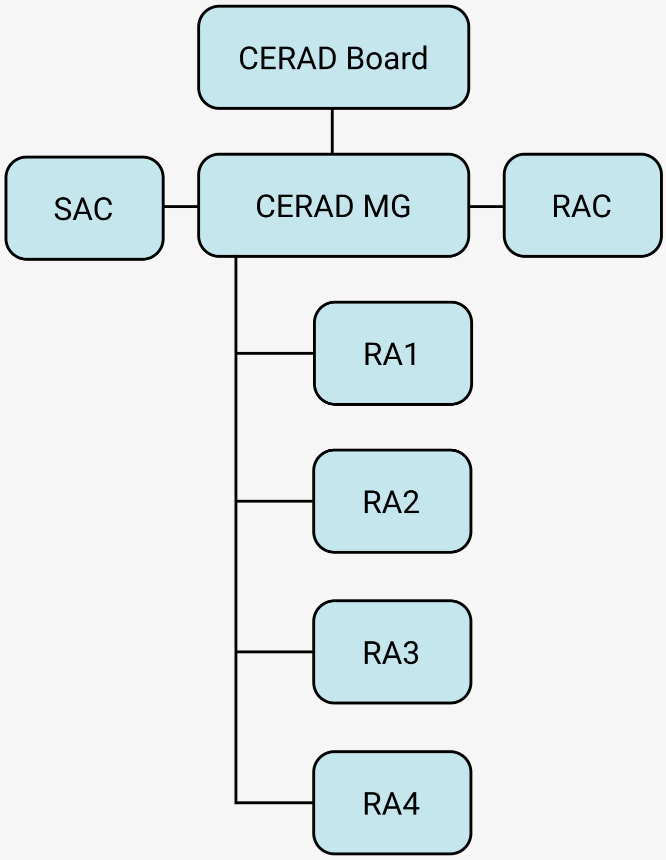


Figure 1. *The CERAD research organization*

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 www.nmbu.no/cerad 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 of 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 2020, 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/Ionizing Radiation and Dosimetry

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 toxicodynamics to toxicokinetics. 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 Dag Anders Brede)

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 2020, the focus areas of RA3 have been:

• Umbrella 3A: Radiosensitivity (Dag Anders Brede and Jorunn Elisabeth Olsen)
• Umbrella 3B: Combined Toxicity and Cumulative Risk (Knut-Erik Tollefsen)
• Umbrella 3C: Transgenerational and Reproduction Effects (Jan Ludvig Lyche and Selma Hurem)

Research Area 4 - Risk Assessment and Ecosystem Approach

(Knut-Erik Tollefsen and Deborah 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 2020, 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 (Yevgeniya Tomkiv).

The following sections contain research highlights from 2020, as presented during CERAD's Annual Conference in May 2021. Major achievements of the centre since the start in 2013 can be found in publication lists on https://www.nmbu.no/en/services/centers/cerad/publications.

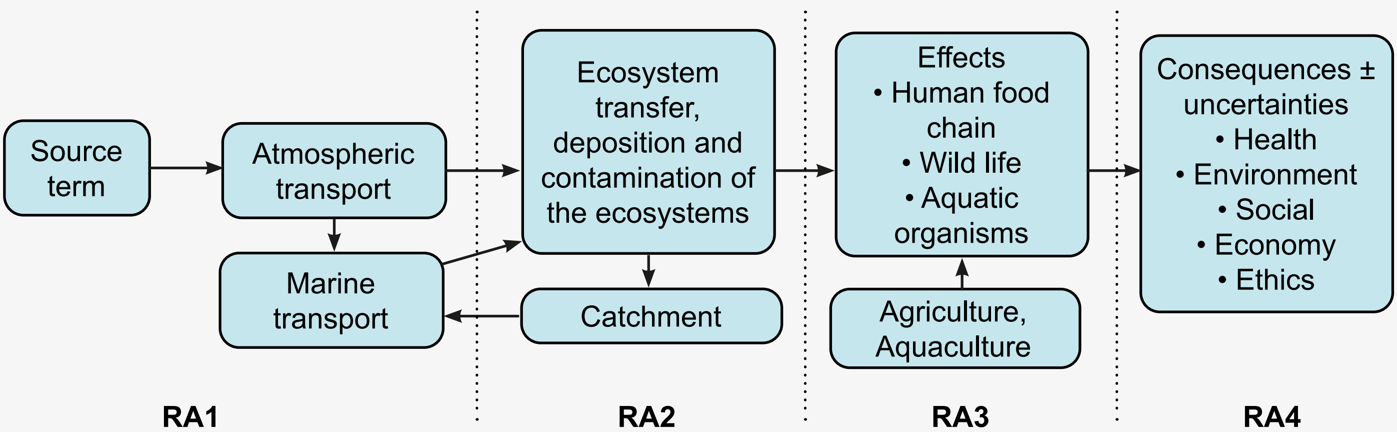


Figure 1. *Linking models from source term via ecosystem transfer to the impact for humans and the environment, for the society, economy and ethics. The research within RA1 to RA4 should reduce the overall uncertainties associated with modelling the impact and risk.*

Unusual Elemental Composition of Radioactive Particles from Dounreay, Scotland

Highlight writer:
Ian Byrnes

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

Objectives:
To characterize elemental composition of highly radioactive particles originating from nuclear fuel reprocessing at the United Kingdom Atomic Energy Authority's Dounreay Facility that were inadvertently released to the environment in the late 1950s to 1970s and have subsequently been found on site grounds and local beaches.

Methods:
Sample particles were obtained with the assistance of the Scottish Environmental Protection Agency (SEPA) that are representative of two types of uranium (U) fuel particles (~75% ^{235}U enrichment): (1) from the Materials Test Reactor (MTR) and (2) from the Dounreay Faster Reactor (DFR). To properly characterize the particles, a range of laboratory techniques were employed including micro-X-ray Fluorescence (µ-XRF, Bruker M4 Tornado), Scanning Electron Microscopy (SEM, JOEL JSM 840), and Inductively Coupled Plasma Mass Spectrometry (Agilent 8900 QQQ-ICP-MS).

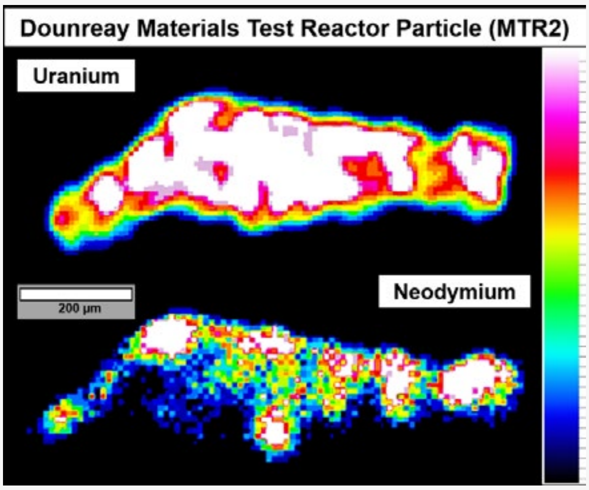


Figure 1: *Elemental mapping by µ-XRF of an MTR particle (normalized intensity color scale) showing uranium and neodymium (atomic concentration ~1-2%).*

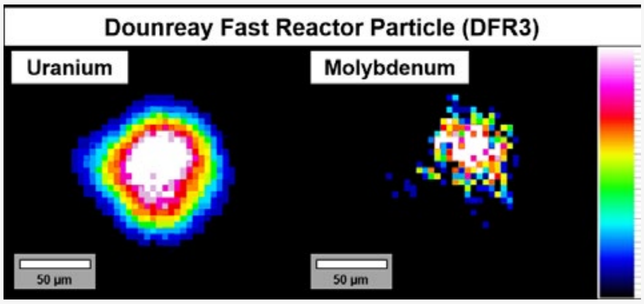


Figure 2: *Elemental mapping of a Dounreay Fast Reactor particle (normalized intensity color scale) with U and Mo (atomic concentration 1%) shown.*

Results:
Elemental mapping of MTR particles found U and aluminium (Al) inhomogeneously distributed in a way that is likely indicative of the design of the U-Al dispersion fuel used in the MTR. In addition, relatively high atomic neodymium (Nd) concentrations of 1-2%, spatially correlated with the U was observed (Fig.1). In DFR particles, U was found along with niobium (Nb) commensurate with the presence of UNb_2O_7 in DFR particles originating from high temperature reactions associated with accidental fires during DFR fuel reprocessing. Molybdenum (Mo) was also identified in both types of particles and shown to be spatially correlated with U at atomic concentrations of 1% (Fig.2).

Conclusion:
Particle characterization is an important step towards an effective environmental risk assessment. Here, MTR particles were shown to contain Nd in concentrations that imply it was used as part of the source fuel. In DFR particles, Mo was identified at atomic concentrations of ~1%. Literature suggests DFR fuel contained Mo (15%) as a moderator. The analysis of the particle here indicates a significant loss of Mo, potentially as MoO_3 during the original, high temperature formation of the particles.

References:

- *Byrnes, I., Lind, O.C., Hansen, E.L., Janssens, K., Salbu, B., 2020. Characterization of radioactive particles from the Dounreay nuclear reprocessing facility. The Science of the total environment 727, 138488-138488. doi:10.1016/j.scitotenv.2020.138488*

IAEA CRP: Environmental Behaviour and Potential Biological Impact of Radioactive Particles

Highlight writer:
Ole Christian Lind

Team members:
O.C. Lind, B. Salbu (NMBU)

Objectives:

The objectives of the International Atomic Energy Agency Coordinated Research Project (IAEA CRP) were to enhance the International Atomic Energy Agency (IAEA) Member States' capabilities in assessing the long term environmental behaviour and potential biological impact of radioactive particles released to the environment.

Methods:

To systemize existing data as well as to harmonize methods for obtaining novel data on the environmental behaviour of radioactive particles including 1) transformation rates and mechanisms, 2) transfer, retention, and biological effects in biota, as well as 3) dose assessments for biota and humans exposed to inhomogeneous distributions of radionuclides.

Results:

The CRP, chaired by the former CERAD director Brit Salbu, had a large international impact as more than 50 scientists from 18 research organizations in 14 countries across four continents (Australia, Europe, North America, and Asia) were involved. Among the outputs was a special issue of the Journal of Environmental Radioactivity, entitled "IAEA: Coordinated Research on Radioactive Particles" with significant contributions from CERAD, containing 11 papers and an editorial. Furthermore, the CERAD research director led the development of a joint EC COMET-RATE/IAEA CRP protocol for the standardization of abiotic and biotic particle leaching experiments (Salbu and Lind, 2020).

Conclusion:

The CRP has significantly contributed to the improvement of scientific evidence and knowledge on the abundance, forms, properties, and hazards associated with radioactive particles. The CRP participants expressed a strong interest in the continuation of research on the effects of radioactive particles in the environment and strongly recommended the IAEA consider organizing a new CRP on this subject.

Participants of the IAEA CRP at the IAEA headquarters, Vienna. Photo: IAEA

References:

- *Kashparov, V., Salbu, B., Levchuk, S., Protsak, V., Maloshtan, I., Simonucci, C., Courbet, C., Nguyen, H.L., Sanzharova, N., Zabrotsky, V., 2019. Environmental behaviour of radioactive particles from chernobyl. J Environ Radioact 208-209, 106025. Lind, O.C., Tschiersch, J., Salbu, B., 2020. Nanometer-micrometer sized depleted uranium (DU) particles in the environment. J. Environ. Radioact. 211, 106077.*
- *Lukashenko, S., Kabdyrakova, A., Lind, O.C., Gorlachev, I., Kunduzbayeva, A., Kvochkina, T., Janssens, K., De Nolf, W., Yakovenko, Y., Salbu, B., 2020. Radioactive particles released from different sources in the Semipalatinsk Test Site. J. Environ. Radioact. 216, 106160.*
- *Salbu, B., Fesenko, S., Ulanowski, A., 2019. Radioactive particle characteristics, environmental behaviour and potential biological impact. J. Environ. Radioact. 201, 56-57.*
- *Salbu, B., Lind, O.C., 2020. Analytical techniques for characterizing radioactive particles deposited in the environment. J. Environ. Radioact. 211, 106078.*

High resolution meteorological dataset for the Chernobyl accident

Highlight writer:
Erik Berge

Team members:

E. Berge, A. Dobler, H. Klein (Norwegian Meteorological Institute - MET)

Objectives:

To generate a high-resolution meteorological dataset for the time period of the Chernobyl accident to assess and develop the atmospheric dispersion model SNAP enabling improved long range dispersion modelling of radioactive particles and gases from the source to deposition in Scandinavia.

Methods:

Use the present operational meteorological model of MET for regional downscaling of historical global reanalysis from ECMWF (European Centre for Medium-Range Weather Forecasts).

Results:

Previous studies of the transport of radionuclides from Chernobyl to Norway were based on meteorological data of 10 km horizontal resolution. However, meteorological processes of large importance for the dispersion, such as vertical transport, dry and wet deposition often takes places on scales <10 km. Therefore, a higher resolution (2.5 km) meteorological dataset has been developed as a basis for new studies and validation of the SNAP model. The dataset spans the period from 25 April 1986 (one day before the accident) until 15 May 1986 (21 days). Whereas meteorological data are key input, a unique dataset of observations (e.g. activity concentrations and dose rates in air) during and after the accident will be crucial

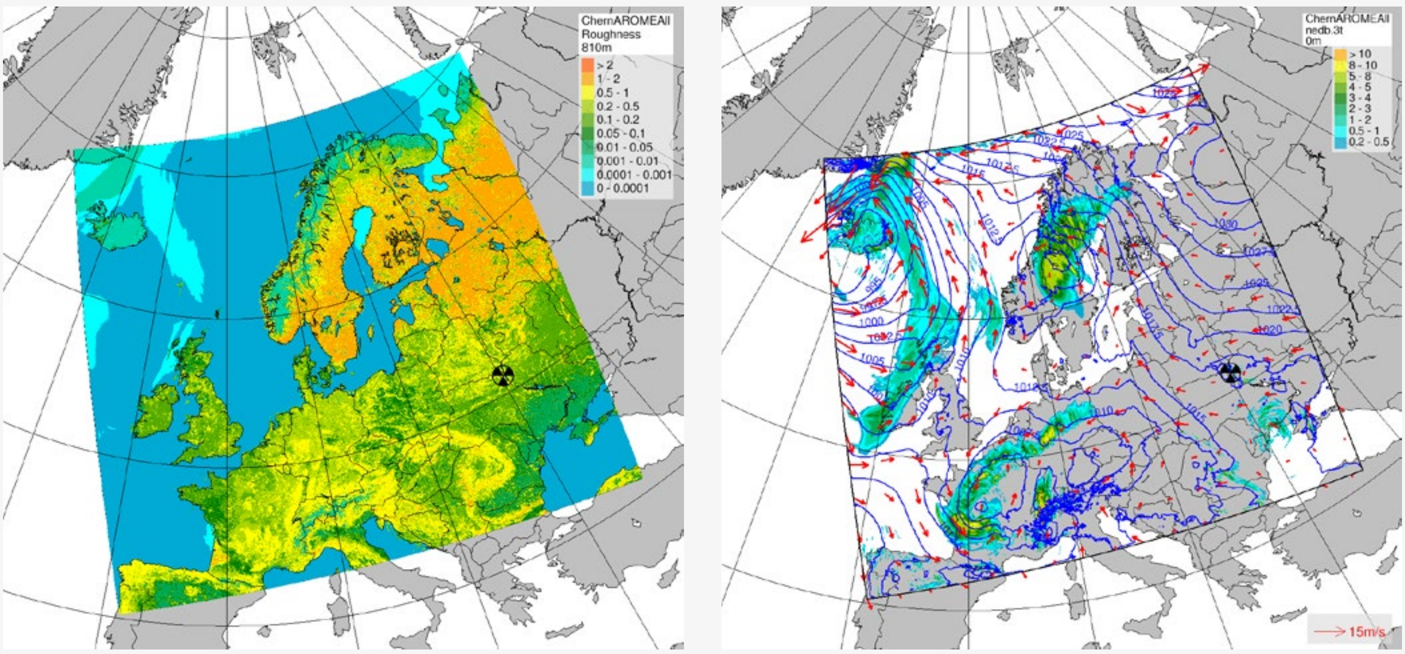


Figure 1: *Left panel shows surface roughness (m), while right panel shows surface pressure (hPa) in blue lines, 10 m wind speed and direction as red arrows and 3 hour accumulated precipitation (mm) at 12 UTC 26.04.1986, i.e. around the time of the initial accidental releases.*
Data originate from the Chernobyl hindcast dataset.

for further atmospheric dispersion model development and validation.
The method applied is regional downscaling of global reanalyses of the atmosphere also known as hindcasts (see for example Reistad et al., 2011, for a description of the hindcast method). MET's weather prediction model (Müller et al. 2017) were applied together with the ERA5 reanalysis (ERA5, 2021) to obtain the hindcasts. Each hindcast were run for 18 hours starting at 00 UTC and 12 UTC for the 21 days. The first 6 hours of each hindcast were discarded due to spin-up of cloud and precipitation. Thus, one day consisted of two hindcasts covering a 12 hours period each.
At the surface the 1 km resolution ECOCLIMAP data set (Faroux et al., 2013) was applied. The data set is based on 14 main land-use classes, which are used to describe for example surface roughness, albedo and the leaf area index. Of particular importance for dispersion and dry deposition of radionuclides is the near surface turbulence field, which is largely dependent on the surface roughness. The left panel of Figure 1 shows the surface roughness derived for the entire domain. The surface roughness is largely static over land, but with some temporal variation due to tree foliage changes with season, variation in snow cover etc. Over the oceans the surface roughness is variable depending on the sea state. The largest roughness values (1-2 m) are encountered in the coniferous forest areas of Scandinavia and Russia, somewhat lower values are seen in the Chernobyl area (0.2-1 m). Low values are found over the oceans and in the bare mountain areas in Scandinavia.

The right panel of Figure 1 depicts the weather pattern at noon the first day of the accident (26.04.1986). Surface low pressures were encountered over France, Scandinavia and near Iceland, while a surface high pressure dominated over northwest Russia. The pressure differences gave rise to easterly and south-easterly near surface flow in Chernobyl, carrying high levels of radionuclides toward central Europe and Scandinavia in the forthcoming days. Frontal type of precipitation was found in France, Germany, Scandinavia and northern parts of UK. In the Chernobyl region more scattered convective type of precipitation dominated during the first day of the accident.
Further work will include validation of the meteorological and dispersion calculations for Chernobyl as well as analysis of new approaches for dry and wet deposition parameterizations in SNAP. Furthermore, total deposition maps for the Vefsna catchment and fjord areas in Nordland county, Norway will be employed in ongoing aquatic and estuarine modelling CERAD projects for these areas.

Summary:

A high resolution (2.5 km) hindcast meteorological dataset has been established and will be applied to research and development of the atmospheric dispersion modelling within CERAD.

References:

- *ERA5. 2021. https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5*
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- *Müller, M., Homleid, M., Ivarsson, K-I., Køltzow, M. A. Ø., Lindskog, M., Midtbø, K. H., Andrae, U., Aspelien, T., Berggren, L., Bjørge, D., Dahlgren, P., Kristiansen, J., Randriamampianina, R., Ridal, M. and Vignes, O. 2017. AROME-MetCoOp. A Nordic Convective Scale Operational Weather Prediction Model. Weather and Forecasting. DOI: 10.1175/WAF-D-16-0099.1.*
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Implementing process-based models for radionuclide soil to plant transfer in FMDT

Highlight writer:
Justin Brown

Team members:
J. Brown, A. Hosseini (DSA)

Objectives:

To consider the implications of employing process-based models on predictions for radionuclide activity concentrations in grass and cow milk.

Methods:

The FDMT model (Food Chain and Dose Module for Terrestrial Pathways as used in the decision support systems JRodos and ARGOS) has been transferred to a modelling platform enabling sub-models to be modified and replaced. The default soil model of FDMT has been replaced by the 'Absalom' soil-to-plant transfer model, which predicts ^{137}Cs in soil solution and grass with time. Radionuclide deposition data for a hypothetical release from the Borssele Nuclear Power Plant, in the Netherlands, has been mapped and combined with constructed soil type data and output from the models to make predictions of radionuclide activity concentrations in selected endpoints.

Results:

The implementation of process-based models can lead to quite dramatic differences in predicted activity concentrations of radionuclides in grass and milk compared to a default FDMT set-up for time periods later than a few weeks post deposition. Considering transfer within a spatial context, by combining information from the outputs of process-based models with illustrative soil maps, leads to the observation that the most elevated ^{137}Cs and ^{90}Sr concentrations in grass and milk might not necessarily occur in areas where deposition is highest.

Conclusion:

Process based soil-plant transfer models appear to have clear utility especially for periods several months post-accident. Not accounting for soil type when modelling food chain transfer might lead to the sub-optimal allocation of resources or misidentification of the most vulnerable areas in the long-term after an accidental release.

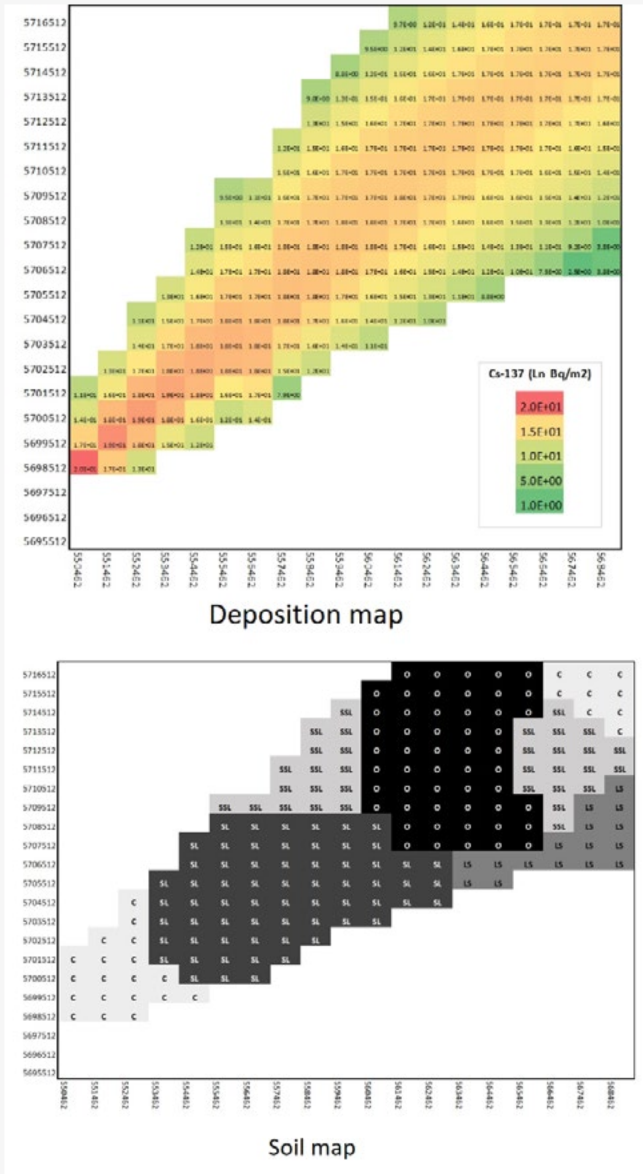


Figure 1: *Combination of deposition and soil data as input to food-chain transfer models (FDMT and Absalom) allowing prognoses of ^{137}Cs activity concentrations in grass and milk.*

References:

• *Brown et al. (2020). Radioprotection, 55 (HS1). S109-S117.*

Method development for the determination of ^{90}Sr in biological samples by triple quadrupole ICP-MS

Highlight writer:
Estela Reinoso-Maset

Team members:
E. Reinoso-Maset, K.A. Jensen, H.-C. Teien (NMBU)
S. Levchuk, V. Kashparov (NUBiP)

Objectives:

Precise and accurate determination of radionuclides in biological matrices is essential to study radionuclide behaviour and fate, including transfer to organisms through the food chain. Radioactive strontium(Sr) can be taken up by biological systems from soil and water and concentrate in Ca rich tissues such as bone due to its chemical similarity to Ca^{2+}, thus becoming of high radiological importance in ^{90}Sr contaminated areas. This work focused on establishing a mass spectrometry methodology for routinely measuring ^{90}Sr at environmentally relevant levels in a faster manner than that provided by classical radiometric methods.

Methods:

Ashed bone material of fish (pike, carp, rudd, asp, perch) caught in lakes of the Chernobyl exclusion zone were microwave acid digested (0.05-0.5 g) with ultra-pure HNO_3 followed by a clean-up step using commercial Sr-resin cartridges to reduce total dissolved solids. Clean digested samples were then analysed directly in a triple quadrupole ICP-MS (ICP-QQQ), where the isobar interference from ^{90}Zr was eliminated by using a mixture of O_2 and H_2 in the collision-reaction cell. Certified bone reference materials were also analysed to evaluate the method's precision and quantification limits. The activity concentrations of ^{90}Sr measured in fish bone by ICP-QQQ were compared to those obtained by a non-destructive, direct beta-spectrometry method (counting for up to 3600 s) and the classical method through measurement of its β-emitting daughter nuclide, ^{90}Y (~2 weeks to reach secular equilibrium).

Results:

The clean-up, preconcentration step using the Sr-resin resulted in an excellent, full recovery for Sr (100 ± 4%) and a highly effective removal of Ca and Zr (decontamination factors of 2 to 4 orders of magnitude). The method presented a quantification limit for ^{90}Sr in the pg/L level (~1 Bq/g), with a good instrumental repeatability (< 6% RSD) and a slightly higher overall reproducibility (< 9% RSD) due to the wide range of ^{90}Sr activity concentrations in the samples (from 0.5 to 550 Bq/g). Quantification of the different ^{90}Sr activity concentrations levels by the optimised ICP-QQQ methodology was in excellent agreement with the radiometric measurements (Fig.1), with the benefit of a significant improvement on analysis time (< 2 min/sample).

Conclusion:

This work has shown the advantages of ICP-MS analysis for the determination of ^{90}Sr in contaminated biological samples and its capability to replace the radiometric methodologies, especially when emergency analyses are required and short analysis time is desired.

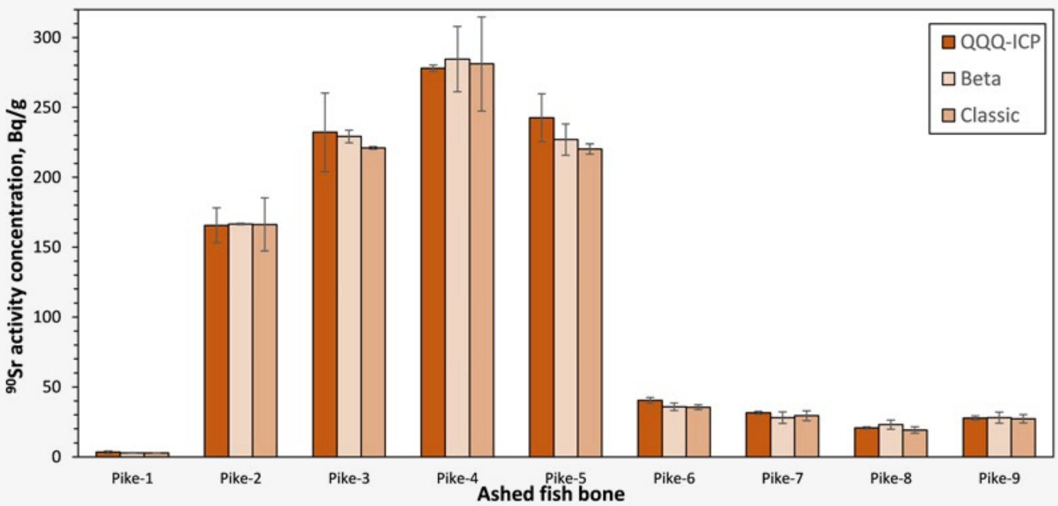


Figure 1: *Strontium-90 activity concentrations determined in ashed fish bone after microwave acid digestion and a resin clean-up step compared to measurements obtained following radiometric procedures (beta-spectrometry and classic ICP-QQQ*

Highlight writer:
Shane Scheibener

Uranium toxicokinetics and toxicodynamics in the crustacean *Daphnia magna*

Team members:
S. Scheibener, H-C. Teien, B. Salbu (NMBU)
Y. Song, K.E. Tollefsen (NIVA)

Objectives:

As a part of improving assessment models by implementing dynamic transfer of radionuclides, the goal of this work was to quantify U toxicokinetic parameters (uptake, loss rates, steady-state and bioconcentration factors) in *D. magna*, characterize the differences between external and internalized fractions of U, determine the degree of maternal transfer and investigate early stress responses.

Methods:

The transfer (48-h) of U from water to D. magna was investigated at environmentally relevant concentrations (0-200 µg L^{-1}) and was followed by a 48-h depuration period. Modelling of toxicokinetic parameters was determined using first-order exponential kinetic equations. Additional endpoints which were measured included major ion homeostasis (Ca, Mg, Na and K), mitochondrial response (mitROS and membrane potential), gene expression, growth inhibition, survivorship and molt frequency. U associated with the external daphnid surface (exoskeleton) was studied by measuring U in daphnia and molts after successful molting events. Upon molting, offspring were released and collected to determine maternal U transfer.

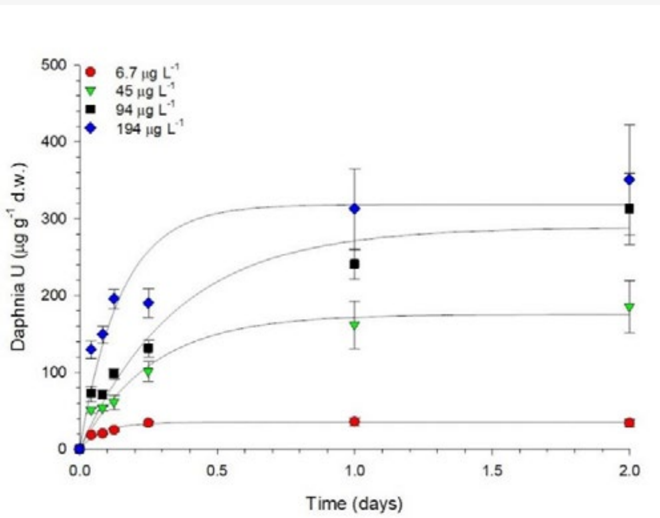


Figure 1: *U uptake in D. magna (µg g^{-1} d.w.) over the course of 2 days from exposure to a range of dissolved U (6.7-194 µg L^{-1}). From Scheibener et al. (2021).*

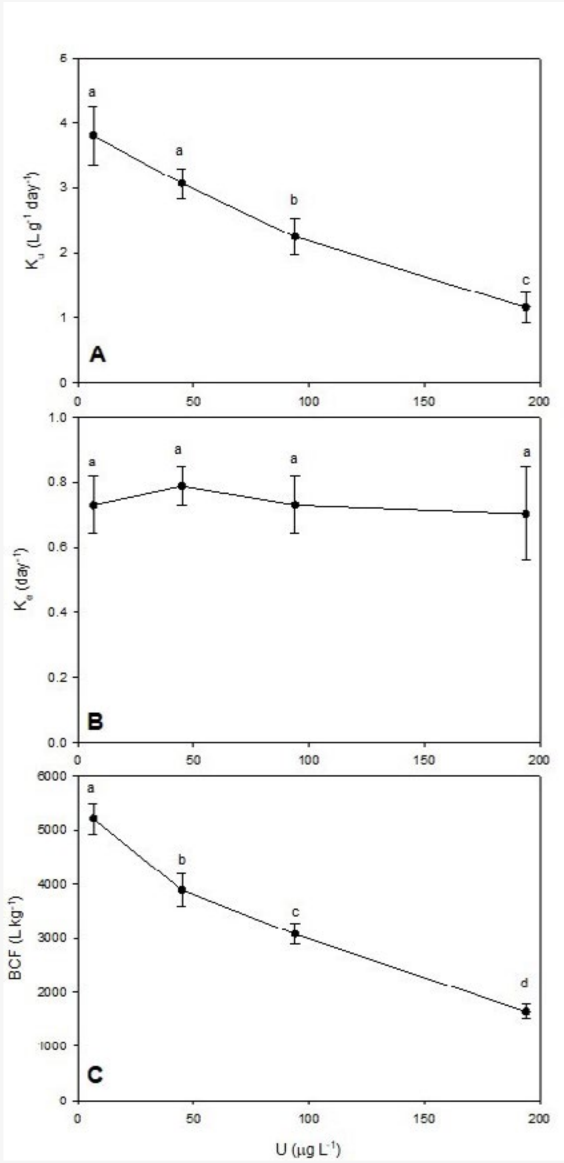


Figure 2: *Uptake rate constants (A), depuration rates (B) and bioconcentration factors (C) at different U concentrations. From Scheibener et al. (2021).*

Results:

U uptake in daphnia was time- and concentration-dependent, whereby steady-state was achieved between 24-48 h across all U exposures (Fig.1). Modelling of kinetic parameters showed U dependent uptake rate constants (k_u) ranging 1.2-3.8 (L g^{-1} d^{-1}) and bioconcentration factors (BCF) ranging 1600-

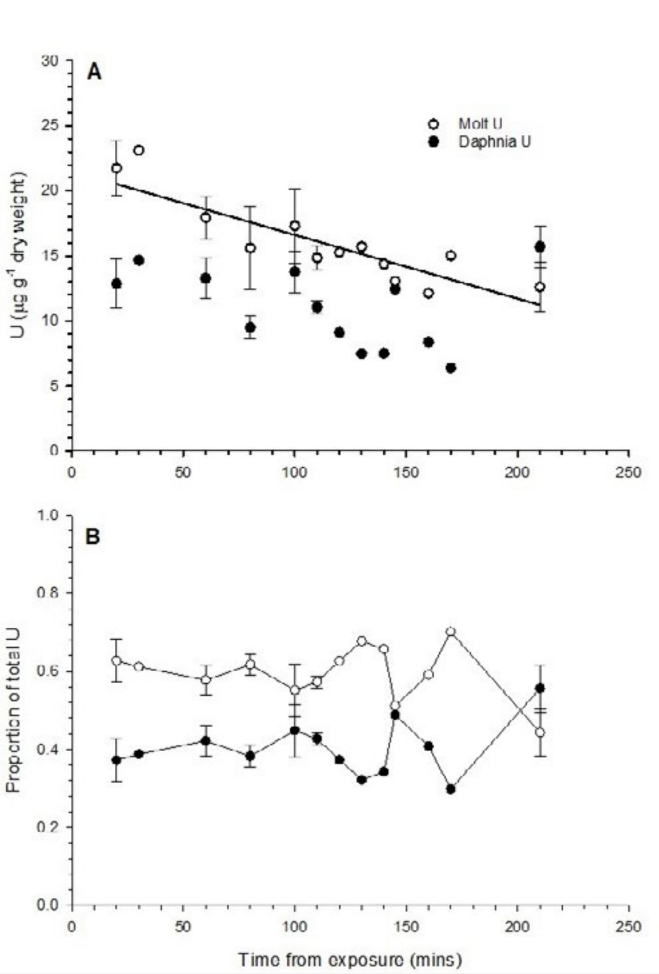


Figure 3: *U associated with daphnia whole-body and molted exoskeleton as either U (A) or proportion of total U (B). From Scheibener et al. (2021).*

5200 (L kg^{-1}), while maintaining a constant depuration rate (ke = 0.75 d^{-1}) across all U concentrations (Fig.2). The majority of U was found to be bound to the exoskeleton (~50-60%) (Fig. 3) and upon release of offspring, daphnia maternal transfer was 1-7% of internalized U. Effects from short term exposure to U included alteration in major ion homeostasis, increased expression of osmoregulatory genes (Ca and Na transporters), and adverse effects on growth and survivorship (Fig. 4). No mitochondrial responses (ROS induction or membrane potential) were observed.

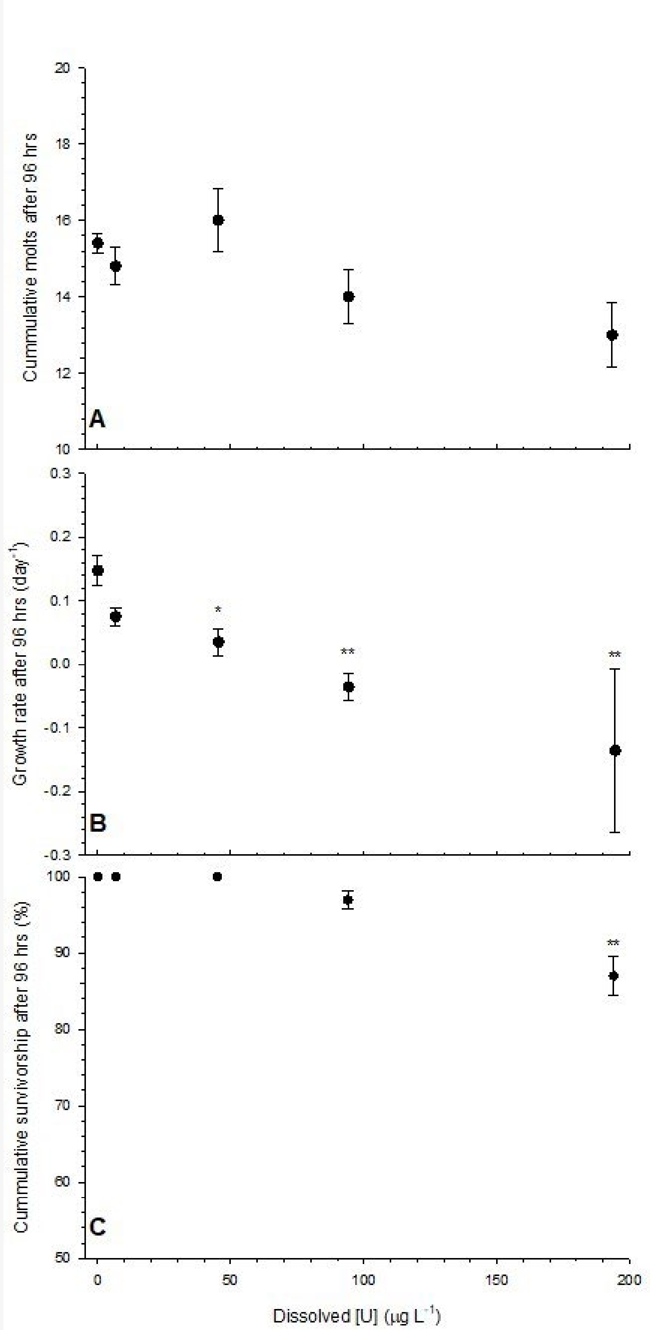


Figure 4: *Cumulative molts (A), growth rates (B) and survivorship (C) after exposure to U. From Scheibener et al. (2021).*

Conclusion:

Daphnia have high uptake rate constants and depuration rates when compared inter- and intra-specifically to other metals. This indicates that U accumulation is rapid and that turnover (loss) is an important process in removing U from daphnia. Additionally, a large fraction of U binds to the exoskeleton and is lost upon molt, suggesting another route to protect daphnia from U accumulation and internalization. Although daphnia can remove a significant amount of U through depuration processes, effects on ion homeostasis, growth and survivorship indicate an inability for daphnia to cope at U concentrations observed in the environment. This work highlights the importance of incorporating toxicokinetic approaches to aid in explaining toxic responses and species sensitivity.

References:

• *Shane Scheibener You Song, Knut Erik Tollefsen, Brit Salbu, Hans-ChristianTeien Uranium accumulation and toxicokinetics in the crustacean Daphnia magna provide perspective to toxicodynamic responses. Aquatic toxicology, 2021; 235. https://doi.org/10.1016/j.aquatox.2021.105836*

Low dose UV and gamma radiation combined exposure effects during early life in the zebrafish (*Danio rerio*)

Highlight writer:
Selma Hurem

Team members:
S. Hurem E.M.K. Rasmussen, D.A. Brede, L.C. Lindeman, T.W.K. Fraser, I. Mayer, D. Oughton, P. Aleström, J.L. Lyche (NMBU)
T. Christensen (DSA)
T. Gomes (NIVA)

Objectives:
To study the effects of low doses of UVA and UVB alone and UVB combined with gamma radiation on the development, behavior, oxidative stress parameters and global gene expression (omics) in zebrafish.

Methods:
Blastula stage ABwt zebrafish (*Danio rerio*) were exposed to gamma radiation (^{60}Co, Figaro) of 10 mGy/h for 3h, combined with UVB radiation of 25 (low) and 100 J/m^2 (high) (Philips Pl 12, 4.2 W/m^2) (1). Positive controls were separate UVB exposure of 126 – 760 J/m^2 (30-180 s) and UVA radiation of 94000 – 374000 J/m^2 (Osram GmbH DULUX S BL UVA 9 W/78, 104 W/m^2) for 0.25, 0.5 and 1 h (2). ROS formation and lipid peroxidation (LPO) was analysed using fluorometric and colorimetric methods, including transcriptomics in the combined exposure by RNA-seq at 5.5 hpf.

Results:
Exposure to high doses of UVB and UVA caused reduced heart rate, while UVA exposure caused lower activity in zebrafish larvae (2). The combined exposure to UVB and gamma radiation showed no significant interaction of the two different radiation types for the developmental parameters. The ROS formation measured in larvae from 75-120 hpf increased in the high doses of UVB and gamma groups, but were highest when both stressors were combined compared to controls (Fig 1). UVA exposure increased lipid peroxidation significantly (2). RNA-seq revealed 282, 420 and 2172 differentially expressed genes (DEGs) in the low UVB, gamma and combined exposure, respectively, while 1987 and 849 DEGs were found in the high UVB and UVB-gamma combination, respectively. Comparison of gene transcription changes revealed low UVB to activate reparatory pathways (RXR). High UVB and combined exposure activated pathways involved in cellular metabolism differentiation and apoptosis (RARa), but also pathways involved in oxidative stress, decreased mitochondrial respiration and organismal injury, among which, cardiac dysfunction was the most prominent.

Conclusion:
No developmental changes despite increased cellular ROS after exposure to low doses of UVB and UVA, corroborated by the gene pathways, suggests that short term UV radiation exposure plays a role in modulating the reparatory mechanisms. Higher doses or long-term UV and UV-gamma exposures upregulate pathways related to cellular metabolism disruption and organismal injury, indicating a potential for latent effects. This work contributes to a better understanding of the molecular effects of combined environmental stressor exposures based on omics data.

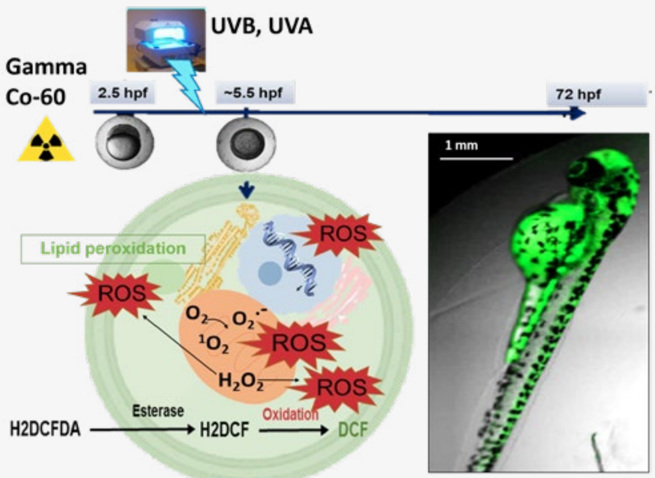


Figure 1: *Timeline of exposure to UV (UVB 25-100, UVA 94000-374000 J/m²) and gamma radiation (10 mGy/h) from 2.5-5.5 hpf and effects on the cellular oxidative stress parameters (ROS and LPO) persisting in 75 hpf ABwt zebrafish larva.*

References:
• *1.Hurem et al. 2021. Low dose UVB and gamma radiation combined exposure effects during early life in the zebrafish (Danio rerio) (manuscript to be submitted) Photochemistry and photobiology*
• *2.Hurem et al., 2018. Ecotox. and Environ Safety 166 359-365 doi:10.1016/j.ecoenv.2018.09.082*

Highlight writer:
Selma Hurem

Transgenerational gamma radiation effects in the zebrafish (*Danio rerio*) exposed during germline development

Team members:

P. Aleström, D.A. Brede, S. Hurem, E.M.K. Rasmussen, O.C. Lind, L.C. Lindeman, J.L. Lyche, D. Oughton, B. Salbu (NMBU)
J. Ballangby, A-K. Olsen (NIPH)
J. H. Kamstra (Utrecht University)
L.M. Martin (Camaguey University)

Objectives:

To study transgenerational effects (F0-F3) in zebrafish (Zf) exposed to gamma radiation during embryogenesis, germline development and gametogenesis.

Methods:

ABwt Zf (*Danio rerio*) were exposed during gametogenesis and transgenic (vas:egfp) Zf with fluorescent label of primordial germ cells (PGCs) were exposed to 1-40 mGy/h gamma radiation (^{60}Co, Figaro NMBU) from 2.5 hours post fertilization (hpf) for either 3 h or 21 days. Imaging, histopathology, transcriptomics (mRNA-seq), and chromatin accessibility profiling (ATAC-seq) were analyzed.

Results:

The gene expression data from F1 embryos of exposed ABwt parents during gametogenesis predicted reproductive hormone signaling pathways to be affected by differentially expressed genes (DEGs), predicted mRNA targets of differentially expressed microRNAs, such as insulin receptor, NFkB and PTEN pathways, linked to immune response, apoptosis, and cancer, including DNA methylation changes that persisted up to F3 generation (1-4). The gene expression and ATAC-seq analyses in vas:egfp F0 exposed to 1, 10 and 40 mGy/h revealed a dose-response relationship in the number of DEGs (Fig. 1) and 346, 1774 and 8483 loci with altered access in chromatin structure, respectively. Estrogen receptor (*ESR1*) involved in folliculogenesis in Zf was the most prominent upstream regulator. Survival was significantly lower in F0 exposed to 40 mGy/h in the last stage of sex differentiation (from 21-40 days pf), while a small number of adults developed tumors and pigment disorganization. Only a small number of females developed in F0 exposed to 10 mGy/h (the rest were males), while in 40 mGy/h only a small number of male fish were found post-euthanasia (the rest did not develop reproductive organs). Reproductive success in F0 exposed to 1 mGy/h was higher compared to control. F1 and F2 from exposed F0 to 1 and 10 mGy/h showed decreased PGC fluorescence compared to control (Fig. 1). Further analyses of how the molecular changes affect the phenotype as well as the compilation of an adverse outcome pathway (AOP) are in process.

Conclusion:

Exposure of Zf to gamma radiation at sensitive life stages causes a range of reprotoxic effects as shown by omics analyses and germline-related developmental effects, which may persist in multiple generations and can be plotted into AOP predictions. The finding that gamma radiation affects chromatin accessibility towards more closed regions in a dose-response relationship manner, suggests a model where chromatin compaction as a stress response protects the DNA against damage. Further plans include assessing the heritability of these effects in following generations.

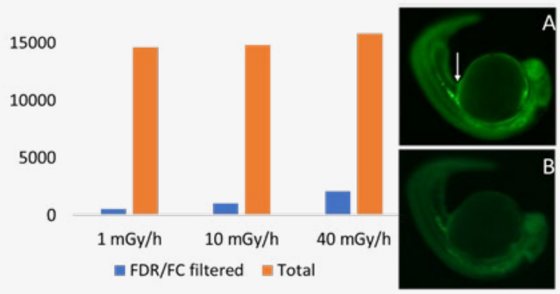


Figure 1: *Left: Differentially expressed genes relative to control in F0 zebrafish embryos exposed to gamma radiation: 1, 10 and 40 mGy/h, tg(vas:egfp) during 2.5-5.5 hpf. Right: GFP fluorescence in F1 embryos of exposed F0 parents (A) control (B) exposed.*

References:

- *1.Martin et al. 2021. Sci Rep 11, 4142 (2021).*
- *2.Lindeman et al. 2019. PLoS ONE 14, e0212123 (2019).*
- *3.Kamstra et al.. 2018. Sci Rep 8, 15373 (2018).*
- *4.Hurem et al. 2018. Environ. Pollut. 234, 855–863 (2018).*

Genotoxic stress and mitochondrial DNA copy-number variation in *C. elegans*: droplet digital PCR analysis

Highlight writer:
Erica Maremonti

Team members:
E. Maremonti, D. A. Brede (NMBU)
D. M. Eide, A.-K. Olsen, E. S. Berg (NIPH)

Background:

Increased copies of mitochondrial DNA (mtDNA) have been reported in mammals exposed to ionizing radiation. Therefore, changes in the ratio mtDNA/nuclear DNA (nDNA) have been proposed as a potential biomarker for mitochondrial dysfunction. However, the widely adopted method based on standard quantitative PCR (qPCR) for mtDNA/nDNA quantification presents low accuracy and inherent limitations.

Objectives:

Development of a method based on duplex droplet digital PCR (ddPCR) for the assessment of mtDNA copy number variation, and comparison to standard qPCR analysis.

Methods:

Nematodes were exposed for 24, 48 and 72 hours during larval development to a wide range of doses (0.03–72 Gy), and changes in the ratio mtDNA/nDNA were assessed. Five mitochondrial target genes and two nuclear reference genes (*act* and *gpi-1*) were chosen as representative of the mitochondrial and nuclear genomes respectively. These were amplified pairwise in duplex PCR format by both ddPCR and qPCR.

Results:

The optimized method based on ddPCR provided significantly higher precision and greater sensitivity than qPCR for detection of mtDNA copy number variation. The ddPCR method enabled the detection of a significant increase in mtDNA copy number (1.6 ± 0.1-fold) for nematodes exposed to high doses of gamma radiation (≥24 Gy) (Fig. 1), whereas no significant difference was measured by standard qPCR. Dose-rates of gamma radiation below 100 mGy/h, however, did not significantly affect mtDNA copy number despite previous studies having shown down-regulation of mitochondrial genes that are essential for the proper assembly of the oxidative phosphorylation system. This suggests that *C. elegans* can compensate for genotoxic stress and maintain chromosomal integrity via increased copy number.

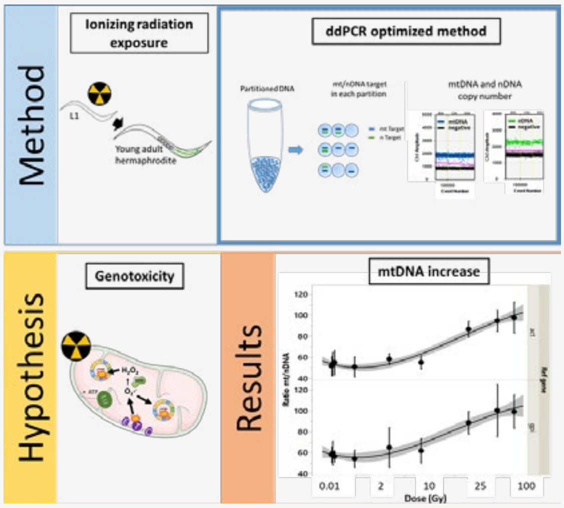


***Figure 1:** Duplex ddPCR assay optimized for mtDNA/nDNA ratio measurements on nematodes exposed to low and high dose-rates of ionizing gamma radiation (up to 72 Gy), by using five mitochondrial targets and two nuclear reference genes (gpi-1 and act) (1).*

Conclusion:

This study demonstrates that ddPCR duplex analysis enables a simple and robust means of quantification of mitochondrial genome content, circumventing the inherent limitations of qPCR. Thus, ddPCR represents a novel and valuable tool for the assessment of mtDNA copy number variation that may be adopted to any other species exposed to genotoxic insult.

References:

• *Maremonti, E., Brede, D. A., Olsen, A. K., Eide, D. M., & Berg, E. S. (2020). Ionizing radiation, genotoxic stress, and mitochondrial DNA copy-number variation in Caenorhabditis elegans: droplet digital PCR analysis. Mutation Research/ Genetic Toxicology and Environmental Mutagenesis, 858, 503277.*
• *Maremonti E. Investigating sensitivity and tolerance to chronic gamma irradiation in the nematode Caenorhabditis elegans. PhD-thesis 2020:8, ISSN 1894-6402*

Radiosensitivity in embryogenic cells of Norway spruce

Highlight writer:
Jorunn E. Olsen

Team members:

Y.K. Lee, P. Bhattacharjee, G. B. Gillard, L. Hvidsten, S. R. Sandve, O. C. Lind, B. Salbu, D. A. Brede, JE Olsen (NMBU)
M. Viejo (NIBIO)

Objectives:

Using somatic embryogenesis as a model system for zygotic embryogenesis in the conifer Norway spruce (*Picea abies*) (Fig.1a), the objectives of the current study were to assess radiosensitivity of the embryogenic cells and the molecular events in response to gamma radiation.

Methods:

Embryogenic cells were exposed to gamma radiation at 1-100 mGy h^{-1} for 144 h from a ^{60}Co source. After the irradiation, cellular integrity (microscopy), programmed cell death (Tunel assay), genotoxicity (COMET assay) and cell wall composition (immuno-fluorescence) were assessed and gene expression analysed (RNA seq and qPCR).

Results:

After 144 h of gamma irradiation, significantly increased DNA damage and programmed cell death were observed from ≥10 and ≥1 mGy h^{-1}, respectively. Surprisingly, no difference in cell proliferation was visible among the gamma dose rates (Fig. 1b). However, microscopy revealed cellular abnormalities (Fig. 1c) such as substantial accumulation of amorphous materials in vacuoles and damaged nuclei and mitochondria at all gamma dose rates as well as stress-related cell wall modifications. Furthermore, massive dose-dependent changes in gene expression were observed. Cell division, DNA replication and DNA repair genes were downregulated and genes related to accumulation of misfolded proteins, vesicular transport, protein-targeting to vacuoles (Fig. 1d) and stress-related hormonal pathways were upregulated. Despite similar degree of proliferation up to 20 weeks post-irradiation and subsequent somatic embryo formation irrespective of dose rate, cellular abnormalities, and programmed cell death persisted. However, specific DNA repair genes showed increased expression. Embryos with normal number of cotyledons were formed in unexposed embryogenic cultures only.

Conclusion:

Despite surprisingly similar cell proliferation and embryo formation after all gamma dose rates and the unexposed controls, cellular abnormalities and a massive dose rate-dependent shift in gene expression towards stress management pathways were observed. Although most DNA repair genes were downregulated at the end of the gamma exposure, later increased expression of such genes suggests a trend towards some recovery.

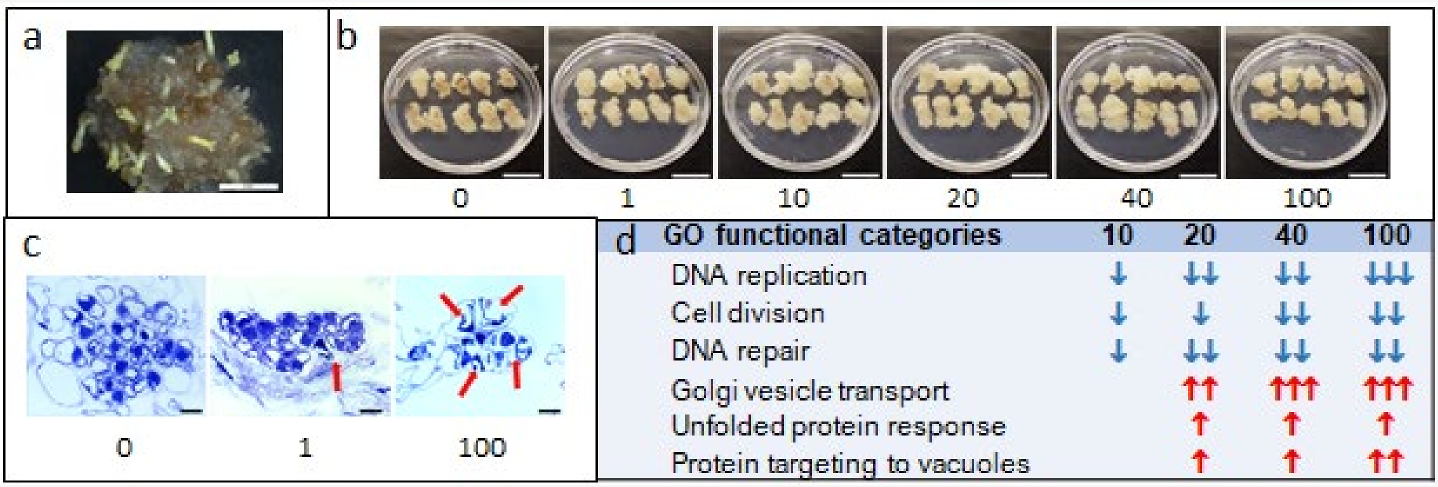


Figure 1: *Radiosensitivity of embryogenic Norway spruce cells. a) Somatic embryos. b) Gamma-irradiated cell cultures (mGy h^{-1}). c) Micrographs of gamma-irradiated cells. d) Examples of affected GO terms (gene groups).*
↓ Downregulation, ↑ Upregulation.

Deciphering the combined effects of gamma and ultraviolet B radiation in the aquatic plant *Lemna minor*

Highlight writer:
Li Xie

Team members:
L. Xie, K.E. Tollefsen, Y. Song, K. Petersen (NIVA)
K.A. Solhaug, H.C. Teien, O.C. Lind, D.A. Brede, J.E. Olsen, B. Salbu,
B. Johnsen (NMBU)
B. Johnsen (DSA)

Objectives:

The main objective is to provide an in-depth understanding of independent and combined effects of UVB and gamma (γ) radiation in the aquatic plant *Lemna minor* using experimental studies and computational models to quantify combined effects at multiple levels of biological organization.

Methods:

Lemna minor was exposed to UVB (0.5 w/m²), γ-radiation (13, 20 and 47 mGy/h), and their combination. The effects were characterised using a combination of functional and adverse toxicity assays, including changes to ROS, lipid peroxidation (LPO), oxidative phosphorylation (OXPHOS), photosystem II (PSII) efficiency, mitochondrial membrane potential (MMP), photosynthetic pigments and ATP content together with growth parameters like reproduction and frond developments. Additionally, the expression of biomarker genes was quantified by qPCR to characterise the potential mode of action. The combined effects of the stressors were characterised by a combination of a 2W-ANOVA and a modified combined effect model (independent action).

Results:

Exposure to γ-radiation alone induced significant dose rate-dependent effects (≥20 mGy/h), including the induction of ROS formation and activity of antioxidants as well as reduction of PSII activity, pigments, MMP and growth. UV-B (0.5 W/m²) alone enhanced oxidative stress and reduced MMP. Co-exposure (UVB and γ) caused antagonism for oxidative stress, DNA damage, OXPHOS and glycolysis, while synergistic interactions were observed for the antioxidant defence gene GST (20 mGy/h) and reproduction for all dose rates. Additive combined effects were observed in PSII efficiency, ATP and pigments content, DNA damage and individual growth at all dose rates. Conceptual toxicity pathways were developed to summarize observations (Figure 1).

Conclusion:

Combined effects (additive, antagonistic and synergistic) were highly dose-dependent and target-specific. Differential propagation of combined effects along the full putative toxic pathway was observed and represents an initial effort to decipher the complex interactions occurring. Similar approaches will be used to characterise interactions of other binary and ternary mixtures of UVB, γ-radiation and depleted uranium in 2021.

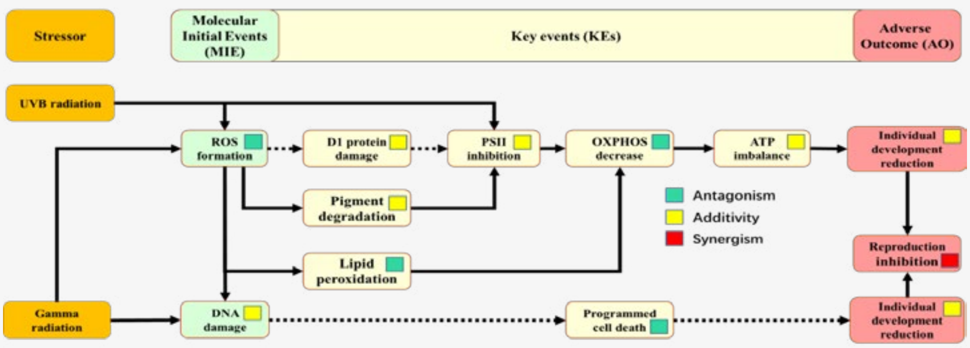


***Figure 1:** Putative toxicity pathway framework of UVB and γ-radiation in Lemna minor. The yellow, green and red squares in the endpoint matrices indicate the additive, antagonistic and synergistic effects, respectively. Direct experimental evidence and inference from supporting data is indicated as solid line and dotted line, respectively.*

References:

• *Xie, L. (2021). Single and combined toxicity of gamma and UVB radiation in the aquatic macrophyte Lemna minor (PhD thesis). Norwegian University of Life Sciences, Ås, Norway.*

Quantitative Adverse Outcome Pathways (qAOPs) for predicting the hazards of single and multiple stressors

Highlight writer:
You Song

Team members:
Y. Song, K. E. Tollefsen, S. J. Moe, L. Xie, R. Wolf (NIVA)
Y. Lee, K. A. Solhaug (NMBU)
Chloe Eastabrook, Gary Caldwell (Newcastle University)

Objectives:
The main goal is to develop novel statistical models (qAOPs) for predicting the adverse effects of ionizing and non-ionizing (UV) radiation and radionuclides towards aquatic organisms.

Methods:
A qAOP captures the quantitative Key Event relationships in a causal pathway, allowing better alignment of the AOP framework with regulatory decision-making. Two datasets were used to demonstrate our strategies for the qAOP development: acute effects of ultraviolet B (UVB) radiation on *Daphnia magna*, and chronic effects of 3,5-dichlorophenol (DCP) on *Lemna minor*. A frequentist approach using advanced regression analysis was used to develop the UVB-qAOP network, whereas a probabilistic approach using Bayesian networks was employed to construct the DCP-qAOP network. In addition, uncertainties were assessed for the DCP-qAOP. The NIVA Risk Assessment Database/RAdb (www.niva.no/radb) organized data and served as a platform for integrating new qAOP models.

Results:
Two qAOP networks were successfully constructed (Fig. 1) and published (Song et al., 2020; Moe et al., 2020) Future modelling work will include the effect data from Daphnia exposed to gamma radiation, *Tisbe battagliai* exposed to UVB (mediated by DNA damage) and combined UVB-metals, and *Lemna* exposed to combined gamma radiation and UVB. The resulting computational approaches will be integrated with tools such as the Source To Outcome Predictor (STOP, www.niva.no/stop) to facilitate user-friendly risk assessment of single and multiple stressors.

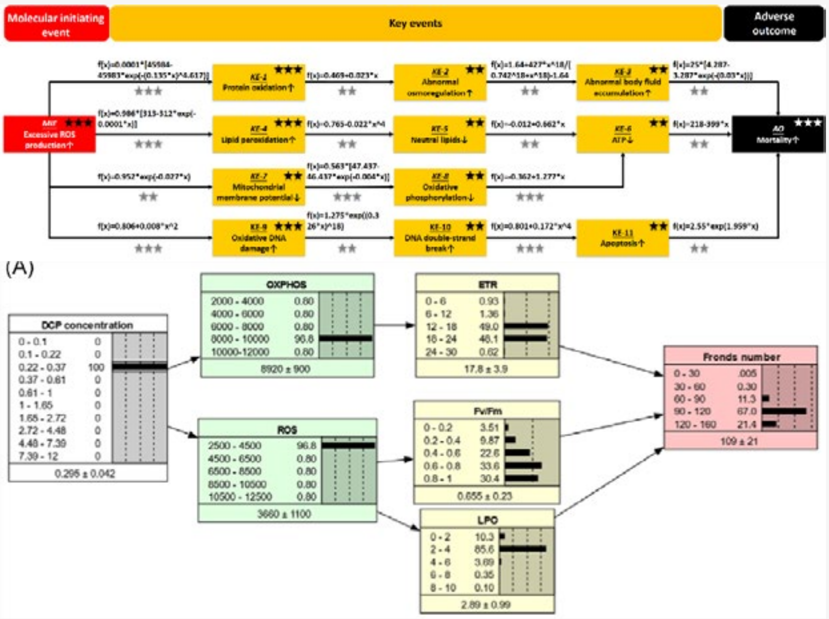


Figure 1: *Quantitative Adverse Outcome Pathway (qAOP) networks for (A) ultraviolet B (UVB) radiation mediated effects on Daphnia magna, and (B) 3,5-dichlorophenol mediated effects on Lemna minor.*

References:
• *Song, Y., Xie, L., Lee, Y.K., Tollefsen, K.E. (2020), De novo development of a quantitative adverse outcome pathway (qAOP) network for ultraviolet B (UVB) radiation using targeted laboratory tests and automated data mining. Environmental Science & Technology 2020, 54, (20), 13147-13156.*
• *Moe, S.J., Wolf, R., Xie, L., Landis, W.G., Kotamäki, N. and Tollefsen, K.E. (2021), Quantification of an Adverse Outcome Pathway Network by Bayesian Regression and Bayesian Network Modeling. Integr Environ Assess Manag, 17: 147-164.*

Highlight writer:
Hildegunn Dahl

Low dose rate ionising radiation modulate hepatic transcriptional profile differently than high dose rates in mice

Team members:
H. Dahl, D. Eide, N. Duale, T. Tengs, A-K. Olsen (NIPH)
D. Oughton (NMBU)
J. Kamstra (Utrecht University)

Introdution:

There is an ongoing debate over the biological effects of chronic, low dose rate exposure to ionising radiation, as compared to acute high dose rate exposures. This controversy is also relevant for other stressors (i.e. various chemicals). New knowledge based on molecular events such as gene expression responses, known to underpin apical effects, may contribute to understanding how dose rate impacts on the response to ionising radiation.

Objectives:

To test the hypothesis that ionizing radiation given at low dose rates would lead to different biological responses than the same dose given at high dose rates, by applying hepatic transcriptional analyses in mice.

Methods:

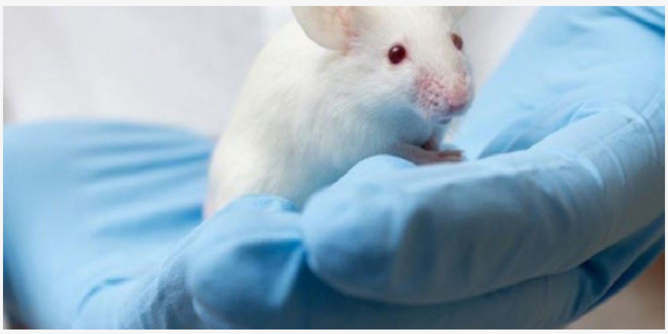
CBA and B6 mice were exposed to low dose rate (LDR 2.5 mGy, 1200h), mid dose rate (MDR 10 mGy/h, 300h) and high dose rate (HDR 100 mGy/h, 30h) to a total dose of 3 Gy. Mice were sacrificed one day (early effect) and >100 days (late effect) post-irradiation. Liver total RNA was subjected for genome wide transcriptome analyses by RNA sequencing (poly-A), after which significantly differentially expressed genes (DEGs) were used to identify perturbed KEGG and Gene Ontology gene sets by over-representation analyses utilising EnrichR. Global DNA methylation (5mC and 5hmC) was assessed by LC-MS.

Results:

Hepatic transcriptional analyses showed marked numbers of significant DEGs one day post-radiation after LDR in both mouse strains (CBA 444, B6 813), with an increase with dose rate in CBA (MDR 530; HDR 2155) that was not seen in B6 (MDR 432, HDR 834), with rather similar numbers of DEGs in LDR and HDR. The observed changes show dose rate specific gene expression profiles, as demonstrated by: a) different numbers of DEGs for each dose rate; b) different significant DEGs for each dose rate; c) differences in enriched KEGGs between dose rates; and d) different DEGs related to GO Term for oxidative stress and response to oxidative stress for each dose rate group and strain. Moreover clear strain specific gene expression responses were observed. The number of DEGs between treatment groups and controls was significantly lower after a period of recovery (>100 days post-radiation).

Conclusion:

Our data support the hypotheses that a different response is elicited following chronic low dose rate exposure compared to an acute high dose, when given to a common total dose. Two mouse strains, both showed different hepatic transcriptional responses after chronic LDR vs acute HDR exposure. The identified perturbed biological pathways are known to be associated with ionising radiation, i.e. cancer, cardiovascular disease (lipid metabolism), inflammation, xenobiotics metabolism, complement and coagulation cascade and cell death. Interestingly, biological pathways involved in non-cancer effects were enriched also following low dose rate exposures. Our study contributes with valuable molecular knowledge to the ongoing controversy regarding the impact dose rate may have on inducing adverse biological effects of ionising radiation.



Source To Outcome Predictor (STOP) – linking source characterisation to environmental impact

Highlight writer:
Knut Erik Tollefsen

Team members:
K.E. Tollefsen, L. Xie, K. Petersen, V. Girardin (NIVA)
J. Brown (DSA)

Objectives:
Use of a graphical user interface to visualize linkage between emission sources, exposure, effects, and risk of multiple stressors.

Methods:
A graphical user interface (GUI) has been developed to visualize cumulative risk predictions from the NIVA RAdb™ (www.niva.no/radb). The GUI, titled Source To Outcome Predictor (STOP, www.niva.no/stop), presents predictions of cumulative impact of complex chemical and non-chemical stressor exposures. The tool allows identification of total risk, sensitive species groups (taxa), and risk drivers using concepts outlined in Beyer et al. (2014) and Salbu et al. (2020). Scenario-specific exposure data (marine and freshwater) and effect data for a range of stressors (organic chemicals, metals, ionising, and non-ionising radiation) are currently available in NIVA RAdb to support such cumulative risk assessments (CRA). The data are organised according to principles of Aggregate Exposure Pathways (AEPs) and Adverse Outcome Pathways (AOPs) to stay consistent with other research initiatives in the chemical and radiation research community.

Results:
A simulation study of a hypothetical accidental emission of hazardous waste in the freshwater lake "Jarenvatnet" at Hadeland (Norway) was used to perform CRA for multiple stressors (radionuclides, UVA, UVB, trace metals, background gamma and organic chemicals). The STOP predictions demonstrated spatio-temporal patterns in risk and were able to link source-specific exposure to the risk for different species groups, effects and risk drivers (Fig. 1).

Conclusion:
STOP provides a user-friendly and interactive GUI to facilitate CRA for complex natural and anthropogenic exposure scenarios, waste emissions, and decommissioning activities.

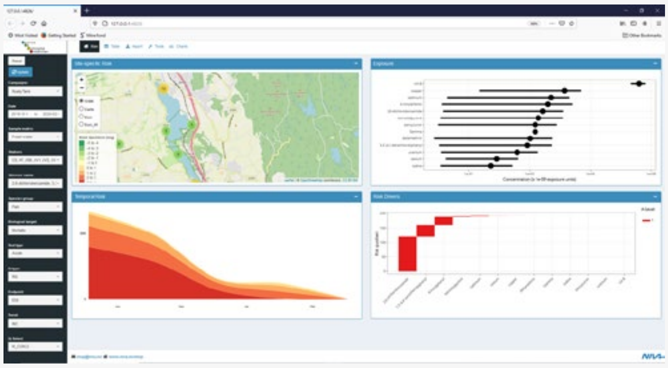


Figure 1: *The Source To Outcome Predictor (STOP) used to perform cumulative risk assessment of a hypothetical spill of nuclear and chemical waste into Jarenvannet, Hadeland (Norway). The simulation study involves an accident with a special waste transport passing Jaren on route to a theoretical remote waste repository north of Oslo.*

References:

- *Beyer, J., Petersen, K., Song, Y., Ruus, A., Grung, M. Bakke, T., Tollefsen, K.E. (2014). Environmental risk assessment of combined effects in aquatic ecotoxicology: a discussion paper. Mar. Environ. Res. 96: 81-91*
- *Salbu, B., Lind, O.C., Teien, H.C., Tollefsen, K.E. (2019). Why is the multiple stressor concept of relevance to radioecology? Int J. Rad Biol. 11:1-10. doi: 10.1080/09553002.2019.1605463*

Fen litterbag study: Reduced soil fauna decomposition in a high background radiation area

Highlight writer:
Runhild Gjelsvik

Team members:
H. Haanes & R. Gjelsvik (DSA)

Objectives:

Assess impact of naturally occurring radionuclides (NOR) on soil fauna litter decomposition.

Methods:

Deploy litterbags along Fen gradient for one year. Sample soil cores beneath coarse-meshed bags to attain soil parameter variation.

Results:

Litter loss was unambiguously greater in coarse (soil mesofauna access) than fine meshed litterbags (no access), and when litter had been dried in room temperature rather than in oven. All soil parameters had unique variation among localities. Best model for litter loss (coarse bags) for radionuclide distributions included litter drying, soil organic matter content (OM), soil particle size and ^{226}Ra but not ^{228}Ra (adj $R2=0.38$, $F(40, 4)=7.9$, $p<0.001$). The best corresponding model based on dose rate (DR) modelled for either of four organisms in ERICA tool, included DR for the smallest possible tube geometry, OM, litter drying and soil pH (adj $R2=0.36$, $F(41, 4)=7.4$, $p<0.001$).

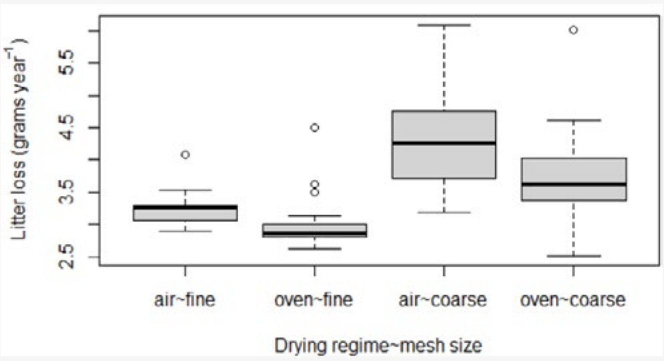


Figure 1: *Box plot of litter decomposition in coarse and fine meshed litterbags with litter dried in oven or at room temperature.*

Conclusion:

This study indicates that NOR have adverse effects on litter decomposition in Fen. The higher explanatory power of ^{226}Ra than ^{228}Ra also suggests effect of ^{238}U toxicity.

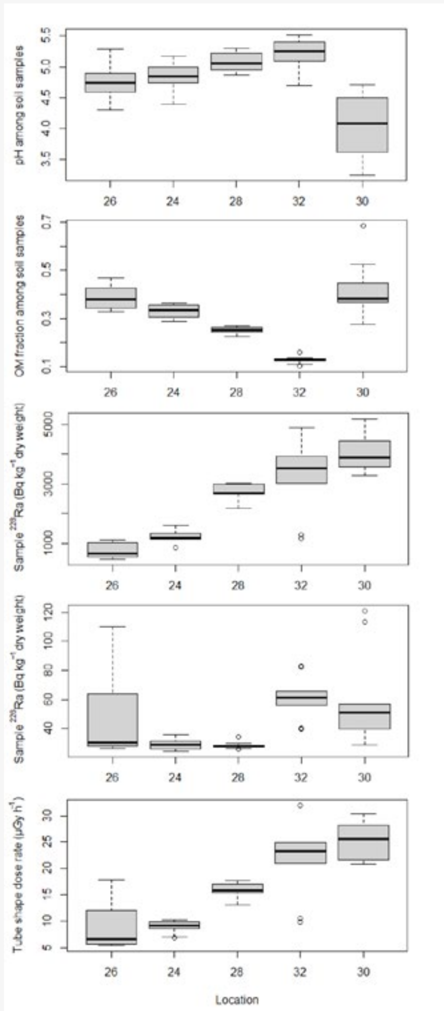


Figure 2: *Box plots showing the variation of soil parameters along the Fen gradient where litterbags were placed for litter decomposition.*

References:

• *Haanes, H., Gjelsvik, R., 2021. Reduced soil fauna decomposition in a high background radiation area. PLoS One 16, e0247793. doi.org: 10.1371/journal.pone.0247793*

Highlight writer:
Yevgeniya Tomkiv

How will citizens react to official advice in a nuclear emergency?

Team members:

Y. Tomkiv, D. Oughton (NMBU)
A. Liland (DSA)
C. Turcanu, T. Perko, B. Abelshausen (SCK CEN)
R. Sala, C. Oltra (CIEMAT)
N. Zeleznik (EIMV)

Objectives:

Nuclear accidents pose many challenges, from potentially large-scale, long-lasting environmental contamination to differing perceptions of radiological risks by experts and affected populations. However, the manner in which people respond to emergency management, also plays an important role in determining society's vulnerability in these events. There are certain assumptions about public response that underlie decision-making, which might not be valid in practice. Therefore, the purpose of this study was to investigate what would influence the potential behavior of citizens in an emergency situation.

Methods:

Surveys were performed in Belgium (N=1,398), Norway (N=1,000) and Spain (N=808). In Belgium and Spain both national and local (people residing close to nuclear installation) samples were used. A number of variables were measured: self-assessed compliance with and knowledge about protective actions; trustworthiness of communicators; perceived social norm (expectation of other residents' behaviour); perceived effectiveness; and perceived difficulty of protective actions.

Results:

Most respondents expect to follow actions advised by authorities, except for leaving children at school or avoiding the use of phones (fig.1). Moreover, large fractions of local and wider publics may seek to avoid risks by rejecting food produced in affected areas, even when it satisfies legal norms, or by taking iodine tablets when not needed. Norway showed the highest levels of compliance and Spain the lowest, with Belgium in between.

Self-assessed compliance with protective actions was positively correlated with perceived social norm, perceived effectiveness and compliance with other actions; and negatively correlated with perceived difficulty. Higher trust in the regulator was associated with higher compliance with some actions, but mostly among the local populations.

Conclusion:

Nuclear emergency management can be vulnerable to public response. Therefore, understanding peoples' concerns, motivations, beliefs and value judgements underlying individual decision-making in an emergency situation is crucial to improving the governance of nuclear incidents and accidents. Each recommended action might trigger a particular response, due, for instance to its perceived effectiveness. Therefore, clarifying and anticipating societal concerns will contribute to enhancing societal resilience and strengthening the response to nuclear accidents.

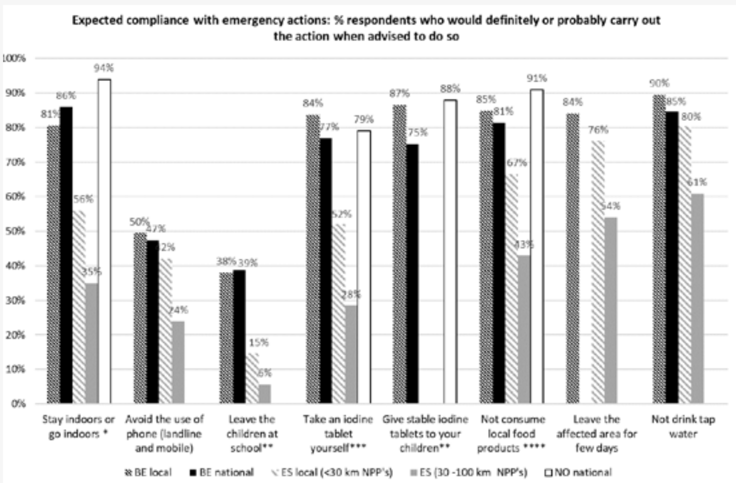


Figure 1: *Participants expected compliance with the protective actions.*

References:

• *Turcanu, C., Sala, R., Perko, T., Abelshausen, B., Oltra, C., Tomkiv, Y., Oughton, D., Liland, A., Zeleznik, N. (2020) How would citizens react to official advice in a nuclear emergency? Insights from research in three European countries. Journal of Contingencies and Crisis Management. doi:10.1111/1468-5973.12327*

International Collaboration

By Anne Liv Rudjord, Deputy Director

The year 2020 has been a challenge for international collaboration because of the obvious impediments introduced by the Corona pandemic and the concomitant event cancellations and meeting restrictions this has entailed. Nonetheless, during 2020, CERAD has maintained its bilateral and international collaboration through virtual meetings and events held online. An example of this is the EU-funded project RadoNorm "Towards effective radiation protection based on improved scientific evidence and social considerations – focus on radon and NORM" where CERAD is an active participant and leader of several radon and NORM international activity tasks. The project started in September 2020 with a successful virtual Kick-off meeting, followed up in the subsequent months by several online Task Group meetings. In the coming years, RadoNorm is expected to provide answers to open questions related to radon and NORM exposure of humans and the environment and to provide sound, feasible and applicable solutions for radiation risk reduction which are widely acceptable for the individuals and the public. As with earlier EU-funded projects, this will allow members from CERAD to further build upon their positions as a partner in the European Joint Programme for the Integration of Radiation Protection Research (CONCERT).

CERAD continues to be 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 although there have been some understandable delays in some cases owing to the pandemic. 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), (Social Sciences and Humanities in Ionising Radiation Research) SHARE, and the European Radiation Dosimetry Group (EURADOS). In 2020, CERAD hosted and co-arranged a series of international webinars in collaboration with SHARE and NERIS.

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. International collaboration within the academic arena 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. In June of 2020, the course 'Assessing Risk to Humans and the Environment' was successfully organised entirely online.

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). With regard to UNSCEAR, 2020 was an intense period of activity with regards the final preparations of a report marking the 10-year anniversary of the Fukushima Daiichi accident-due for publication in March 2021.

Our experts work in ICRP task groups, an example being TG 99: Reference Animals and Plants Monographs, CERAD's Center Director is a member of UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), and their work on Artificial Intelligence (AI) and Internet of Things (IoT) has been linked to the Shamisen-Sings project on ethical challenges of Radiation Dosimetry Apps. CERAD has cooperated with the Nuclear Energy Agency (NEA) of the Organisation 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 former Deputy Director.

Knut Erik Tollefsen (NIVA/NMBU/CERAD) has been a Norwegian delegate to the Organisation for Economic Co-operation and Development (OECD) Extended Advisory Group for Molecular Screening and Toxicogenomics (EAGMST) for almost a decade, and in 2020 expanded his international commitments by co-chairing the Nuclear Energy Agency (NEA)/OECD joint task force (TF) focusing on advancing chemical and radiation Adverse Outcome Pathways. The group is currently scoping the terms of reference for the TF, developing tangible workplans, engaging with various national and international organisations to consolidate the work, and a number of other activities that are envisioned to facilitate developing AOPs for radiation. A joint MELODI and ALLIANCE workshop on AOPs will be organised in 2021 with assistance from the TG.

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 former 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 within radioecology continued through 2020. This has culminated in a collaborative publication in the International Journal of Radiation Biology this year on the issues involved in developing an ecosystem approach for environmental radiation protection (Mothersill et al, 2020)

Experimental Facilities, Models and Tools

By 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-X-ray fluorescence (µ-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 Accelerator Mass Spectrometry (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.
A unique particle archive is available for CERAD research at the Isotope laboratory containing submicrometre 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).
Equipment available at NMBU for in situ and in lab speciation analysis include the following:

- CERAD has chromatography-hollow fibre and tangential flow systems available for field expeditions of aquatic research projects all over the world.
- A Flow Field Flow Fractionation system interfaced with ICP-MS (FIFFF-ICP-MS) used for speciation work in the Isotope laboratory.
- A High-Performance Liquid Chromatography coupled to ICP-MS (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, SLS in Switzerland and Diamond in the UK.
- The Imaging Centre of NMBU is developing a state-of-the-art facility for microscopy (ESEM-EDX, analytical 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).
- A CAMECA NanoSIMS 50L with ppm or better detection limits for most elements, 50 nm imaging and depth profiling capabilities as well as isotopic analyses of major and minor elements has recently become available through collaboration with Chalmers University of Technology and University of Gothenburg.

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. FIGARO is licensed for a number of different test organisms, including GMOs, and is to our knowledge, the first facility dedicated to multiple stressor studies that combine the simultaneous exposure of gamma radiation and other stressors (e.g., UV, metals).
- 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 NPIH - for transfer

Bear den in Gävleborg county, Sweden, subject to dosimetry as part of dose assessment for hibernating bears
Photo: Sam Steyaert

and effect studies on mice.
- NMBU's phytotron: Greenhouses, for experiments on plant uptake and effects.
- NMBU's custom built climate chambers for combined UV and gamma exposure.

Wildlife dosimetry

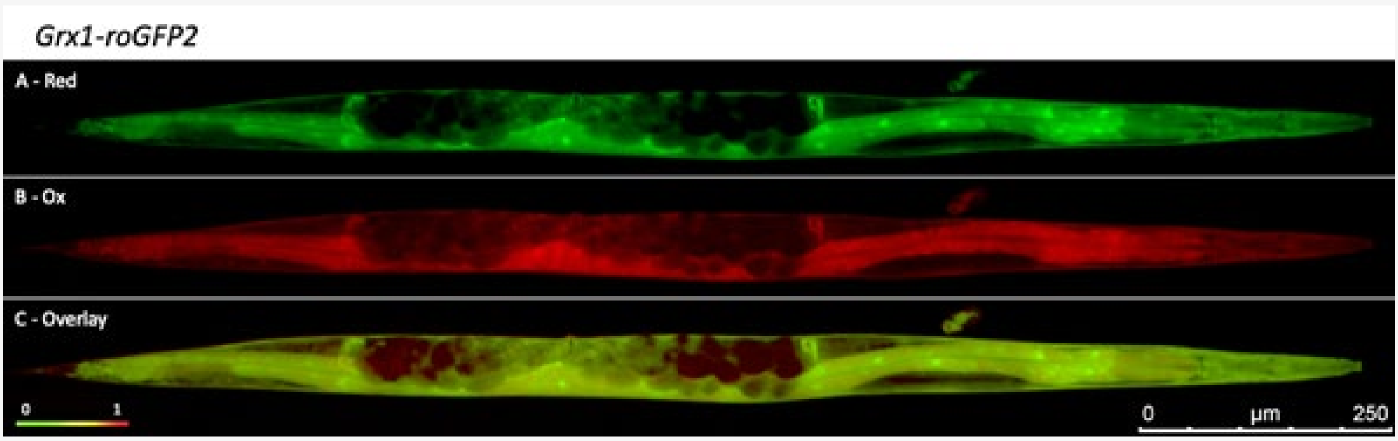
In collaboration with international research partners, we have attached dosimeters with GPS to free-ranging wildlife (Reindeer in Norway, Brown Bear in Sweden, and Wild Boar and Snakes in Japan). The instruments collect dosimetry as well as location data of the animals in almost real-time frequencies, as the animals move naturally through habitats that vary widely in contaminant levels. We have thus obtained much more accurate measurements than have been possible before (external dose was derived from soil samples and a Concentration Ratio, with large uncertainties). This research has shown us how animals use spatially complex micro-habitats over time, and how this results in dose variations. The added precision is most important in dose-effect research, which has traditionally been undermined by large uncertainties. Our research is providing much needed data on the effects of chronic exposures to low-dose rate exposures and some results of mammalian models, such as boar, can be extrapolated to humans.

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. 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. Model species selected so far include mammals, fish, invertebrates and plants, including the specific GMO strains of both C. elegans and Zebrafish.

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.



Epifluorescence images of Grx1-roGFP2 ratiometric C. elegans biosensor quantification of glutathione redox changes measured after chronic exposure to gamma radiation.
Photo: E. Maremonti

Aerial view of Diamond Light Source, the UK's national synchrotron facility. Image courtesy Diamond Light Source.

To that effect, several models of CERAD's partners were interfaced:

- Dispersion and Transfer Models: Advanced models of atmospheric and oceanic transport for real time and historic data and also future projections are further developed by MET and DSA. This has been exemplified by riverine runoff from Storelva to Sandnesfjorden and River Vefsna to the fjord of Vefsn by applying the oceanic Tracemass model as well as assessments concerning hypothetical releases from sunken and dumped nuclear objects in the Arctic seas. Outputs from the atmospheric model Severe Nuclear Accident Program (SNAP) were linked to a bespoke food-chain transfer model to provide prognosis regarding radionuclide activity concentrations in various plants and animals. This in turn allowed radiological risks to humans and the environment to be quantified.
- 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.

Field Studies and Expeditions

By Associate Professor Hans-Christian Teien,
Co-chair RA2

Several expeditions and fieldworks have been performed every year within CERAD. Since the start of CERAD, fieldwork or expeditions concerning accidental release of radionuclides, nuclear test sites, naturally occurring radioactivity (NORM) sites as well as case studies have been performed. The CERAD fieldwork provide input to all CERAD research areas (RA), as investigations carried out relate to the speciation of radionuclides (RA1), mobility and transfer in the environment and bioavailability towards aquatic and terrestrial organisms (RA2) and also possible effects in the studied organisms from both radionuclides and other stressors (RA3). Thus, most results feed into the environmental risk assessment performed in RA4. Obviously Covid restrictions have reduced the amount of fieldwork carried out in 2020, but CERAD scientists were able to carry out a few expeditions.

Field work campaign in the Chernobyl exclusion zone

The National University of Life and Environmental Sciences of Ukraine (NUBIP) and one CERAD PhD candidate at NUBIP performed several small field campaigns in the Chernobyl exclusion zone (ChEZ), Ukraine. The field work focused on the aquatic environment and included sampling of fish in contaminated and non-contaminated lakes to identify transfer of radionuclides.

Fieldwork at NORM sites

CERAD performed fieldwork at the Taraldrud legacy alum shale site and at Gran, an earlier site of road construction in an alum shale

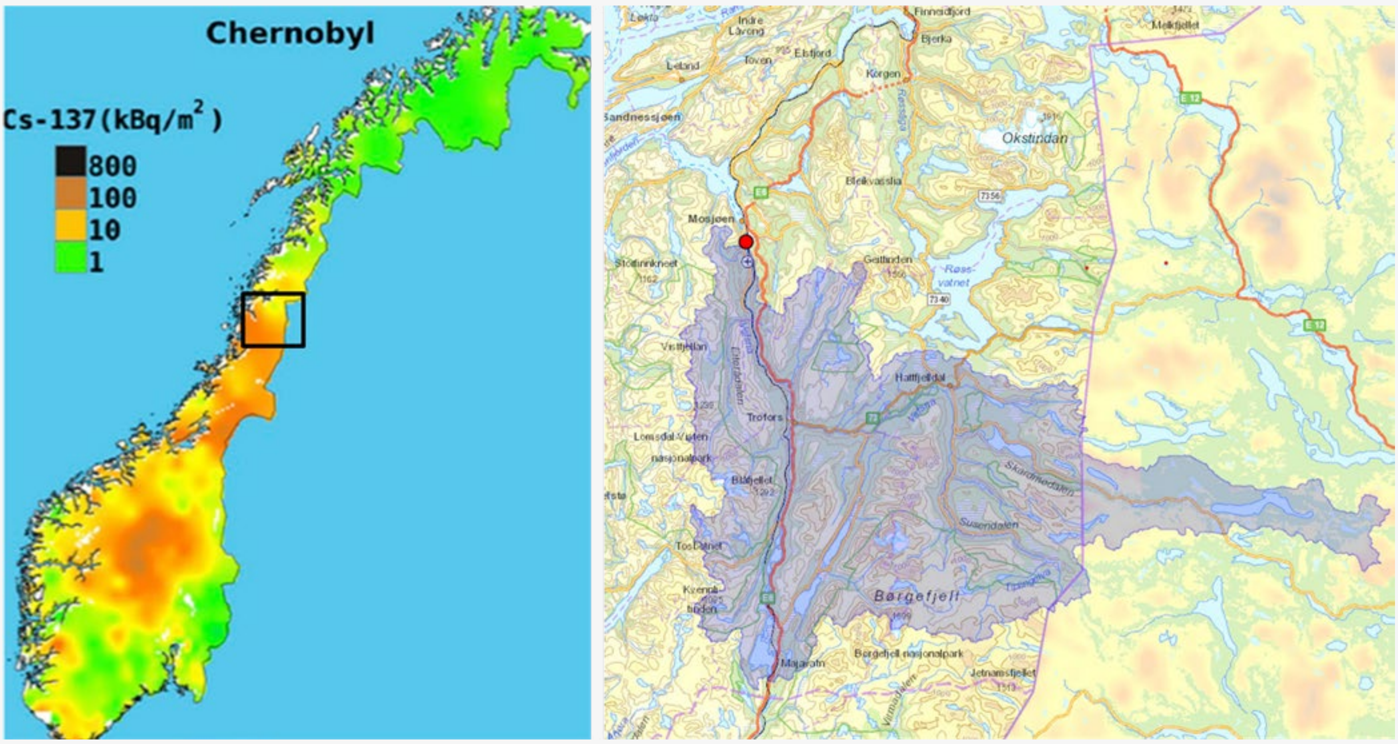


Figure 1: *Field work area. Deposition map for ^{137}Cs fallout from the 1986 Chernobyl accident (Backe et al., 1986), with the Vefsna catchment area marked with a rectangle (left). Map of the Vefsna Catchment (shadow) and Vefsnfjord area (https://nevina.nve.no/).*

Figure 2: *The Vefsna field work team.*
Photo: Estela Reinoso Maset.

rich area. This study is part of a PhD project. The fieldwork included *in situ* fractionation of water and sampling of sediments to study the mobilization of uranium and other naturally radionuclides. There have also been several field studies at Th-rich sites in Fen (Ulefos) to look more closely into transfer of Th and other NORM nuclides in the terrestrial environment. These studies formed part of an MSc student project.

Fieldwork to study freshwater-estuarine transport models

CERAD carried out fieldwork from 27th October to 1st November in the Vefsna catchment, Vefsna river and in Vefsnfjord to obtain data needed to improve the development of a transport model for ^{137}Cs covering both catchment and estuarine processes. River water and sediments were collected from the main river and 3 large tributaries, and soil samples from nearby sites. In Vefsnfjord the depth, temperature and salinity water profiles were measured at several sites at an increased distance from the outlet of river Vefsna at several repeated times and at different tides to validate estuarine models. Water with different salinity, sediments and biota (seaweed and blue mussels) were collected from different places at increasing distance from the outlet of river Vefsna. *At site* fractionation of both freshwater and seawater were performed to separate between particles, colloids and low molecular mass species of ^{137}Cs. Water samples were processed in field with tracer to reduce volume from between 100-400 L to small samples transported to NMBU for gamma spectrometry. Radiocesium in water was also preconcentrated on site using affinity-specific resin packed columns to determine the long-lived ^{135}Cs isotope. The Norwegian Institute of Marine Research (IMR) collected the sediment samples in the middle and the outer part of the Vefsnfjord. An MSc student took part in the field work.

Education Program

By Professor Lindis Skipperud, Director of Education

Providing education is an important part of CERAD's activities. The EU Commission, national authorities, the nuclear industry and research institutes need post-graduates in radiochemistry, radioecology, environmental modelling, radiation protection, radiobiology and dosimetry. The training programme at NMBU and collaborating universities is to provide this future workforce. We consider networking during education crucial for future employment opportunities and stimulate that students interact with research projects, potential employers and the wider radioecology community.

MSc in Radioecology

MSc Radioecology is a two-year, Bologna-accredited MSc programme (120 ECTS) and is the only one of its kind in Europe. Apart from CERAD staff, experts from other European as well as North American institutions teach on our courses. In the first year, compulsory and optional courses are offered. The main ones focus on radioecology, radiochemistry and ecotoxicology. All courses are taught in English and are run as blocks, to make it easier for students from abroad to attend only selected ones. In the second year, MSc students work on research questions associated with CERAD's projects.

The MSc programme is hosted at NMBU, where students can take all courses required for the degree (Table 1). However, students may also obtain credits from courses at specified collaborating universities and other collaborating institutions.

The PhD course in Environmental Radiobiology (MINA 410) aims to give students an introduction of the fundamental principles of radiobiology, within the context of research on radioecology and the environmental effects of radiation. The course covers up-to-date knowledge about the biological effects of radiation on humans, including recent epidemiological studies, as well as how research into bystander and non-targeted effects are challenging established paradigms on mechanisms of radiation effects. Areas covered include fundamental radiobiology, biological responses to ionising radiation, the use of biomarkers and toxicogenomics, factors linked to differences in radiation sensitivity, non-targeted effects (bystander, genomic instability, adaptive response, etc.) and multiple stressors.

PhD and PostDoc students in CERAD

So far, 17 PhD students connected to CERAD have completed their PhD education, and of these, 2 defended their work in 2020:

- Kine J. Aurland-Bredesen, 2020, "Policies and economic instruments to deal with climate change" Thesis number 2019:63, ISSN 1894-6402, ISBN 978-82-575-1623-9
- Erica Maremonti, 2020, "Strategies used to protect animals and cells from ionizing radiation- an evolutionary perspective" Thesis number 2020:8, ISSN 1894-6402, ISBN 978-82-575-1674-1

Further, 13 PhD defences are expected in the coming years. In total, this will amount to 30 PhD students associated with CERAD during the 10-year period and the years after. CERAD also consist of PostDoc positions and so far, 11 PostDocs have been or still are part of CERAD.

Of course, the year 2020 was a year giving challenges to the progress of both PhD and PostDoc students due to the Covid-19. Restrictions gave limited access to lab facilities and for some students we might expect some delay in their work. But we managed to provide some progress, and hopefully the delay will not be too much.

International cooperation

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.

Education and training platforms

The CERAD courses 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 and CONCERT-TERRITORIES. The Radioecology Exchange website, including the Education and Training Platform is now maintained by the Radioecology ALLIANCE. It presents the education and training opportunities within radioecology and environmental radioactivity offered by members of the ALLIANCE.

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
KJM351	Experimental Radioecology	10	http://www.nmbu.no/course/kjm351	Ole Christian Lind
KJM340	Instrumental Inorganic Analysis	10	http://www.nmbu.no/course/kjm340	Elin Gjengedal
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

Completed PhDs

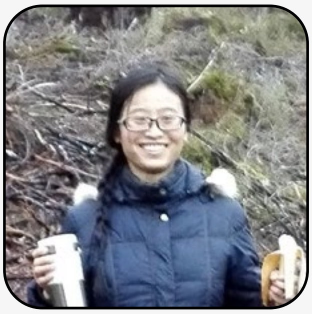
Erica Maremonti

On February 14th, 2020 Erica Maremonti defended her PhD thesis "Investigating sensitivity and tolerance to chronic gamma irradiation in the nematode Caenorhabditis elegans" and gave the trial lecture "Strategies used to protect animals and cells from ionizing radiation- an evolutionary perspective". Her main supervisor was Dr. Dag Anders Brede (NMBU) and she was co-supervised by Professor Brit Salbu, Professor Deborah H. Oughton, Professor Ole Christian Lind, and Professor Peter Aleström (all NMBU). The evaluation committee, consisting of first opponent Dr. Christelle Adam-Guillermin (Institut de Radioprotection et de Sûreté Nucléaire, PSE-SANTE, France) and second opponent Professor Hilde Loge Nilsen (Akershus University Hospital, University of Oslo), coordinated by Dr. Hans-Christian Teien (NMBU), approved the thesis, lecture and the defense of the thesis and recommended that Erica Maremonti be awarded the degree Philosophia Doctor (PhD). Erica is continuing her studies as a CERAD Post doc.

Kine Josefine Aurland-Bredsen

On February 27th, 2020 Kine Josefine Aurland-Bredsen defended her PhD thesis «Optimal economic management of catastrophic risk» and gave the trial lecture "Policies and economic instruments to deal with climate change". Her man supervisor was Professor Eirik Romstad (HH, NMBU) and she was co-supervised by Associate Professor Olvar Bergland (HH, NMBU). The evaluation committee, consisting of first opponent senior researcher Alexandra Brausmann (Eidgenössische Technische Hochschule Zürich (ETZ), Switzerland) and second opponent Professor Bård Harstad (University of Oslo (UiO), Norway), coordinated by Professor Dag Einar Sommervoll (HH, NMBU), approved the thesis, lecture and the defense of the thesis and recommended that Kine Josefine Aurland-Bredsen be awarded the degree Philosophia Doctor (PhD). Kine is currently working at the Ministry of Environment.

New PhDs



Hengyi Zhu

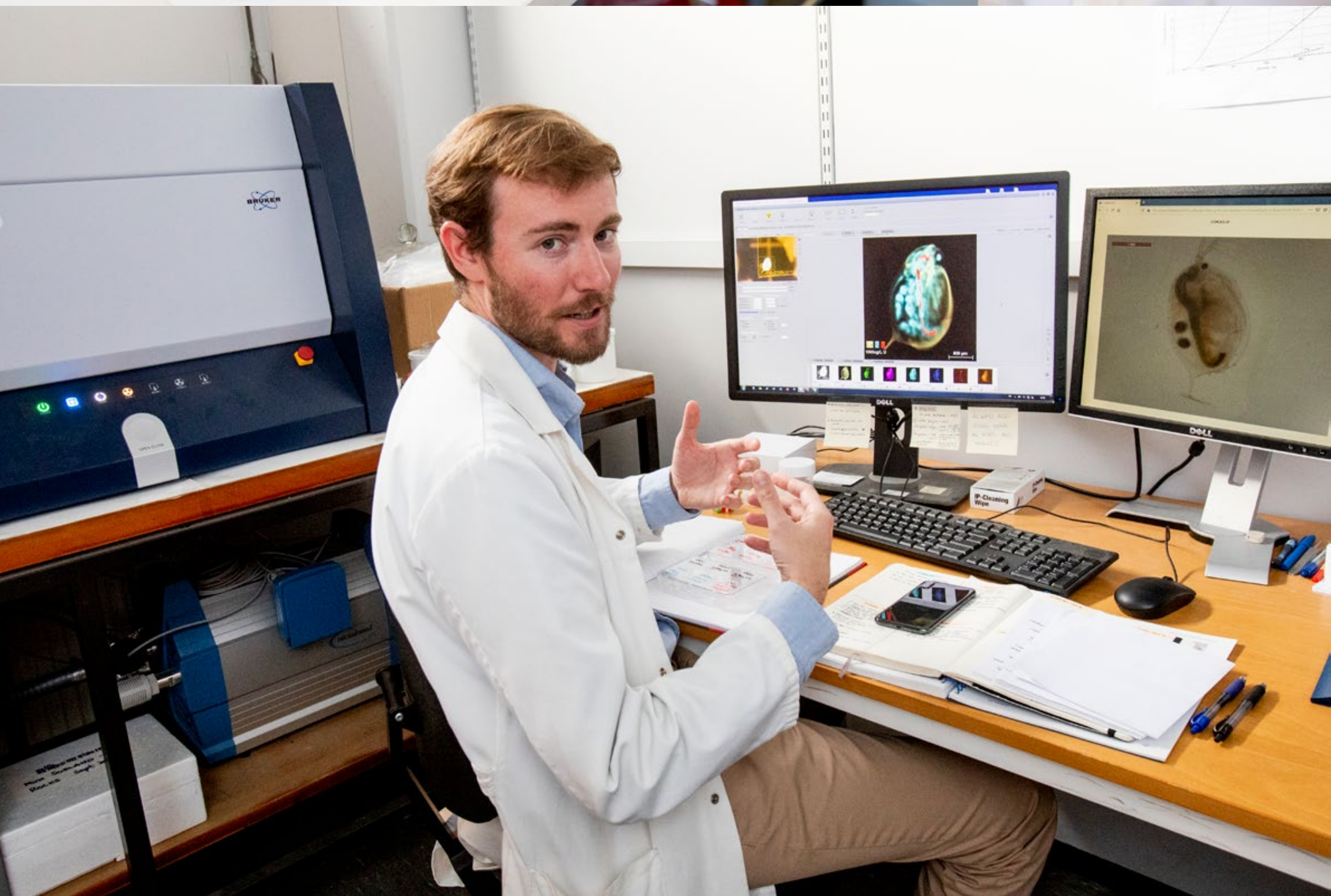
Hengyi Zhu started her PhD at CERAD in February 2021. She will be working at the Isotope laboratory and focusing on the impacts of chronic ionizing irradiation on reproduction using C. elegans. She received a MSc in molecular biology in 2016 at the University of Oslo, where she studied aging and stress responses using C. elegans (C*aenorhabditis elegans*), and she also has a MSc in evolutionary biology, where she studied the evolution of microRNAs by identifying and functional analyzing microRNAs in a group of unicellular organisms.

Mila Pelkonen

Mila Pelkonen started her PhD at CERAD in March. Her research at the Isotope laboratory will focus on radionuclide speciation and dynamic terrestrial ecosystem transfer, with a specific focus on naturally occurring radioactive materials (NORM). Mila has a background in radiochemistry and environmental radioactivity. She received her MSc in radiochemistry in 2018 at the University of Helsinki where her research focused on mobilization of radionuclides and trace metals in tailings at mining sites in Finland.

Jonas Lystrup Andresen

Jonas Lystrup Andresen started his PhD at CERAD in August. In collaboration with the entomology section at MINA (Tone Birkemoe and Anne Sverdrup-Thygeson), he will be looking into the behaviour of radionuclides in food webs by studying transfer and impacts of radiation on arthropod communities in Chernobyl, supported by laboratory studies on insect decomposition cycles. Jonas received his MSc in Environmental Science at the University of South-Eastern Norway with a thesis on the importance of bilberry (*blåbær*) as a resource for bumble bees in the forest-mountain ecotone.



Top: Simon Mark Jerome checking radioactivity in rock samples, with different screens. Photo: Håkon Sparre
Bottom: Ian Thomas Behnke Byrnes at a benchtop, micro-XRF (Bruker M4 Tornado). Photo: Håkon Sparre

Funding and Expenditures

By Hans Christoffer Tyldum,
Incoming Management Director

The turnover for CERAD in the eight operational year was MNOK 44.

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

The direct core funding contribution from RCN was MNOK 15.5 in 2020. 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 about MNOK 26.

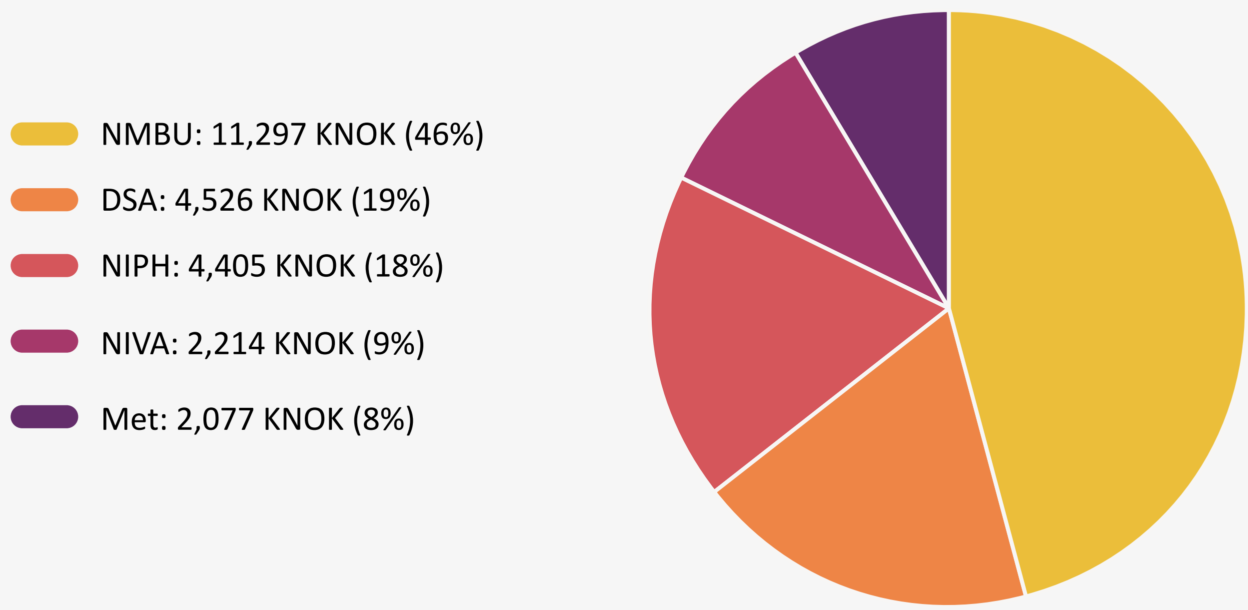
In addition, several ongoing RCN (EU) funded projects at NMBU/Isotope Laboratory are included as a financial source for CERAD (MNOK 2.3).

The expenditure is primarily connected to salaries, amounting to MNOK 37, which includes overheads covering indirect costs.

Other running expenses amounted to MNOK 7.

CERADs financial situation provides a solid foundation for stable and flexible project management.

Partners' contribution to CERAD's total turnover in 2020



CERAD's former director Brit Salbu knighted

His Majesty the King has awarded Professor emerita Brit Salbu the title Knight 1st Class of the Royal Norwegian Order of Saint Olav for her work benefitting society. The decoration was bestowed at a ceremony in the Clock Building, at NMBU Campus Ås, Monday 5 October, attended by NMBU and CERAD colleagues as well as Brit's family and friends. In his speech at the ceremony, NMBU Rector Sjur Baardsen said: "The knighthood is a major recognition of Brit Salbu's fantastic effort in the service of science over several decades. Brit Salbu's research has been decisive in shaping better risk assessments tied to radioactive radiation and environmental toxins.

"She has been a pioneer, both nationally and internationally, within the field of radiochemistry. We are very proud that one of our researchers has received such a distinction, and we can only congratulate Salbu on yet another well-deserved acknowledgement of outstanding research."

The Chancellor Mette Tverli presented the Cross of the Order of St. Olav and outlined why this honor was given to Brit Salbu. The award recognized Brit's international work such as leading NATO's Environmental Security Panel (ESP), and research programs under the International Atomic Energy Agency (IAEA) and has held many important volunteer and leadership roles tied to her research, both nationally and internationally. Recognition of her work in Chernobyl included her honorary professorship at the National University of Life and Environmental Sciences Ukraine (NUBIP) for her pioneer role and large effort within research on radioactive contamination. She has also received the V.I. Vernadsky Medal for her outstanding contribution towards

Chancellor Mette Tverli, and NMBU colleagues, friends and family look on as Christian Aasland appoints the Cross of the Order of St Olav to Professor Brit Salbu
Photo: Håkon Sparre, NMBU

Cross of the Order of St. Olav.
Photo: Private

the development and dissemination of Radioecology.

During the ceremony, several colleagues from Norway; former Rector Knut Hove, the new DSA Director Per Strand and professor Emeritus Bjørn Olav Rosseland, and well as internationally; Professor Tom Hinton, Professor Peter Stegnar and Professor Valery Kashparov, paid their tribute.

In Brit's acceptance speech she alluded to her many field expeditions "In the course of my research career I have participated in more than 50 expeditions: in Norway and in many other countries, from the Chernobyl areas in Ukraine, Belarus and Russia, and further north, to Kola and Ural, to nuclear test explosion and uranium mining sites in most countries of Central Asia, via the atomic bomb accident in Spain and depleted uranium munitions used in the wars in Kosovo and Kuwait, and to the accident in Fukushima," Salbu explains, and concludes:
"The most important thing we have learned from the large atomic accidents is that competency must be in place when needed. So further research is important both nationally and internationally to reduce the uncertainties in impact assessments. For the same reason the education and recruitment of competent young researchers is important, both in Norway, Europe, and internationally."

"I am rather overwhelmed by the honor I have received, and I am also rather humble as I have several people to thank for a rewarding professional life,"

The day ended with a celebration dinner at the Hotel Continental, one of the few times in 2020 that CERAD colleagues, were able to meet face-to-face. On Monday April 12, 2021, Brit Salbu was received in an audience at the Castle by King Harald V.

Brit Salbu and six former supporting NMBU rectors and pro-rectors at the celebration dinner.
Photo: Lindis Skipperud

Annual Conference

The annual CERAD conference was organised at the Norwegian Academy of Science and Letters in Oslo, Norway, February 10-11th, 2020.

A total of 85 participants attended the conference, including researchers from all partner institutions, members of the scientific advisory and relevance advisory committees and CERAD board, together with a number of invited speakers and guests. The topic of the conference was “Status 2019 – Future research priorities”. The participants presented research highlights of the past year and discussed challenges and new promising research areas.

Several guest lecturers were invited this year to present the challenges associated with the new research topics CERAD will be addressing in the coming years. These included the head of the Norwegian Nuclear Decommissioning Commission (NND), Pål Mikkelsen, on decommissioning of Norway’s two research reactors, Steinar Høibråten, Norwegian Defence Research Establishment (FFI) on Nuclear weapons – current developments and potential consequences of their use, and Andrzej Wojcik, Stockholm University on Health effects of exposure to radon in combination with other stressors. The second day of the conference was dedicated to the Young Scientist Session - 11 PhD students, postdocs and researchers presented highlights of their work. Their presentations covered a variety of CERAD's research areas, from atmospheric dispersion modelling to effects of radiation on a variety of organisms.

The concert by HYBRIS, the CERAD House-band has become a good tradition of annual conferences and was greatly enjoyed prior to dinner at the Norwegian Academy of Sciences.

Participants of the annual conference in 2020.
Photo: Yevgeniya Tomkiv

Prof. Andrzej Wojcik, Stockholm University, giving a talk on health effects of exposure to radon in combination with other stressors.
Photo: Yevgeniya Tomkiv

PhD student Shane Scheibener
Photo: Yevgeniya Tomkiv

Societal Impact

By Deborah H. Oughton, Centre Director and Yevgeniya Tomkiv, UMB4c leader

As detailed in the International Collaboration section, CERAD's output is of importance to a large number of national and international policy makers. Our researchers have contributed to many high-level reports, white papers and policy documents. Since 2013, these have included three White Papers for the UNSCEAR Committee, and numerous reports to IAEA, IUR, ICRP, and AMAP. Further details can be found in the International Section.

CERAD also carries out social science research on the impacts of nuclear events. We continue outlining the societal and ethical aspects of the Fukushima and Chernobyl accidents, in collaboration with WHO, NEA, IAEA and Fukushima Medical University. Public surveys, observation exercises, reviews and focus group studies, as well as other stakeholder engagement activities, have been used in research on emergency preparedness and risk communication. Results have been used to develop recommendations in the EU SHAMISEN (Nuclear Emergency Situations: Management and Health Surveillance) and CONFIDENCE projects, and have 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 to the psychosocial aspects of nuclear emergencies. In collaboration with the iClear project, CERAD has also participated in the current debate on 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. Stakeholder dialogues have the added advantage of facilitating dissemination of CERAD's research results and may lead to an increased public understanding of the

SHARE consortium at the first general assembly, July 2019, Barcelona, Spain.
Photo: SHARE

ISGlobal Policy statement
Sarukhan, Cardis, Liutsko, Crouaïl, Zölzer, Oughton, 2021

technical, organisational and socioeconomic challenges of radiation risk assessment and governance.
CERAD has also 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. CERAD continues to be involved in work on socioeconomic aspects of nuclear accident remediation, including the economic impact of countermeasures.
In 2020, CERAD joined the SYCOMORE initiative started by ISGlobal and drafted a joint policy statement adapting SHAMISEN Recommendations on Nuclear Emergencies to the Covid-19 pandemic. A series of webinars on similarities between nuclear emergency management and communication and Covid-19 arranged by the EU platforms SHARE and NERIS, hosted by CERAD, and involving CERAD researchers, attracted up to 800 participants.

We are still assessing the ecological impacts of the Fukushima and Chernobyl accidents, in collaboration with National University of Life and Environmental Sciences of Ukraine and Fukushima University, and also in response to UNSCEAR reviews of environmental effects.
In addition, our research considers the economic and societal consequences, through assessment of impacts on ecosystem services.

As stated previously, CERAD members participate in most of the Horizon 2020 programme boards of the European Atomic Energy Community (EURATOM), and have been instrumental in formulating topics and text for the EU EURATOM calls. CERAD was a co-founder of the platform for Social Sciences and Humanities in Ionising Radiation Research (SHARE), and Yevgeniya Tomkiv joined the SHARE Bureau in 2020. New EURATOM calls published in 2020 include communication and perception of risks and societal aspects of radiological protection within EU research. CERAD's multidisciplinary approach to research is fully in line with this focus.

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Top: The NMBU MINA Group. Photo: Håkon Sparre
Bottom: Mirian van Heist, Lindis Skipperud, Deborah Oughton and Ole Christian Lind. Photo: Håkon Sparre

CERAD in Media

Et forlatt hus nær Tsjernobyl. (Foto: Yevgeniya Tomkiv)

Områdene rundt Tsjernobyl kan få nytt liv

Myndighetene i Ukraina vurderer å lette på restriksjonene for områdene som ble hardest rammet av Tsjernobyl-ulykken.

Morten Nordahl Ellingsen
KOMMUNIKASJONSRÅDGIVER

NMBU – Norges miljø- og biovitenskapelige universitet

https://forskning.no/nmbu-norges-miljo-og-biovitenskapelige-universitet-partner-politikk/omrade-ne-rundt-tsjernobyl-kan-fa-nytt-liv/1675668

Radon er en luktfri gass som dannes ved nedbrytning av radioaktive grunnstoffer, uran og thorium, i mineraler i berggrunnen. (Illustrasjon: NTB scanpix)

Ny forskning på radon og naturlig radioaktivitet

NMBU – Norges miljø- og biovitenskapelige universitet

https://forskning.no/nmbu-norges-miljo-og-biovitenskapelige-universitet/ny-forskning-pa-ra-don-og-naturlig-radioaktivitet/1638370

I 2014 oppdaget forskere spesielt høye verdier av den radioaktive gassen thoron i lufta utenfor de gamle jerngruvene i Gruveåsen i Fensfeltet, som ligger på et område på land nedenfor bukta midt på dette kartet. (Skjermdump: Google Maps, Maxar Technologies)

Høy naturlig radioaktivitet utenfor gruver i Telemark

Det gamle gruveområdet i Fensfeltet ved Ulefoss i Telemark er kjent for bergarter med uvanlig høye nivåer av naturlig radioaktivitet. Nye målinger avdekker at luftstrømmer fra de gamle gruvene kan gi høye nivåer av den radioaktive gassen thoron enkelte steder i lufta utenfor.

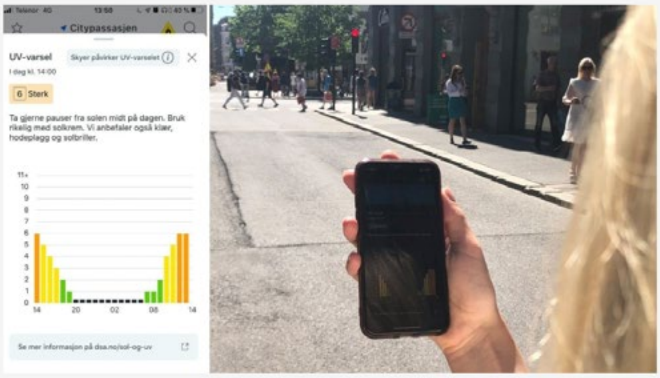
Jofrid Egeland
KOMMUNIKASJONSRÅDGIVER

Direktoratet for strålevern og atomsikkerhet

https://forskning.no/direktoratet-for-stralevern-og-atomsikkerhet-gass-partner/hoy-naturlig-ra-dioaktivitet-utenfor-gruver-i-telemark/1617965

Været

Drømmevær: Slik sjekker du UV-strålingen



Nå kan du sjekke UV-strålingen der du er. Det kan komme godt med de neste dagene, for det blir både varmt og mye sol de fleste steder i det neste uken. *Foto: Kjetil Bortelid Mæland (Nettavisen)*

Det meldes om sydenvær i hele landet, og nå kan du sjekke akkurat hvor mye stråling det blir.

https://www.nettavisen.no/nyheter/drommevar-slik-sjekker-du-uv-stralingen/s/12-95-3423982395

Ozonlaget i stratosfæren er litt tynnare no enn til vanleg. Meir sol slepper derfor gjennom og fagfolk ber folk om å beskytte seg. Arkivfoto: Vegard Wivestad Grøtt/NTB scanpix/NPK

Ozonlaget er ekstra tynt no

Ozonlaget i stratosfæren er litt tynnare no enn til vanleg. Meir sol slepper derfor gjennom og fagfolk ber folk om å beskytte seg.

https://www.firdatidend.no/nyhende/ozonlaget-er-ekstra-tynt-no/

Personnel

Professors / Scientists / Academic staff	Affiliation
Deborah H. Oughton, Professor	NMBU/MINA
Ole Christian Lind, Professor	NMBU/MINA
Lindis Skipperud, Professor	NMBU/MINA
Brit Salbu, Professor/Prof. Emerita	NMBU/MINA
Bjørn Olav Rosseland, Professor	NMBU/MINA
Hans-Christian Teien, Senior Scientist	NMBU/MINA
Dag A. Brede, Senior Scientist	NMBU/MINA
Estela Reinoso-Maset, Senior Scientist	NMBU/MINA
Simon Jerome, Senior Scientist	NMBU/MINA
Sondre Meland, Associate Professor	NMBU/MINA
Desiree Auren, Scientist	NMBU/MINA
Knut Asbjørn Solhaug, Professor	NMBU/MINA
Line Nybakken, Associate Professor	NMBU/MINA
Eirik Romstad, Associate Professor	NMBU/HH
Ståle Navrud, Professor	NMBU/HH
Jorunn Elisabeth Olsen, Professor	NMBU/BIOVIT
YeonKyeong Lee, Senior Scientist	NMBU/BIOVIT
Peter Aleström, Professor	NMBU/VET
Jan Erik Paulsen, Professor	NMBU/VET
Jan L. Lyche, Professor	NMBU/VET
Selma Hurem, Scientist	NMBU/VET
Leif Lindeman, Scientist	NMBU/VET
Vidar Berg, Senior Engineer	NMBU/VET
Ann-Karin Olsen, Senior Scientist	NIPH
Dag Marcus Eide, Senior Scientist	NIPH
Nur Duale, Senior Scientist	NIPH
Kristine Bjerve Gutzkow, Senior Scientist	NIPH
Oddvar Myhre, Senior Scientist	NIPH
Birgitte Lindeman, Senior Scientist	NIPH
Tim Hofer, Senior Scientist	NIPH
Christine Instanes, Senior Scientist, Department Director	NIPH
Einar Sverre Berg, Senior Scientist	NIPH
Torstein Tengs, Senior Scientist	NIPH
Per Strand, Director	DSA
Justin Brown, Senior Adviser	DSA

Terje Christensen, Scientist	DSA
Håvard Thørring, Scientist	DSA
Naeem Ul Syed, Senior Adviser	DSA
Ian Barraclough, Senior Adviser	DSA
Mikhail Iosjpe, Senior Scientist	DSA
Lavrans Skuterud, Senior Scientist	DSA
Tanya Helena Hevrøy, Scientist	DSA
Bjørn Johnsen, Scientist	DSA
Hallvard Haanes, Scientist	DSA
Runhild Gjelsvik, Scientist	DSA
Louise Kiel Jensen, Scientist	DSA
Anne Liv Rudjord, Head of Section	DSA
Malgorzata Sneve, Director	DSA
Hilde Skjerdal, Senior Adviser	DSA
Knut Erik Tollefsen, Senior Researcher, Associate Professor	NIVA
Andres Ruus, Senior Research Scientist	NIVA
Karina Petersen, Research Scientist	NIVA
You Song, Scientist	NIVA
Jannicke Moe, Senior Research Scientist	NIVA
Magnus Dahler Norling, Research Scientist	NIVA
Yan Lin, Scientist	NIVA
Tania Cristina Gomes, Research Scientist	NIVA
Øyvind Garmo, Regional Director	NIVA
Joachim Tørum Johansen, Research Assistant	NIVA
Lene Fredriksen, Research Assistant	NIVA
Guri Andersen Sogn, Scientist	NIVA
Kristoffer Kalbekken, Research Manager	NIVA
Raoul Wolf, PostDoc	NIVA
Lars-Anders Breivik, Research Director	MET
Magne Simonsen, Scientist	MET
Erik Berge, Senior Scientist	MET
Heiko Klein, Senior Scientist	MET
André Brodtkorb, Scientist	MET
Andreas Dobler, Scientist	MET

PhD students	Affiliation
Mila Kristiina Pelkonen	NMBU/MINA
Jonas Lystrup Andresen	NMBU/MINA
Erica Maremonti	NMBU/MINA
Shane A. Scheibener	NMBU/MINA
Ian Thomas. B. Byrnes	NMBU/MINA
Emil Jarosz	NMBU/MINA
Kine J. A. Bredesen	NMBU/HH

Hildegunn Dahl	NIPH
Astrid Liland	DSA
Ali Hosseini	DSA
Li Xie	NIVA
Magnus Ulimoen	MET

PostDocs	Affiliation
Yevgeniya Tomkiv	NMBU/MINA
Lisa Rossbach	NMBU/MINA
Erica Maremonti	NMBU/MINA
Payel Bhattaharjee	NMBU/BIOVIT

Technical/Administrative Staff	Affiliation
Mirian Wangen, Adviser	NMBU/MINA
Karl Andreas Jensen, Senior Engineer	NMBU/MINA
Marit Nandrup Pettersen, Chief Engineer	NMBU/MINA
Yetneberk A. Kassaye, Senior Engineer	NMBU/MINA
Jorunn Hestenes Larsen, Senior Adviser	NMBU/MINA
Miriam van Heist, Senior Adviser	NMBU/MINA
Erik Rasmussen, Department Egnineer	NMBU VET
Jill Andersen, Siv. Engineer	NIPH
Dina Behmen, Engineer	NIPH
Arip Ihksani, Engineer	NIPH
Jarle Ballangby, Engineer	NIPH
Hege Hjertholm, Senior Engineer	NIPH
Anne Marie Frøvig, Senior Adviser	DSA
Ståle Mygland, Financial Adviser	NIVA
Anders Høkedal, Assistant	NIVA

INTERNATIONAL SCIENTIFIC NETWORK: Scientific Advisory Committee (SAC)
Dr David Clarke, USA
Dr Valeriy Kashparov, Ukraine - Adjunct prof. NMBU
Prof. Koen Janssens, Belgium
Prof. Peter Stegnar, Slovenia
Prof. Carmel Mothersill, Canada
Prof. Colin Seymour, Canada
Dr Tom Hinton, USA
Dr Clare Bradshaw, Sweden
Prof. Sisko Salomaa, Finland
Prof. Janet Bornman, Australia
Prof. Graham Smith, UK

Guest scientists

Simone Cagno, Italy - Adjunct Scientist NMBU
Jakub Jaroszewicz, Poland
Christina Søyland Hassfjell, Senior Scientist, Ullevål
Chloe Eastabrook, PhD student, Great Britain
Brian Wynne

Conferences and Workshops

CERAD Annual Conference

The Norwegian Academy of Science and Letters,
Oslo 10th-11th February 2020
Organizer: CERAD

SHARE Webinar

Lessons we are Learning from the COVID-19 pandemic for Radiological Risk Communication
Zoom 26th March 2020
Organizer: SHARE. Host: NMBU/CERAD
https://www.ssh-share.eu/webinar-2/

SHARE Webinar

Balancing Action and Longer-term Outcomes during a Time of Crisis
Zoom 23rd April 2020
Organizer: SHARE. Host: NMBU/CERAD
https://www.ssh-share.eu/webinar-2-3/

NERIS Webinar

Chernobyl Wildfires
Zoom 28th May 2020
Organizer: NERIS, NMBU/CERAD
https://www.eu-neris.net/home/newsletters.html?start=5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