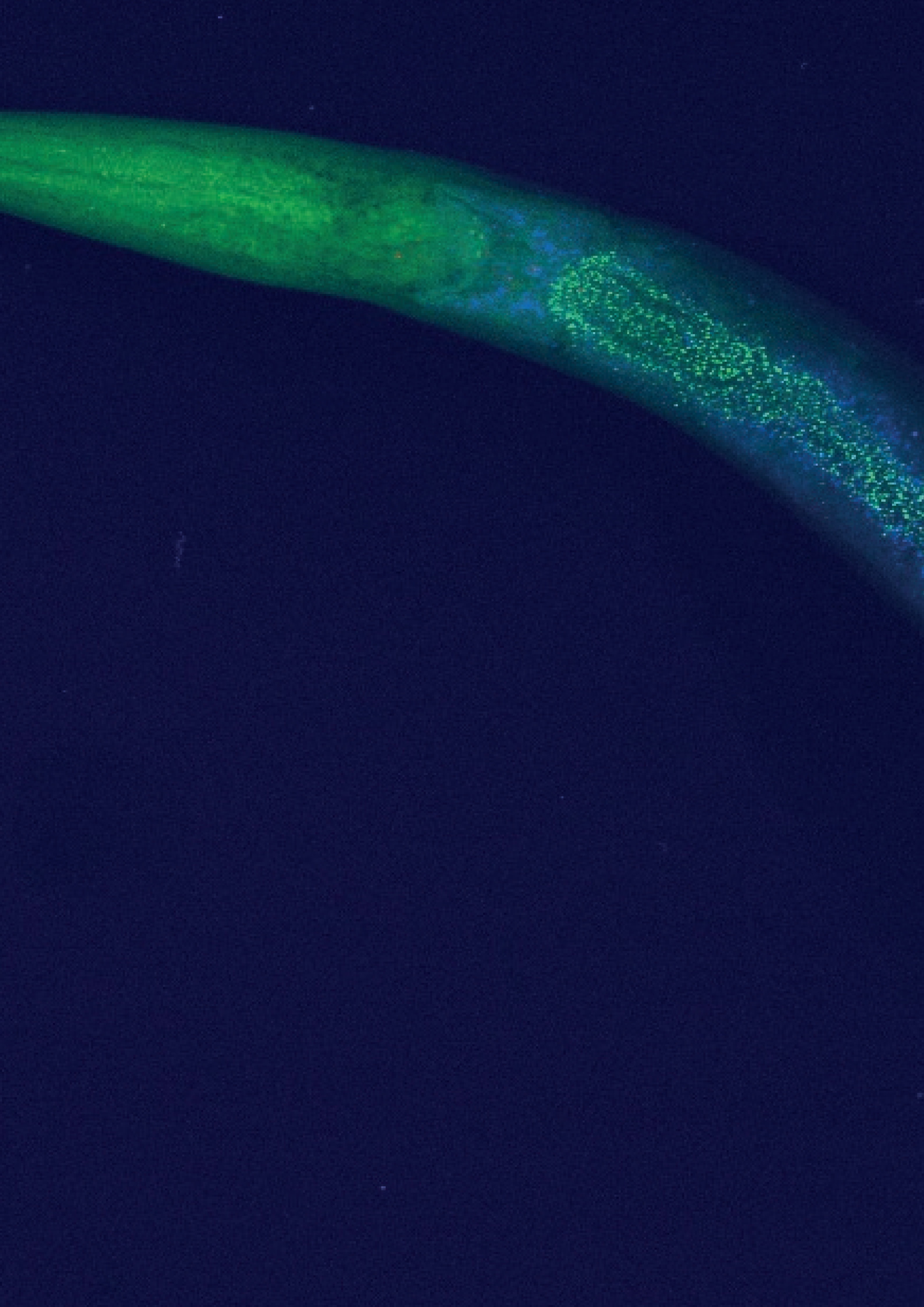
Norwegian Centre of Excellence

The Research Council of Norway

CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

ANNUAL REPORT 2021



CERAD

CENTRE FOR ENVIRONMENTAL RADIOACTIVITY

CERAD Annual Report 2021 (RCN Project Number 223268)

Coverpage:
Fisheye of Prussian Carp (*Carrius gibelio*) from Lake Glubokoye
in Chornobyl exclusion zone, October 2021
Photo:
Hans-Christian Teien

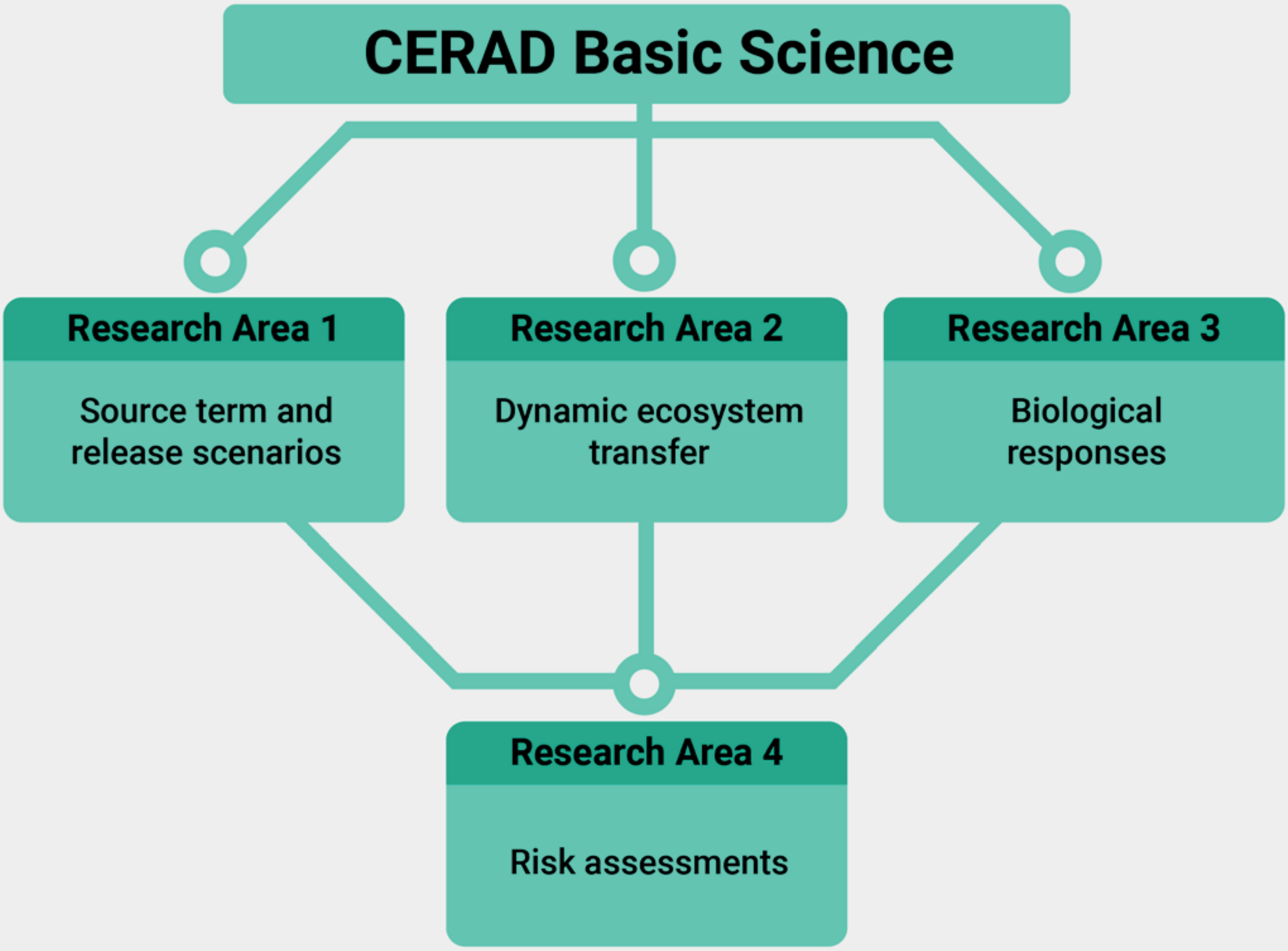
Coverpage inside:
Synchrotron X-ray mapping of zinc and calcium
in the model organism *C.elegans*
Photos:
Ole Christian Lind and Dag Anders Brede

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	Platform for Social Sciences and Humanities in Ionising Radiation Research
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

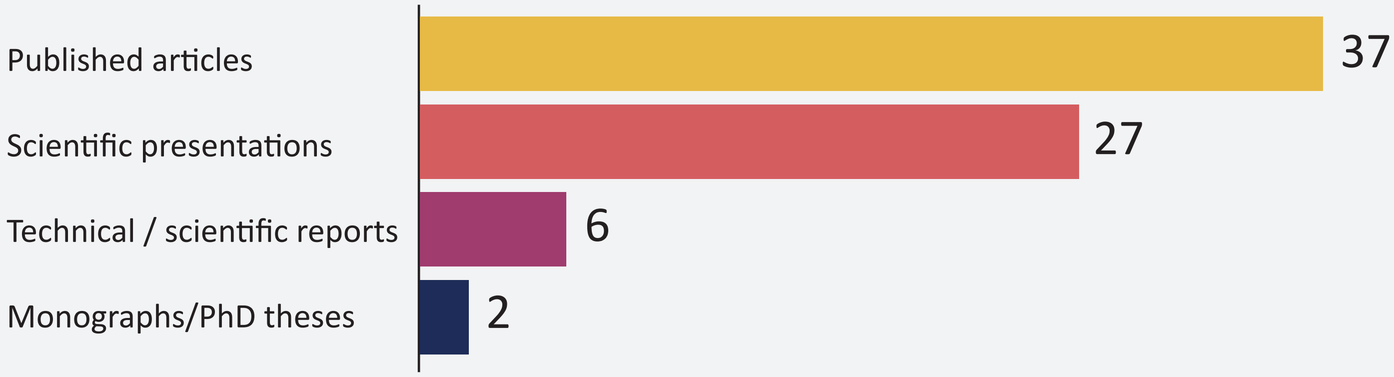
DSA Norwegian Radiation and Nuclear Safety Authority

NIVA Norwegian Institute for Water Research

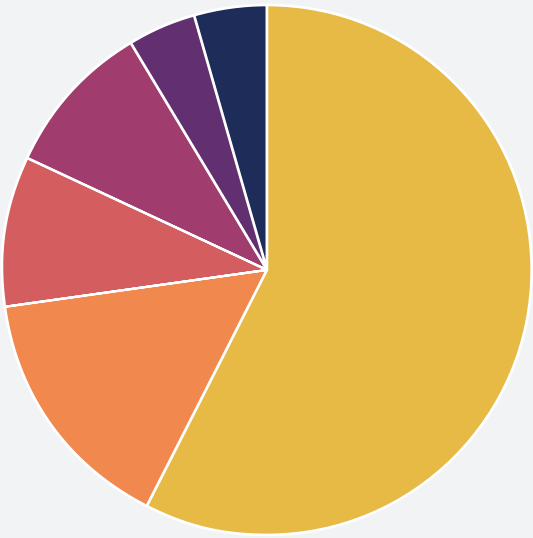
NIPH Norwegian Institute of Public Health

Norwegian Meteorological Institute

Scientific output in 2021

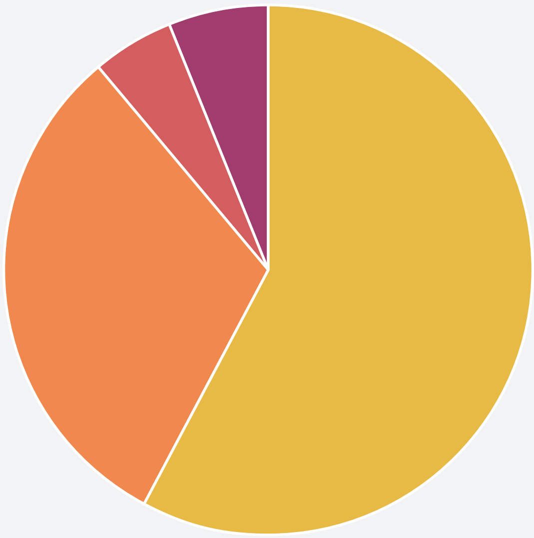


Full- and part-time personnel in 2021
Total: 118



- Professors, scientists: 68
- Technical/administrative: 18
- PhD students: 11
- Scientific Advisory Committee (SAC): 11
- Guest scientists: 5
- PostDocs: 5

Funding in 2021
Total: 44 MNOK



- Partners in-kind personnel: 58%
- RCN: 31%
- NMBU & DSA in-kind direct: 5%
- Other external projects: 6%

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 80 part-time scientists, 30 PhDs, 15 PostDocs and 25 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 2021, 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 weapons 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. The impact of Covid-19 on CERAD research plans caused CERAD to apply for a 6-month extension, accepted by the Research Council of Norway. 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 H. Oughton

A few weeks before this report was due, Russia invaded Ukraine. The war has had impacts on CERAD's staff and research in many dimensions. We have many long-term collaborators in Ukraine, both in Kyiv and the Chornobyl area. There are concerns about the radiological risks from physical or cyber attacks on nuclear facilities in war zones, and potential impacts in the Ukraine and further afield, including Norway. CERAD partners are key players in Norwegian nuclear preparedness, both as the leader of the Crisis Committee for Nuclear Preparedness (Norwegian Radiation and Nuclear Safety Authority, DSA) and as Committee advisors (Norwegian Meteorological Institute, MET; Norwegian Institute for Public Health, FHI; The Norwegian University of Life Sciences, NMBU). The Isotope Laboratory at the Environmental Chemistry section, NMBU also acts as an emergency laboratory for measurement of radioactive samples.

The decades of experience that CERAD scientists have in studying the effects of ionising radiation on humans and the environment, including the impact of Chornobyl in Norway, has a heightened significance in these unprecedented times. CERAD research includes advanced source characterisation, transport and transfer modelling, assessment of the environmental, health and societal impacts of radioactivity, as well as measures to mitigate and communication about radiological risks. Our work on dispersion and transport modelling is particularly relevant for the preparedness phase of a nuclear emergency, namely when there is an increased risk of a release but no actual release of radioactivity, which is the current situation in Ukraine. Since the start of the war, MET has been constantly updating meteorological forecasts and running dispersion models of potential releases at facilities. There has been an increased focus on the potential risks from detonation of nuclear weapons, a topic that CERAD partners have been working on for the past few years as part of our "new challenges and sources" initiative. We sincerely hope that our knowledge will stay of theoretical rather than practical importance. But should an event occur, we are prepared.

Decommissioning of Norway's research reactors is another key new challenge for CERAD research. Over the past twelve months we have made good progress in evaluation of the science, regulation and teaching and training requirements of decommissioning and waste management. Regarding education, NMBU has joined IAEA initiatives on international training programmes, and decommissioning is included as a case study on our courses. We have also established good contacts with the Decommissioning Cluster led by Smart Innovation Norway in Halden, with the participation of NND, IFE and local municipalities. The next years will see an increasing need for research competence, qualified candidates, and a trained workforce to meet the task of decommissioning in Norway.

Both the war in Ukraine and the new challenges from decommissioning emphasize the need for an organization like CERAD. It also underlines the importance of providing balanced, factual information to the public and decision-makers. The radiological risks of armed conflicts need to be put into perspective with the actual distress that the Ukrainian people are suffering, including many of CERADs long term collaborators and friends. CERAD has instigated new research projects with Ukrainian scientists, and been collaborating with national and international refugee agencies, especially those linked to academic and research initiatives, in order to be as best prepared to meet not only the research needs, but also the immediate needs of the humanitarian crisis of the war.

Comments from the outgoing chair of the board, Siri Fjellheim

CERAD is founded on a strong partnership between academia, research institutes and regulators, with the support of international collaborators. 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, together with the faculty of Landscape and Society as part of the EU project RadoNorm. CERAD's research is profiled 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.

CERAD's 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. The interdisciplinary nature of the research carried is illustrated by the number and wide scope of the publications from the Centre. Since 2013, over 300 articles have been published in international peer reviewed journals, many of which are co-authored by multiple CERAD partners.

I would like to thank all CERAD participants for their excellent work during this past year, and particularly 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). I am sure that the new chair of the board Vitalis Pavlovas will enjoy the discussions and interactions as much as I have, and I wish him all the best for his future work in CERAD.

Comments from the incoming chair of the board, Vitalis Pavlovas, Director of Research and Innovation at NMBU

As CERAD is entering its last year we can look back on a long list of achievements. The list of publications has grown longer and the number of CERAD associated projects granted has expanded. Just like with the rest of the world, the covid pandemic impacted CERAD and delayed some deliverables, so the Research Council of Norway has given us 6 months extension to complete the work started. By this time next year, CERAD shall have achieved all its goals, and then some.

At the same time as a lot has been achieved, the situation in the world is underscoring the need for the competence that CERAD is building. The war in Ukraine, and both the looming threat of nuclear war and the risk of damage to essential nuclear infrastructures, has renewed and moved the importance of CERADs goal of providing new scientific knowledge and tools for better protection of people and environment from harmful effects of radiation. CERAD and its partners are replying to the development and increasing the communication both to the public and to the academic field, on these important elements. New collaborations are springing out of these developments.

The partnership between academia, research institutes and regulators, has been reinforced in CERAD in the years passed, as CERAD has become part of the decommissioning work that Norway will undertake. As head of the board, I would like to thank both domestic and international partners for their hard work to bring CERAD to this point.

Despite being the last year for CERAD in its present form, we look forward to the future. Protection of people and environment from harmful effects of radiation is always very important, and it becomes even more actual in the present volatile world.

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 historically has been chair and CERAD Management Director acts as secretary for the board. From 2022 NMBU Director of Research and Innovation, Vitalis Pavlovas will be chair. 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 2021 have been:

- Pro-rector Siri Fjellheim, NMBU, Chair
- Director General Per Strand, DSA, Deputy chair
- Dean Hans Frederik Hoen NMBU/MINA
- Division Director Toril Attramadal, NIPH. From December 2021: Division Director Christine Instanes
- Deputy Managing Director Tor-Petter Johnsen, NIVA
- Research Director Lars-Anders Breivik, MET
- Scientist Dag Anders Brede, NMBU
- Centre Director Deborah Oughton

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 2021 have been:

- Professor Valery Kashparov, National University of Life and Environmental Sciences of Ukraine/ Prof 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
- Prof Brian Wynne, Lancaster University, UK

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 2021 the RAC included members from:

- The Ministry of Health and Care Services, Espen Andresen
- The Ministry of Climate and Environment, Ingvild Swensen
- The Ministry of Foreign Affairs, Anja Polden
- Norwegian Radiation and Nuclear Safety Authority, Kristin Elise Frogg
- The Norwegian Food Safety Authority, Torild Agnalt Østmo

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 Hans Christoffer Tyldum 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, Section of Research and Development, DSA
- Education Director: Lindis Skipperud, Professor, NMBU
- Research Director: Ole Christian Lind, Professor, NMBU
- Administration Support: Hans Christoffer Tyldum, 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 2021 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 Anders Brede, NMBU
- RA4: Knut Erik Tollefsen, NIVA and Yevgeniya Tomkiv, NMBU.

The Extended MG meets once a month to follow the progression of the funded research, to report findings that should be pursued, to suggest new or revised research topics, and to ensure that the research is of an international standard. Throughout 2021, these meetings were extended to include all Umbrella leaders in order to enhance communication in Covid times.

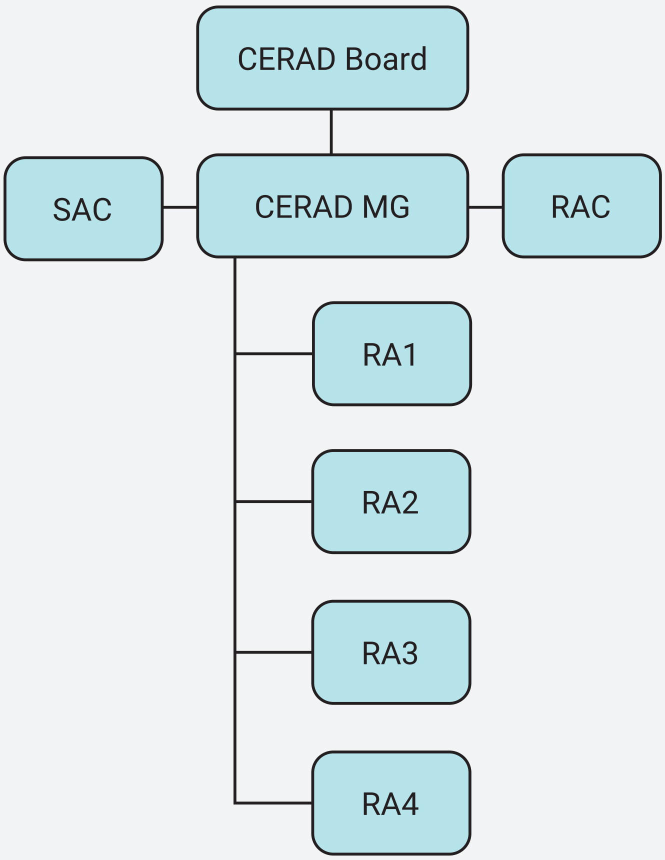


Figure 1. *The CERAD research organization*

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 institutions as well as disciplines. In each RA, at least three CERAD partners participate. The current SRA (2017-2022) 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 2021, 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 radio-protection 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 2021, 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 and Jan Ludvig Lyche)
- Umbrella 3C: Transgenerational and Reproduction Effects (Ann-Karin Olsen and Selma Hurem)

Research Area 4 - Risk Assessment and Ecosystem Approach

(Yevgeniya Tomkiv and Knut Erik Tollefsen)

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 2021, 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 - socio-economics, risk communication, risk perception and stakeholder dialogue (Yevgeniya Tomkiv).

The following sections contain research highlights from 2021, as presented during CERAD's Annual Conference in May 2022. 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.

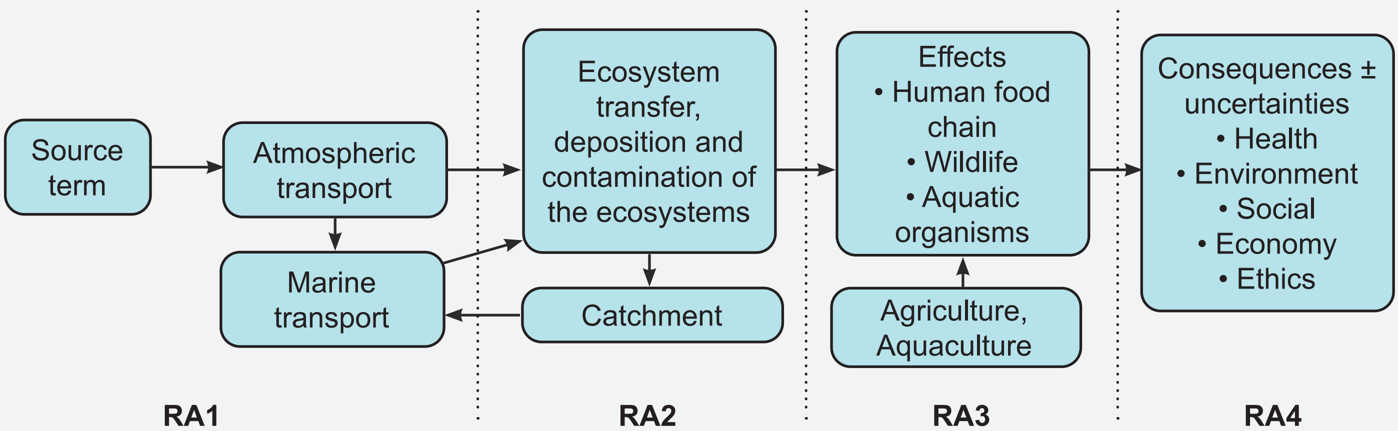


Figure 1. *Linking models from source term via ecosystem transfer to the impact for humans and the environment, for the society, economy and ethics. The research within RA1 to RA4 should reduce the overall uncertainties associated with modelling the impact and risk.*

Highlight writer:
Ian Byrnes

Synchrotron based X-ray Fluorescence Imaging Reveals Uranium Uptake Distribution and Localization in Target Organs of *Daphnia magna* Following Uranium Nanoparticle Exposure

Team members:
Ian Byrnes, Lisa Magdalena Rossbach, Dag Anders Brede, Estela Reinoso-Maset, Brit Salbu, Deborah Oughton, Shane Scheibener, Hans-Christian Teien, Ole Christian Lind (NMBU)
Daniel Grolimund, Dario Ferreira Sanchez (Swiss Light Source)
Gert Nuyts, Koen Janssens (University of Antwerp)
Vaclav Cuba (Czech Technical University)

Background/Objectives:

The objective of this study was to characterize uranium nanoparticle (UNP, 3 - 5 nm) exposure to freshwater model organism *Daphnia magna*. Environmental uranium (U) is often present in a range of physico-chemical species including low molecular mass (LMM, < 3 kDa), colloidal (3 kDa < x < 0.45 µm), and particles (> 0.45 µm). However, the colloidal and particulate fractions often go unassessed despite their potential mobility and bioavailability. Analysis techniques such as micro-focused synchrotron-based X-ray fluorescence (µ-SRXRF) allow for identification of possible target organs and tissue uptake were utilized in this study to better characterize the acute toxicity of aqueous U and UNPs.

Methods:

To characterize the exposure, toxicity tests, exposure media size fractionation, and µ-SRXRF imaging of intact, whole daphnia were used. Acute toxicity tests (48h, 1 – 1000 µg U L^{-1}) were employed to assess the toxicity of UNPs to D. magna and determine a sublethal exposure for µ-SRXRF analysis (320 µg U L^{-1}). Immediately following the test, samples for imaging were prepared by chemical drying, mounted to the end of a toothpick, and scanned at the microXAS beamline at the Swiss Light Source at a 5 µm resolution (Fig.1) for whole body elemental distribution analysis and 2 µm resolution around regions of interest (Fig.1.1 - 1.4).

Results:

Speciation analysis of the exposure solutions revealed U was present in the LMM, colloidal, and particulate fractions indicating dissolution and aggregation of the UNPs. Analysis of the toxicity tests provided a lethal concentration (LC_{50}) of the UNP suspension (LC_{50} = 402 µg L^{-1} [336 - 484]). This was somewhat higher than a comparable uranium reference solution (LC_{50} = 268 µg L^{-1} [229 - 315]). However, analysis of the body burden (ng U daphnid^{-1}) showed a 3 to 5-fold greater uptake of UNPs, indicating that the NPs bore a a lower toxicity compared with standard U reference solutions.

The XRF results revealed U distributed throughout most organs and tissues of *D. magna* (Fig. 1) following UNP exposures with several target areas of accumulation identified. On the external surfaces, U bound to the gills, called epipodites (Fig. 1.4), suggested a potential site of systemic uptake. Uranium was significantly concentrated within the digestive tract where U was measured in association with the luminal contents and the soft tissues, which indicated another potential route of systemic uptake through the epithelial cells. Additionally, high intensity U hotspots were observed in the midgut, suggesting the presence of large (> 2 µm), highly aggregated collections of UNPs. Accumulations in the heart (Fig. 1.1) and the maxillary gland (Fig. 1.3), an organ associated with the excretory system, confirmed systemic uptake of U into the circulatory system of D. magna. Moreover, U identified in the nephridium (Fig. 1.3), a kidney-like organ that is part of the maxillary gland, may be a possible metal removal mechanism. Uranium was also observed in association with the embryos of daphnia exposed to the UNPs (Fig. 1.2), confirming maternal transfer. Additionally, U bearing structures that may be the remains of the chorion were revealed in the brood chamber surrounding the embryos. The damages to the chorion were not observed in the control organisms, suggesting the unusual features shown in Fig. 1.2 were unique to U exposed individuals.

Conclusion:

The exposure characterization in this work provided assessment of the physico-chemical forms of aqueous uranium derived from a UNP suspension as well as identified target organs and tissue of acute exposure. These results are expected to provide novel insights that should improve the understanding of the uptake, retention, and elimination pathways of U in cladocerans.

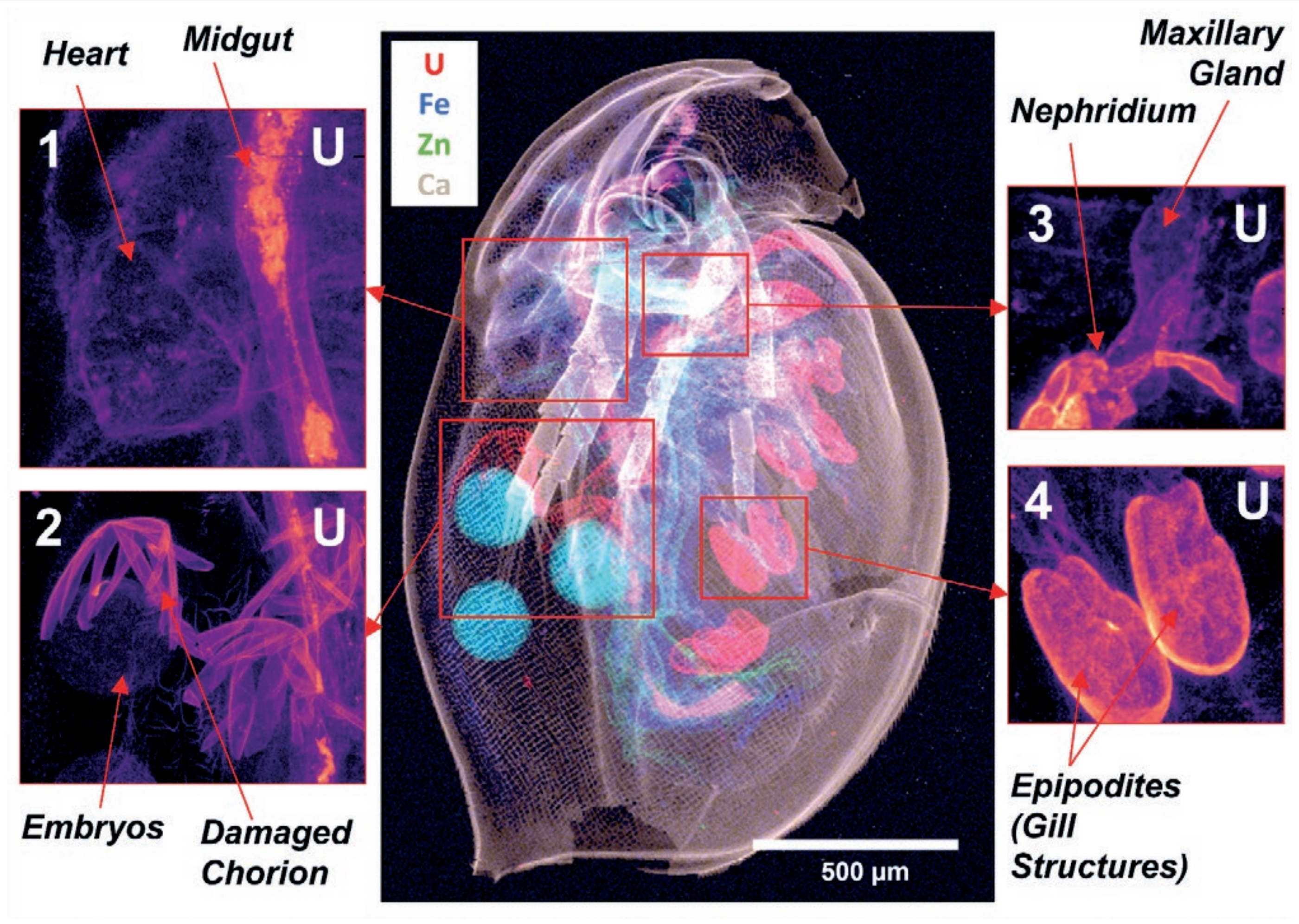


Figure 1: *Micro-focused synchrotron XRF elemental mapping (5 µm resolution) of a UNP exposed daphnia (320 µg U L^{-1}) showing the U (red), Fe (blue), Zn (green), and Ca (brown) biodistributions. Regions of interest are overlaid in red and show the local uranium distribution on the right in an intensity map (2 µm resolution). Region 1 reveals details of the heart and the midgut, including the high U intensity gut contents. Region 2 shows the embryos and the damaged chorion structures around them. Region 3 includes the nephridium and part of the maxillary gland. Region 4 contains a pair of the epipodites (1 of 5), the gills of the daphnia.*

References:

• *Submitted to ACS Nano: Byrnes et al, Synchrotron Based X-ray Fluorescence Imaging Provides New Insights on Uranium Toxicokinetics in Daphnia magna Following Exposure to Uranium Nanoparticles, 2022.*

Linking synchrotron XRF nanoimaging of cerium accumulations to tissue deformities in the nematode *Caenorhabditis elegans*

Highlight writer:
Lisa Rossbach

Team members:
Lisa M. Rossbach, Dag A. Brede, Simone Cagno, Deborah H. Oughton, Ole C. Lind (NMBU/CERAD)
Gert Nuyts, Koen Janssens (UAntwerp)
Gerald Falkenberg (DESY)
Ragni M.S. Olsson (NTNU)

Background:
There is a high demand and ever-increasing annual production of cerium nanoparticles (CeO_2 NPs), that ultimately will lead to non-negligible environmental releases. Despite many studies investigating the toxic effects of the CeO_2 NPs, results vary greatly, ranging from highly toxic, to non-toxic, and even beneficial. Moreover, most studies do not assess whole organism biodistribution and may thus not relate any toxic effects to the uptake and retention at the single cell level in an intact organism.

Objectives:
To characterize systemic uptake of Ce as well as concomitant adverse effects and investigate potential links between biodistribution and tissue specific retention of Ce in the nematode *C. elegans.*

Methods:
Growth, fertility, reproduction, changes in cellular redox status, and physiological deformities were measured following the exposure to either CeO_2 NPs or $Ce(NO_3)_3$ in nematodes. Uptake, retention, and tissue specific biodistribution was measured using submicron resolution synchrotron radiation-based X-ray fluorescence elemental mapping at the microprobe end-station of the P06 Hard X-ray Micro/Nano-Probe beamline, PETRA III storage ring, DESY facility (Hamburg, Germany).

Results:
Significant growth, fertility, and reproduction effects were observed for the $Ce(NO_3)_3$ exposure, while

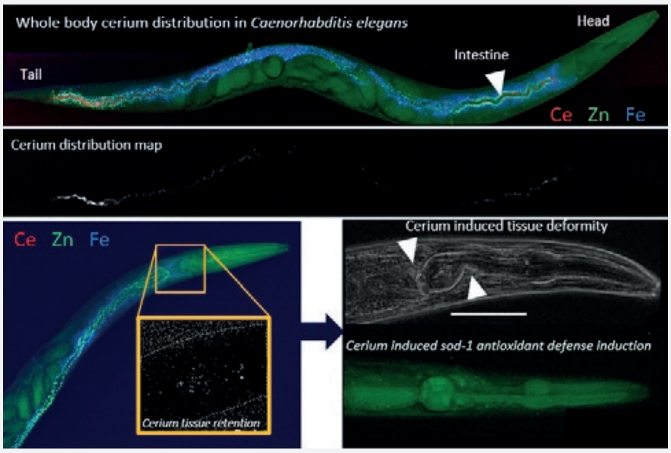


Figure 1: *Synchrotron XRF elemental mapping, with biodistribution of Zn, Fe and Ce, as well as Ce induced tissue deformities and sod-1 antioxidant defence induction in the nematode C. elegans.*

CeO_2 NPs only resulted in minor toxic effects. Both forms of Ce resulted in an increased sod-1 antioxidant defence induction and severe tissue deformities in the pharynx of the nematodes. Synchrotron XRF nanoimaging showed high Ce uptake into the lumen following CeO_2 NPs or $Ce(NO_3)_3$ exposures. In line with increased pharyngeal tissue deformities, increased Ce accumulations surrounding the terminal bulb were observed by 2D XRF analysis.

Conclusion:
Tissue specific deformities coincided with Ce accumulation and increased antioxidant defence response. These findings demonstrate the importance of high resolution, whole-body elemental distribution mapping for accurate evaluation of toxicological effects of metal containing contaminants.

References:
• *Rossbach, L.M., Brede, D.A., Nuyts, G., Cagno, S., Olsson, R.M.S., Oughton, D.H., Falkenberg, G., Janssens, K., Lind, O.C., 2022., Synchrotron XRF analysis identifies cerium accumulation colocalized with pharyngeal deformities in CeO_2 NP-exposed Caenorhabditis elegans. Environmental Science and Technology 56(8): 5091-5089.*

Modelling dry deposition of particles

Highlight writer:
Erik Berge

Team members:
E. Berge, M. Ulimoen and H. Klein (Norwegian Meteorological Institute)

Objectives:

Evaluate different dry deposition schemes for improved parameterization in Severe Nuclear Accident Programme (SNAP) and better input data for the FDMT model (Food Chain and Dose module for Terrestrial Pathways).

Methods:

Apply surface characteristics of land-use, leaf-area index, roughness and near surface meteorological parameters to different dry deposition parameterization schemes. Evaluate and compare the different schemes for accumulated dry deposition in the near-source region during the Chornobyl accident.

Results:

In Figure 1 the dry deposition velocities (v_D) of 1 μm diameter particles to a forest surface are compared for SNAP constant v_D =0.2 cm/s), the EMEP (Simpson et al., 2012), the Zhang (Zhang et al., 2002), and the modified Zhang (Emerson et al., 2020) dry deposition schemes. The data are for a grid square approximately 60 km from Chornobyl, and covers the period 25.04.1986 to 15.05.1986. A key meteorological parameter for dry deposition is the friction velocity u* shown by the left y-axis (black curve). Large similarities in the daily variation of u* and v_D are seen.

The EMEP and the Emerson schemes yield higher v_D during daytime and lower v_D during night-time compared to v_D=0.2 cm/s. The Zhang scheme show smaller v_D than 0.2 cm/s most of the time.

In Figure 2 the accumulated dry deposition of the reference SNAP run (upper panel) and the Emerson scheme (lower panel) is presented. For this particular run the accumulation period is 25.04.1986 to 04.05.1986. The

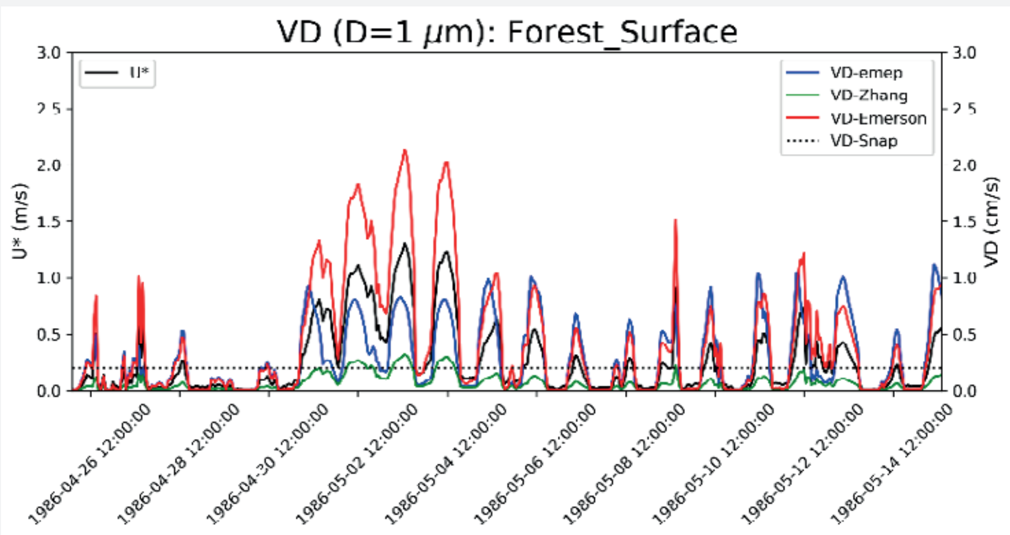


Figure 1: *Dry deposition velocity (right axis) for 1 μm particles and friction velocity (m/s), U*, (left axis) for a selected forest grid-point near Chornobyl during the 26 April to 15 May 1986. Dotted line is the constant SNAP dry deposition velocity (=0.2 cm/s), while the red, blue and green lines correspond to the Emerson, EMEP and Zhang parameterizations.*

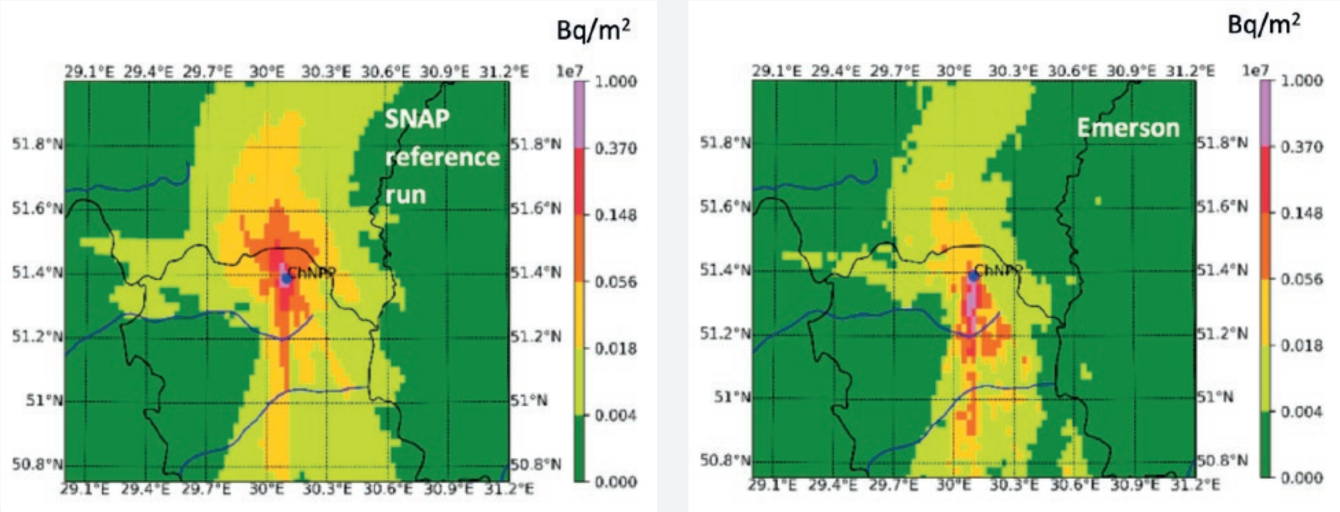


Figure 2: *Upper panel shows accumulated dry deposition (Bq/m²) for the original SNAP dry deposition scheme, while the lower right panel shows the corresponding accumulated dry deposition for the Emerson dry deposition scheme. Accumulation period: 26 April to 4 May 1986.*

overall dry deposition patterns are similar for the two cases, but locally substantial differences are also seen. In particular, less dry deposition is encountered in the Emerson scheme in the sector NW to NE of Chornobyl Nuclear Power Plant compared with the original SNAP run. Toward south higher dry depositions are seen in Emerson compared to SNAP original scheme. The Emerson dry deposition scheme yields larger local variability from one grid square to another. This reflects the influence of local variations in dry deposition velocities due to variations in surface properties and local meteorology, which in turn interacts with the plume of radioactive particles.

Summary:

Large temporal and spatial variation in the modelled v_D of small particles (diameter 1 µm) are encountered, together with substantial deviations from the simpler SNAP constant v_D=0.2 cm/s. The accumulated dry deposition in the near Chornobyl region shows quite large local differences between the SNAP reference version and the new dry deposition schemes, although qualitatively the deposition patterns are similar.

References:

- *Emerson, E.W. Hodshirea, A.L., DeBolta, H.M., Bilsbackc, K.R., Piercec, J.R., McMeekingb, G.R. and Farmera, D.K. 2020. Revisiting particle dry deposition and its role in radiative effect estimates. PNAS, Vol. 117, No. 42., https://doi.org/10.1073/pnas.2014761117.*
- *Simpson, D., Benedictow, A., Berge, H., Bergström, R., Emberson, L. D., Fagerli, H., Flechard, C. R., Hayman, G. D., Gauss, M., Jonson, J. E., Jenkin, M. E., Nyíri, A., Richter, C., Semeena, V. S., Tsyro, S., Tuovinen, J.-P., Valdebenito, Á., and Wind, P. The EMEP MSC-W chemical transport model – technical description, Atmos. Chem. Phys., 12, 7825–7865, https://doi.org/10.5194/acp-12-7825-2012, 2012.*
- *Zhang, L., Gong, S., Padro, J., Barrie, L., 2001. A size-segregated particle dry deposition scheme for an atmospheric aerosol model. Atmos. Environ. 35, 549–560.*

Highlight writer:
Magne Simonsen

Fjord-estuary transport modelling of riverine Al run-off

Team members:
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Øyvind Sætra (MET)
Lars Asplin (IMR)
Ole Christian Lind, Hans-Christian Teien (NMBU)

Objectives:
To describe, predict and validate the transport of a particle-reactive contaminant through the mixing zone in a fjord-estuary by developing and utilizing a high resolution process-based numerical model system.

Methods:
A transport model (OpenDrift) including dynamic speciation and transformation processes was applied, using three-dimensional hydrodynamic flow fields from a numerical ocean model (ROMS). The model domain covers Sandnesfjorden in south-eastern Norway at 32m horizontal resolution. Numerical particles were introduced into the estuary at the location of River Storelva and trajectories were computed along the estuary and fjord. Vertical profiles of salinity and temperature were collected during field work on August 28, 2019. Surface samples of Al were collected from 12 locations. These were fractionated in situ to obtain information of the size distribution.

Results:
The model validation showed improvements compared to previous studies (Simonsen et al., 2019) due to targeted optimization of model configuration. Model results showed good agreement with observed surface values, and the along-fjord decreasing trend was well reproduced. However, the transport modelling identified more scattered and variable fields in areas and during periods for which no observational data exists. During reversed flow events, where strong winds into the fjord opening triggered surface flow in the reverse direction of the average circulation, considerable mixing and redistribution of the different water masses occurred. This affected both the horizontal distribution with coastal water being pushed into the fjord and blocking the river discharges temporarily in the inner part of the fjord, as well as vertically when surface water was mixed with deeper water masses. Such events were shown to have significant impact on the properties and distribution of the water masses and contaminants in the fjord.

Conclusion:
High resolution models capable of resolving the instant concentration and peak values are important to show deviations from the average values. For estimation of biological uptake, detailed estimates are necessary and the new results from this paper should be relevant and important for model development and for interpretation of results from models estimating or predicting transport of any contaminant in coastal regions. Our results show the capability of events to redistribute the general environmental conditions significantly.

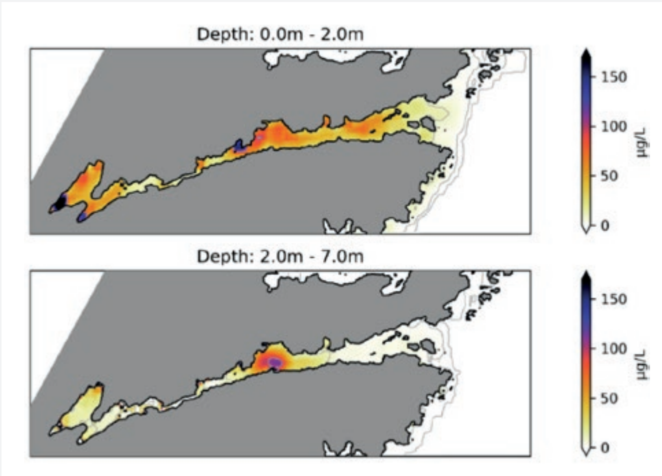

Figure: *Modelled Al concentration in surface (0m-2m, top) and deeper layers (2m-7m,) in Sandnesfjorden at the day when the samples were taken (August 28, 2019).*

References:

• *Simonsen et al., (2019). Modeling key processes affecting Al speciation and transport in estuaries. Sci. Tot Env., 687, doi:10.1016/j.scitotenv.2019.05.318*

Steps towards renewing instruments and infrastructure at UV-monitoring stations. Open access to 25+ years completed, biologically relevant solar UV data

Highlight writer:
Bjørn Johnsen

Team members:
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Objectives:

Upgrade of instruments and infrastructure at solar UV-network stations to ensure still continuous monitoring of health-, environmental- and climate relevant data for the next decades. Open access to quality-controlled surface irradiance data for cross-disciplinary studies.

Methods:

The Norwegian UV-monitoring network (https://uvnett.dsa.no) has been operating since 1995/96, providing scientifically high-quality data from nine locations. Instruments and infrastructure now approach lifetime. New PCs and routers are recently installed at the six DSA stations, providing improved stability in data logging and security to internet attacks. Three new instruments, one of them co-funded by CERAD, are now operating at Finse (Figure 1) and Østerås. The aim is renewal of all DSA and NILU stations. The spectral range is extended to cover the visible and near infrared (290-1650 nm), which implies continuation of the network UV-series as well as providing a link between spectrally resolved measurements from new instruments and total radiation measurements from pyranometers operating in the MET/NIBIO network. As part of the co-operation with MET, pyranometers operating at DSA (Figure 2) is planned to be installed at other locations and integrated with the data storage and distribution system of MET. Measurements from pyranometers, co-located with UV instruments, and overpass data from satellite-based instruments, provide information on attenuation of UV from clouds and ozone. Using the Libradtran radiative transfer model to model clear sky spectra, and using cloud attenuation data, real sky UV data have been reconstructed for the whole period the UV-network has been operating. Gaps in UV-measurements have been substituted with reconstructed data to provide a complete, gap-free data set for all network locations. Biological effects from UV exposure are specific for humans, plants, and smaller organisms. Currently, 11 different action spectra have been utilized, providing a set of 11 dose products for each station. A complete dataset is open accessible on https://github.com/uvnrpa. These data serve as a reference data set for real sky conditions, on which effects studies utilizing artificial lighting, or in combination with other stressors can be related to. Single- and multi-stressor studies on aquatic organisms have been performed at NIVA and NMBU, with an approach to create light- and UV exposure conditions that are realistic with outdoor conditions at the southernmost station in Norway (measurements), as well as in the Tropics (modelling). Lamps and filters in radiation exposure chambers have been spectro-radiometrically characterized to investigate whether exposure is significantly influenced from wavelengths outside nominal wavelength bands. Calibration facilities have recently been upgraded. To match the wider spectral range of new instruments, the Bentham DTM300 scanning spectroradiometer of DSA has got new grating and photodetector. New lamps, new power supply and a lamp monitoring system have been implemented to provide improved accuracy in calibrations and maintenance of a stable irradiance calibration scale.

***Figure:** Solar UV+visible+near-infrared monitoring at Finse Research Station. Hardangerjøkulen in the background.*

Figure: *Testing pyranometers (total solar radiation) before installation at UV-network stations.*

Results:

The recently purchased three instruments have demonstrated stable performance and operation. A new data acquisition system is under development. Most of the stations have now implemented new PCs, as a first approach towards renewing instruments and infrastructure. CERAD members and the public have open access to a set of quality controlled and complete set of health- and environmentally relevant UV-data, representing 25+ years at nine locations. UV-network data is extensively used in international publications. Data from Norwegian stations have been utilized in the report series 'State of the Climate' since 2010. A new report summarizing highlights of the UV-monitoring programme is in preparation.

Conclusion:

The Norwegian UV-network has provided health- and environmental relevant data over almost three decades, open accessible for scientific and public use. The data is utilized in several cross-disciplinary studies. New instrumentation is required for the continuation of the monitoring program. The extended spectral range, including visible and near infrared, adds relevance and versatility for a number of research areas, such as climate studies and utilization of solar energy in Norway.

References:

- *Bernhard G. H., Fioletov V., Gross J.-U., Ialongo I., Johnsen B., Lakkala K., Manney G. L., Müller, R., and T. Svendby (2021): Ozone and UV Radiation [In: State of the Climate in 2020]. Bull Amer Meteor Soc, 102 (8), s299-s303, https://doi.org/10.1175/2021BAMSStateoftheClimate.1*
- *Svendby, T., Johnsen, B., Kylling, A., Dahlback, A., Bernhard, G., Hansen, G. H., Petkov, B., and Vitale, V. (2021):GUV long-term measurements of total ozone column and effective cloud transmittance at three Norwegian sites, Atmos. Chem. Phys., 21, 7881–7899, 2021 https://doi.org/10.5194/acp-21-7881-2021*

Mapping of Uranium Uptake and Biodistribution in the Nematode *Caenorhabditis elegans* following Uranyl or Uranium Nanoparticle Exposure

Highlight writer:
Estela Reinoso-Maset

Team members:

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G. Nuyts (University of Antwerp)
U. Johansson (MAX IV Laboratory, Lund University)

Objectives:

The aim of this work was to compare the uptake of uranium (U) nanoparticles (NP) in biological systems with those of ionic U by studying the distribution of U within the 1 mm nematode *Caenorhabditis elegans (C. elegans)* using synchrotron radiation-based nano-XRF elemental mapping.

Methods:

Synchronized L1-stage populations of *C. elegans* were exposed to uranyl (20 mg U L^{-1}) or 50 nm UO_2 NP (12.5 mg U L^{-1}) in moderately hard reconstituted water (pH 6.8) for 72 h. Exposure solutions for both uranyl and NP were characterized for particulate fractionation and, following test termination, total U uptake was confirmed by digestion and ICP-MS analysis of exposed organisms. Individual C. *elegans* from control, uranyl, and U NP exposures (with and without depuration) were sampled, washed, and fixated followed by a stepwise procedure to chemically dry the organisms. Dried nematodes were then placed directly onto Kapton tape for XRF analysis at the NanoMAX beamline of the MAX IV Laboratory in Lund, Sweden (Figure 1). Biodistribution of U and soft energy elements (e.g., Zn, Fe, Ca, S, P) was obtained with a 57 x 56 nm beam size at an incident energy of 17.5 keV (above the U-L_{III} edge). Two-dimensional scanning was carried out at coarse resolution for the whole body (500 nm step size; 0.05 s dwell time; scan areas up to 90 x 100 µm) and at high resolution for identified regions of interest (60 nm step size; 0.1 s dwell time; 54-30 x 21-3.6 µm areas).

Results:

The coarse resolution maps allowed us to identify the different parts of the nematode body (Figure 2) and areas with high U signal. Subsequent high-resolution scans of these regions enabled the identification of specific organs and neuronal structures as well as U localisation. Both types of exposure resulted in U retained mainly in the intestine (lumen) and in tissues surrounding the grinder, posterior part of the midgut, and the foregut/pharynx; yet, the U from the uranyl solution was taken up and retained to a higher degree than the U NP. XRF-maps of depurated organisms showed that while the UNP remained within the lumen, U from the uranyl solution was transferred into luminal cells in the pharynx of the nematode.

Conclusion:

These preliminary results showed that the accumulation of U in the nematodes depended on the physico-chemical form of U and provided *bona fide* evidence of translocation of U from the lumen into tissues and cells. Future work will study intact specimens that have not undergone chemical dehydration in order to image the internal organs in a pristine, native condition and avoid any potential distortion of the biodistribution due to dehydration.

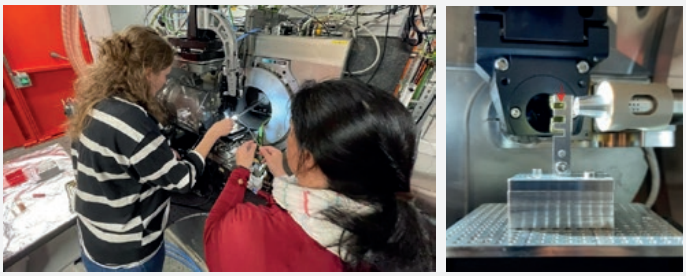

Figure 1: *Overview of the NanoMAX beamline configuration while mounting a sample (left; Photo: I. Brynes). The synchrotron X-ray nanofocused beam comes from the left (tube from out of the red wall), hits the sample placed on an aluminum pin attached to the scanner table (right; Photo: Estela Reinoso-Maset), and the fluoresence signal is collected by a detector positioned at 90°. The red arrow points at 2 nematodes.*

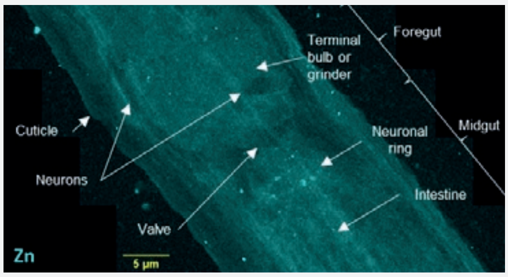

Figure 2: *High resolution X-ray fluoresence Zn map (60 nm step size, 0.1 s dwell time) of the gut region of a dehydrated, un-depurated C. elegans exposed to U NP.*

Radiocaesium transfer from reindeer meat to the blowfly *Calliphora vicina* and the parasitoid wasp *Nasonia vitripennis*

Highlight writer:
Jonas Andresen

Team members:
Jonas Andresen, Deborah H. Oughton, Tone Birkemoe, Anne Sverdrup-Thygeson (NMBU)

Objectives:
To investigate the fate of radiocaesium through a necrophagous insect food chain from carcass to blowflies and further from blowflies to parasitoid wasps.

Methods:
In controlled laboratory experiments, blowfly larvae (*C. vicina*) were reared on reindeer meat containing either low (600 Bq Kg^{-1}) or high (2000 Bq Kg^{-1}) ^{137}Cs activity concentrations to study transfer of ^{137}Cs from meat to blowflies, and from blowfly pupae to parasitoid wasps (*N. vitripennis*). Transferred ^{137}Cs was measured in the body of blowflies throughout development at five developmental stages, in emerged adult parasitoid wasps, and in empty pupal cases.

Results:
Radiocaesium was transferred to blowflies and their parasitoid wasps, but biodilution occurred from meat to blowfly and from blowfly pupae to parasitoid wasps. Third instar feeding stage larvae contained the highest ^{137}Cs concentration, ranging from 460 – 540 and 1490 - 1690 Bq Kg^{-1} for larvae reared on meat containing low and high ^{137}Cs concentrations, respectively. Modelling of the data indicated that the transfer was proportional to the ^{137}Cs concentration in the meat and most of the ^{137}Cs taken up by the larvae was excreted exponentially up until pupariation. Irrespective of ^{137}Cs concentrations in the meat, blowflies showed similar rates of radiocaesium excretion. During pupariation, ^{137}Cs was further excreted to the pupal case, resulting in assimilation of a minor proportion of the initial concentration in the meat in adult blowflies (7-10%). When parasitised by parasitoid wasps, more ^{137}Cs was bound in empty blowfly pupal cases from which adult parasitoid wasps had emerged.

Conclusion:
Radiocaesium transfer to blowfly larvae was high, suggesting that blowflies, and possibly other necrophagous insects, play significant roles in cycling and dispersion of radiocaesium retained in vertebrate carcasses. Additionally, the majority of ingested radiocaesium was excreted during larva development, indicating that radiocaesium is actively removed through excretory mechanisms.

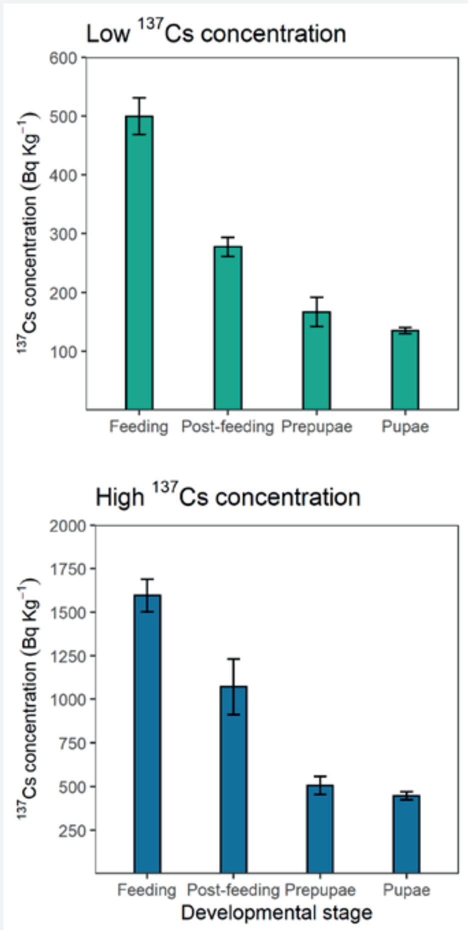

Figure 1: *^{137}Cs activity concentrations (Bq Kg^{-1} fresh weight) in C. vicina larvae and pupae developed on reindeer meat containing either low (600 Bq Kg^{-1}) (green bars) or high (2000 Bq Kg^{-1}) (blue bars) ^{137}Cs activity concentrations.*

Health status in Chornobyl Northern Pike (*Esox Lucius*) from a contaminated and reference lake

Highlight writer:
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Team members:
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O. Kashparova, V. Kashparov, S. Levchuk (UIAR)

Objectives:
To assess the health status in female and male Northern pike (*Esox Lucius*) in a contaminated (Glubokoye) and reference lake (Kashovka) in the Chornobyl Exclusion Zone (CEZ) during March of 2019.

Methods:
The doses to pike from the two lakes were estimated using the ERICA tool. The water quality (temperature, conductivity and ion composition) was measured in both lakes. The levels of trace metals, organic pollutants were determined to provide comprehensive exposure characterization. Biometric, biochemical and histopathological changes (blood, liver, spleen and skin) combined with untargeted metabolomics in fish livers were used to assess effects to fish health.

Results:
Mean values of physico-chemical parameters for water quality (temperature, conductivity, ion composition) did not differ significantly between the lakes. The activity concentrations of 137Cs and 90Sr were 3.3 and 0.118 and 0.023 and 96 Bq/L in the contaminated and reference lakes, respectively. The dose estimation by ERICA tool indicated that the main dose contribution was most likely from the contaminated sediments. Blood biochemistry showed elevated levels of aspartate aminotransferase (AST), creatine kinase (CK) and glucose (Glu) in fish from the Glubokoye lake compared to Kashovka. Histological analyses of whole blood in fish from the contaminated lake showed significantly higher levels of immature, abnormal and anisochromatic erythrocytes (indicating a reduction in haemoglobin and haematocrit), micronuclei, as well as a higher fraction (%) of thrombocytes compared to Kashovka. The histopathological analyses of the liver, spleen and skin are ongoing.

Significant differences in 23 metabolites were identified in metabolomic expression between the two lakes, whereby PUFA (linoleic acid and folate metabolites) and amino acids were among the metabolites showing lower levels in the contaminated lake compared to the reference lake.

Conclusion:
Abnormal blood erythrocytes and thrombocytes in fish from the contaminated lake could indicate a disturbance of the hematopoesis, whereas elevated blood biochemistry parameters could indicate changes in liver function. The metabolic analyses indicated changes in amino acids and folate metabolism. The concentration of metals and organic pollutants was significantly higher in the fish from the reference than in fish from the contaminated lake and it is therefore not expected to have contributed to the observed differences.

***Figure 1:** Sampling sites (red) for Northern pike in the CEZ in Ukraine: Glubokoye (contaminated) and Kashovka (reference) lake. Modified from Mapcreator.*

Gamma radiation induces locus specific changes to chromatin accessibility in zebrafish embryos

Highlight writer:
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Team members:
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Objectives:

Gamma radiation induces damage to nucleic acids and proteins. Chromatin, consisting of both DNA and DNA associated proteins, is the functional form of DNA, and a potential target for epigenetic effects. Here we investigate the potential of gamma radiation to induce changes to chromatin during embryogenesis.

Methods:

Zebrafish embryos were exposed to 1, 10 and 40 mGy/h gamma radiation (Co-60 from 2.5 to 5.5 hour post fertilization (hpf). At 5.5 hpf the endonuclease Tn5 accessible open chromatin was analyzed (ATAC-seq1).

Results:

ATAC-seq revealed a dose response relationship between enriched chromatin and radiation dose rate, wherein the amount of Tn5 accessible chromatin at the transcription start site (TSS) decreased with increasing radiation dose rate, suggesting a global inhibition of gene expression. In the gene body (GB), no global difference in accessible chromatin is observed. Although many genes were compacted at TSS, some genes also obtained a more open chromatin signature.

Conclusion:

The results show dose dependent TSS rearrangements of chromatin in ZF embryos after exposure to gamma radiation and give further insight into molecular stress-responses.

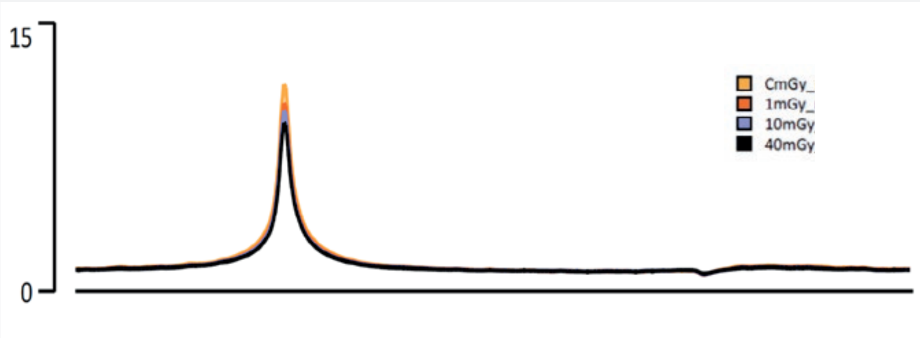

Figure: *Metagene analysis of ATAC-seq signals. The amount of open chromatin is averaged over promoter and a peak reveals at the point where the transcription start site (TSS) is expected.*

References:

• *Buenrostro et al. (2013) Transposition of native chromatin for fast and sensitive epigenomic profiling of open chromatin, DNA-binding proteins and nucleosome position. Nature methods, 10: 1213-18*

Highlight writer:
Erica Maremonti

Deposition of energy leads to population decline via impaired meiosis in *Caenorhabditis elegans*

Team members:

Erica Maremonti, Lisa Magdalena Rossbach, Deborah Oughton, Dag Anders Brede (NMBU)
Elizabeth Dufourcq-Sekatcheff, Sandrine Frelon, Rémi Guédon, Catherine Lecomte-Pradines (IRSN)

Background:

Despite the tolerance demonstrated under exposure to high acute doses (> 1 kGy) of ionizing radiation in the nematode *Caenorhabditis elegans*, adverse outcomes at the reproductive level have been observed under exposure of early stages of larval development to low-medium chronic doses (≥ 2.8 Gy). The Adverse Outcome Pathway (AOP) framework is an important tool that consolidates knowledge on biological mechanisms behind a specific adverse outcome (AO) resulting from exposure to a stressor. The AOP starts from the molecular initiating event (MIE), which defines the very first interaction of a stressor with a biological system, proceeding through causally linked measurable key events (KE), that eventually lead to an AO.

Objectives:

To develop an AOP related to reprotoxic effects of chronic exposure to ionizing radiation in the model organism *Caenorhabditis elegans*.

Methods:

Total brood size was measured after chronic gamma-irradiation during larval development. ROS levels, AODs activation and apoptosis in germ cells were measured in vivo by using specific fluorescent biosensors and reporter strains, and by RNA sequencing analysis. DNA damage was measured via COMET assay on embryonic cells from F1 parentally irradiated nematodes.

Results:

Following from the molecular initiating event (MIE) of energy deposition from ionization and excitation of atoms and molecules after chronic irradiation, the first key events were increased ROS levels (KE1) and AODs. However, these were not accompanied by any adverse effect on somatic cell viability or any visible phenotypical effect, indicating tolerance of somatic tissue compared to the observed adverse effects shown on the germ cells. Nevertheless, the observed redox imbalance suggested a significant contribution of indirect

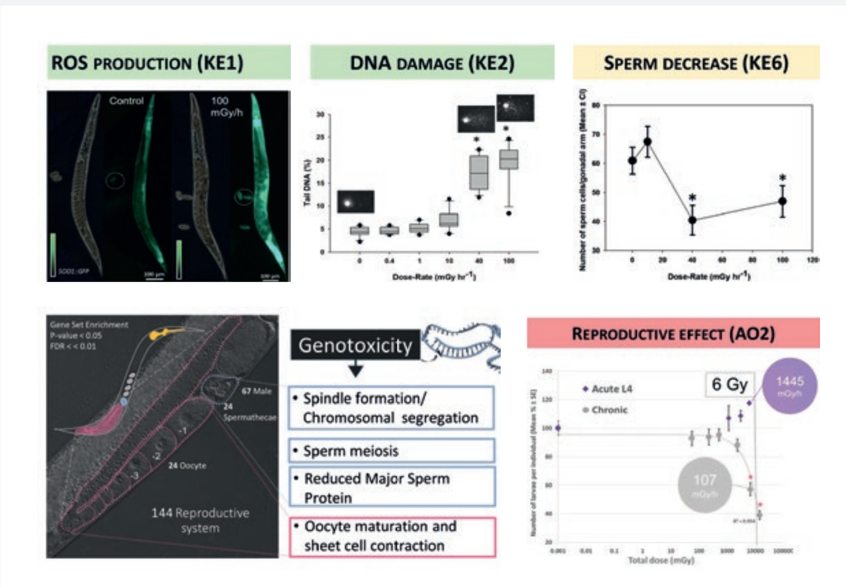

Figure: *Molecular Initiating Event, Key Events and Adverse Outcomes identified from cellular, molecular, and phenotypical endpoints assessed in nematodes chronically irradiated during sensitive stage of larval development.*

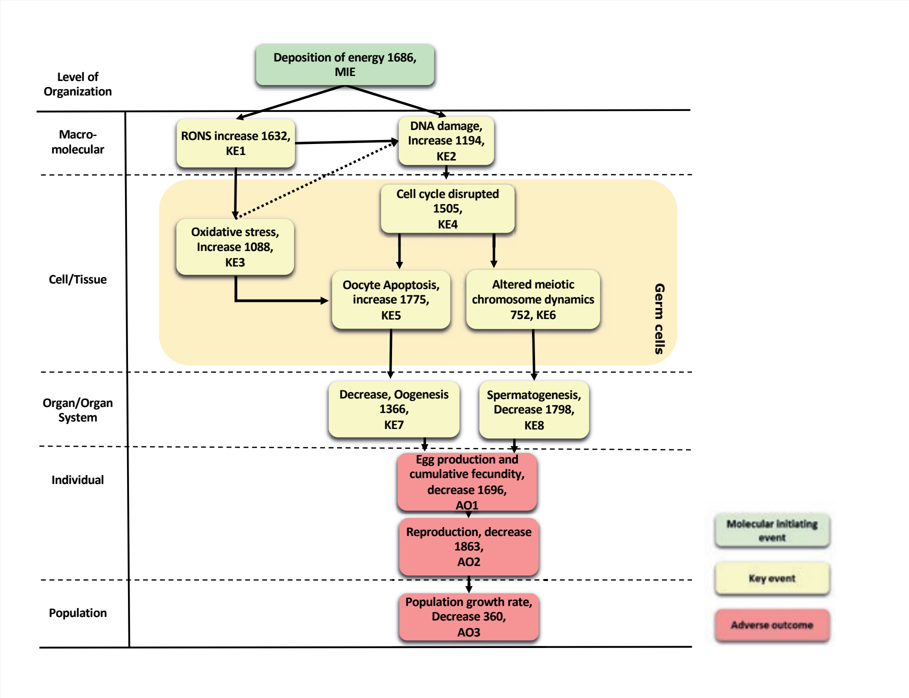

Figure 2: *Adverse Outcome Pathway diagram for ionizing radiation-induced reprotoxic effects in the nematode Caenorhabditis elegans.*

effects, including oxidative damage to DNA (KE2, KE3). Sperm reduction and dysregulation of genes related to sperm meiosis and maturation were identified as key events (KE6, KE8) causing reduced number of progeny (AO1). This related to the observation that L1-L4 larval stages were the most radiosensitive stages of development due to adverse effects on gamete production. Adverse effects of ionizing radiation on proliferative cells were also shown by enhanced germ cell apoptosis (KE5) in F0 nematodes and significant DNA damage in embryonic cells (F1) of irradiated nematodes (KE2), which was corroborated by the dysregulation of genes and proteins related to cell-cycle checkpoints, DNA replication and repair (KE4), embryonic and post-embryonic development.

Conclusion:

At the individual scale, impairment of spermatogenesis and oocyte production leads to a decrease in egg production and cumulative fecundity (AO1), and consequentially to reproduction decrease (AO2), which could cause a decrease in population growth rate (AO3) with obvious implications for environmental protection.

References:

• *Shakes, D. C., Wu, J. C., Sadler, P. L., Laprade, K., Moore, L. L., Noritake, A., & Chu, D. S. (2009). Spermatogenesis-specific features of the meiotic program in Caenorhabditis elegans. PLoS Genetics, 5(8), e1000611.*
• *Buisset-Goussen, A., Goussen, B., Della-Vedova, C., Galas, S., Adam-Guillermin, C., & Lecomte-Pradines, C. (2014). Effects of chronic gamma irradiation: a multigenerational study using Caenorhabditis elegans. Journal of Environmental Radioactivity, 137, 190-197.*
• *Engert, C. G., Droste, R., van Oudenaarden, A., & Horvitz, H. R. (2018). A Caenorhabditis elegans protein with a PRDM9-like SET domain localizes to chromatin-associated foci and promotes spermatocyte gene expression, sperm production and fertility. PLoS genetics, 14(4), e1007295.*
• *Maremonti, E., Eide, D. M., Rossbach, L. M., Lind, O. C., Salbu, B., & Brede, D. A. (2020). In vivo assessment of reactive oxygen species production and oxidative stress effects induced by chronic exposure to gamma radiation in Caenorhabditis elegans. Free Radical Biology and Medicine, 152, 583-596.*
• *Maremonti, E., Eide, D. M., Oughton, D. H., Salbu, B., Grammes, F., Kassaye, Y. A., Guédon, R., Lecomte-Pradines, C., & Brede, D. A. (2019). Gamma radiation induces life stage-dependent reprotoxicity in Caenorhabditis elegans via impairment of spermatogenesis. Science of the Total Environment, 133835.*
• *Maremonti E. Investigating sensitivity and tolerance to chronic gamma irradiation in the nematode Caenorhabditis elegans. PhD-thesis 2020:8, ISSN 1894-6402*
• *Dufourcq-Sekatcheff, E., Cuiné, S., Li-Beisson, Y., Quevarec, L., Richaud, M., Galas, S., & Frelon, S. (2021). Deciphering Differential Life Stage Radioinduced Reproductive Decline in Caenorhabditis elegans through Lipid Analysis. International journal of molecular sciences, 22(19), 10277.*
• *Guédon, R., Maremonti, E., Armant, O., Galas, S., Brede, D. A., & Lecomte-Pradines, C. (2021). A systems biology analysis of reproductive toxicity effects induced by multigenerational exposure to ionizing radiation in C. elegans. Ecotoxicology and Environmental Safety, 225, 112793.*

Radiosensitivity of Scots pine seedlings grown from seeds developed under different radiation levels in the Chornobyl area

Highlight writer:
Jorunn Olsen

Team members:
Y.K. Lee, P. Bhattacharjee, M.M. Rahman, O.C. Lind, B. Salbu, D.A. Brede, J.E. Olsen (NMBU)
V. Kashparov, P. Pavlenko, D. Holiaka (NUBiP)
I. Yakovlev (NIBIO)

Objectives:
To assess the radiosensitivity of Scots pine seedlings grown from seeds developed under elevated radiation levels in the Chornobyl area. The specific aim was to test whether the radiation during seed development can result in rapid adaptation or alternatively, increase the susceptibility of the progeny to radiation.

Methods:
Scots pine seeds developed under different levels of ionising radiation were collected in the Chornobyl area. The seed collection sites had average external dose rates in the air, one m above ground, of 12 and 3 µGy h^{-1} as well as background radiation levels. Young seedlings grown from seeds from the three sites were exposed to gamma radiation at 1-100 mGy h^{-1} for 144 h under controlled conditions, and the plants were subjected to different analyses including growth, DNA damage, antioxidant capacity and expression of specific cell division- and DNA repair-related genes.

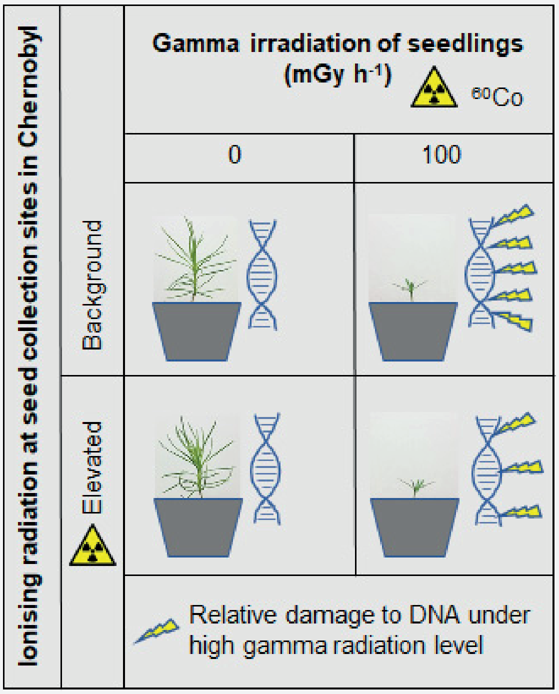

***Figure 1:** Principal effects of gamma irradiation on Scots pine seedlings from seeds from the Chornobyl area*

Results:
The DNA damage was generally significantly lower in the gamma radiation-exposed seedlings grown from seeds developed under elevated radiation levels in Chornobyl compared to those from seeds from background radiation. However, there was no significant difference in growth between the three seedling groups after the gamma-irradiation and growth-inhibition was observed in all seedling groups during the post-irradiation period after exposure to ≥ 20 mGy h^{-1}. Furthermore, there was no difference in total antioxidant capacity or transcript levels of the key cell-cycle control- and DNA-repair-related genes CYCB1, CDKB1, SOG1 and RAD5 between the seedling groups.

Conclusion:
The level of ionising radiation under seed development apparently affects the susceptibility to gamma radiation-induced DNA damage in the progeny, i.e., with less DNA damage in plants from seeds from the elevated ionising radiation levels in Chornobyl. However, since there were no differences in phenotype, total antioxidant activity or expression of specific key cell cycle- and DNA repair-related genes among the seedling groups, the consequences and background of the differences in DNA damage remain to be elucidated.

The MicroClimate Screen – A microscale climate exposure system for assessing the effect of CO_2, temperature and UV on marine microalgae

Highlight writer:
Li Xie

Team members:
L. Xie, A. Macken, M. Norli, O.A. Skogan, K.E. Tollefsen (NIVA)
B. Johnsen (DSA)

Objectives:

The main objective was to develop a microscale (laboratory-based) system to simulate exposures to increased CO_2, temperature and UV radiation (UVR) for high-throughput assessment of climate change and radiation effects on marine phytoplankton.

Methods:

The Microclimate Screen consists of a micro-climate unit and a light-exposure unit (Fig.1.A). The partial pressures of CO_2 (pCO_2), temperature, UV (UVA and UVB) and photosynthetically active radiation (PAR) can be precisely regulated in this system. Changes in physical factors, including pH, dissolved inorganic carbon (DIC), total alkalinity (TA), temperature and salinity in the medium were characterised after 72h exposure to demonstrated the performance of the system. Three independent growth tests with the diatom (*Skeletonema pseudocostatum*), using ISO10253:2016 (ISO, 2016), were conducted with different pCO_2, temperatures and UV radiation to validate the system.

Results:

Performance of the MicroClimate Screen system showed that pCO_2, water temperature and UVR were stable for at least 72 hours, with slight changes in salinity due to atmospheric water evaporation. (Fig.1.B). The validation study with P. *pseudocostatum* demonstrated that elevated CO_2 level and UVB radiation caused singficant effects on the growth, while no growth change was observed for increasing temperature (Fig.1.C).

Conclusion:

The results of the validation tests have demonstrated the stability of the system. The high-throughput exposure system can be addtionally used for studies of other relevant environmental stressors such as ionizing radiation and chemical stressors, alone and in combinations, to support multiple stressor studies with a larger array of phyto- and zooplankton.

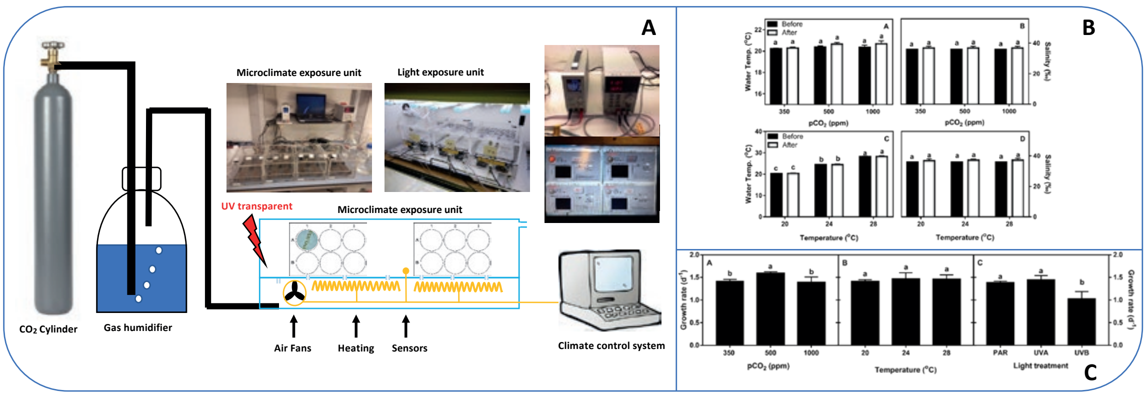

***Figure 1:** Schematic representation of the MicroClimate Screen units (A), Stability of water temperature and salinity under different levels of CO_2 and temperature (B), Growth rates of Skeletonema pseudocostatum after exposure to different level of CO_2, temperatures, light and UVR conditions (C).*

References:

• *ISO (2016),10253 Water quality —Marine algal growth inhibition test with Skeletonema sp. and Phaeodactylum tricornutum.*

Assembling a Toxicity Pathway for UVB Radiation-Induced Effects on the Marine Copepod *Tisbe battagliai*

Highlight writer:
Chloe Eastabrook

Team members:

C.L. Eastabrook, G.S. Caldwell (NEWCASTLE)
L. Xie, Y. Song, K.E. Tollefsen (NIVA)

Objectives:

To develop a robust ecotoxicology toolbox for *Tisbe battagliai*, encompassing genetic through to population level relevant endpoints. The toolbox was used to assemble a putative toxicity pathway for *T. battagliai* exposed to environmentally relevant doses of UVB radiation.

Methods:

Juveniles and gravid females were exposed to UVB spanning nominal irradiances of 0.008 - 0.8 Wm^{-2} for 12, 24 and 48h. Measured endpoints included a suite of stress and repair genes, DNA damage (cyclobutane pyrimidine dimer, CPD), cellular and mitochondrial reactive oxygen species (ROS) production, fecundity, hatching success, and survival.

Results:

Significantly upregulated genes included those coding for UV excision repair, DNA strand break repair, and apoptosis regulation. Cellular ROS production increased significantly after 24h, however mitochondrial ROS levels remained unchanged. CPD-DNA damage increased significantly after 12h at irradiances above 0.2 Wm^{-2}. Fecundity, hatching success, larval development, and female survival were compromised in an irradiance- and time-dependent manner, particularly following 48h of exposure. Adult survival was strongly related to the observed levels of oxidative stress and DNA damage (Fig 1A).

Conclusion:

The assembled putative toxicity pathway (Fig 1B) indicated that oxidative stress, in combination with CPD DNA damage, contributed to DNA strand breaks. In turn, this potentially induced an increase in apoptosis that resulted in compromised reproductive output, poor levels of larval fitness, and a reduction in the survival of gravid females. These responses to environmentally relevant UVB irradiances would indicate that significant impacts could be expected in *T. battagliai* after prolonged UVB exposures in shallow waters.

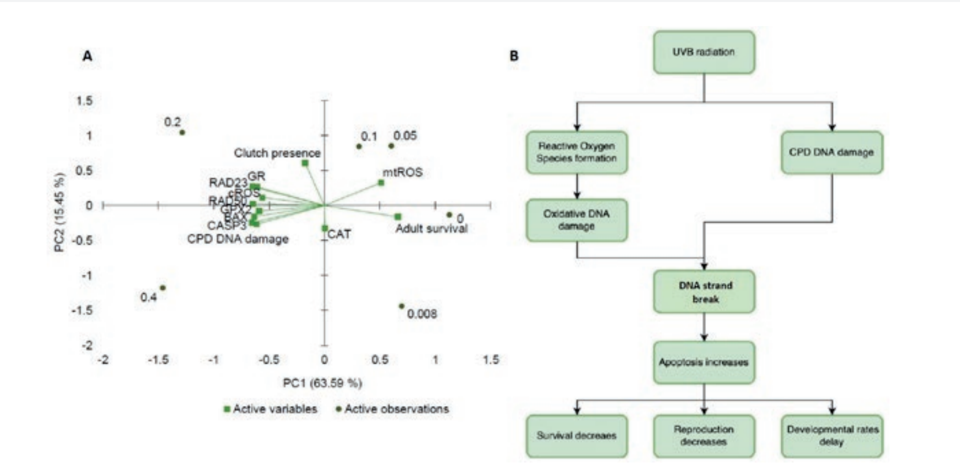

Figure 1: *(A) Principal component analysis of responses in T. battagliai following exposure to environmentally relevant UVB irradiances, ranging from 0.008 to 0.8 W m^{-2} for 24 h. (B) A putative toxicity pathway for short-term UVB radiation exposure in T. battagliai. The direction of the arrow indicates the trend in the measured endpoint.*

References:

• *Eastabrook CL. 2022. Applying an integrated ecotoxicological approach to assess stress from exposure to trace metals and UVB radiation. PhD thesis, Newcastle University, UK.*

3D-Modelling of Radionuclides in Water Bodies

Highlight writer:
Ashenafi Gragne

Team members:

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O. C. Lind (NMBU)

Objectives:

To develop the tools and competence needed to simulate the movement of contamination plumes in open waters such as lakes and reservoirs. In a hypothetical simulation scenario, polonium (8.3×10^{15} Bq ^{210}Po, $t_{1/2}$=138 d) was released into to a large volume lake (135 km^2, ~14 billion m^3, dmax=290 m) in Eastern Norway. 3-D modelling was used to estimate the time before Po was distributed sufficiently to enter the drinking water intake for a major Norwegian city.

Methods:

The open source Telemac-Mascaret framework was used, covering both the hydrodynamic TELEMAC-2D/3D and the water quality (WAQTEL) models. MICROPOL module of WAQTEL was connected to simulate advection and dispersion of Po, assumed to be completely dissolved in the water bodies. The module incorporated the following compartments: water, suspended particulate matter, and bottom material. The travel time of Po between the discharge and water intake points was estimated using both the 2D and the 3D models. The vertical dispersion was described best using a 3D model.

Results:

The model domain was discretized with triangular elements (46,961) of horizontal mesh size 6-100 m. Each column representing a triangular element in the 2D model was intersected by five horizontal planes in the 3D model (resulting in 187,844 triangular elements). Four open boundaries were defined. Stable initial conditions were reached by running a 2D steady-state simulation for 90 days. 2D simulation over 30 days revealed that the Po reaches the drinking water intake in 8 days and 15 hours, the concentration increases exponentially and the dose limit for human concern (1 mSv/year ~830 Bq) was exceeded at the water intake 16 days and 15 hours from the time of discharge.

Conclusion:

The competence required to 3D simulate the movement of contaminants in open water has been acquired. Future work will focus on extending simulation periods of the 3D model in order to get better insights into the arrival time and maximum concentrations of Po at the water intake along with the vertical dispersions at cross-sections of interest. Efforts will be undertaken to link the 2D/3D models to impact models that can readily characterise risk for human and environmental effects of Po.

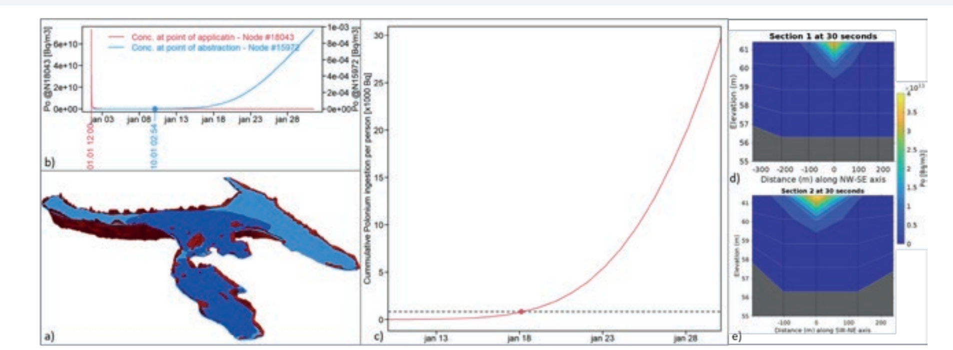

***Figure 1:** a) Spatial distribution at the time polonium reached the drinking water intake (abstraction) point (3D view); b) Time evolution of the radionuclide at the point of discharge and drinking water intake; c) Cumulative polonium ingestion (red solid line) and the public dose limit (833.3 Bq; doted black line); d&e) Vertical dispersion 30 seconds after discharge across sections 1 & 2 respectively.*

References:

• *EDF R&D, TELEMAC-2D User manual, Version 8.2, December 2020.*

Outdoor measurements of thoron progeny in a ^{232}Th-rich area with deposition-based alpha track detectors and corrections for wind bias

Highlight writer:
Hallvard Haanes

Team members:
Hallvard Haanes, Hilde Kristin Skjerdal, Anne Liv Rudjord (DSA)
Rosaline Mishra (Bhabha Atomic Research Centre, India)

Background:

In Fen igneous complex (Norway), Mining hill is a legacy site with naturally occurring radioactive material (NORM) in the uranium and especially the thorium decay series radionuclides. Abundant mine openings and waste rock involve high but variable outdoor levels of radon, thoron and progeny, which are important contributors to dose (Figure 1). However, due to the short half-life of thoron, measurements of thoron progeny with a longer half-life should be used for risk and dose assessment. Deposition-based alpha track detectors for such progeny are, however, biased by air movement like outdoors winds.

Methods:

Deposition detectors for thoron progeny and radon progeny, as well as alpha track gas detectors for ^{220}Rn and ^{222}Rn, were set up outdoors at the Fen complex in Norway. Airflow along deposition detectors was measured during deployment in different winds to assess wind bias and statistical models were used to attain location-specific sheltering factors.

Results:

Airflow along detectors was variable (0-2.7 m s^{-1}, SD: 0.19) but overall low (mean: 0.23, median: 0.19). Statistical models showed that point measurements with anemometer and levels of ^{220}Rn and ^{222}Rn explained variation in deposition detector measurements of TnP and RnP. For all the detector types, unrealistically, high equilibrium values (F) were found between progenitor noble gas and progeny before correcting for wind bias. Results suggest a magnitude of wind bias on TnP deposition detectors being a fraction of 0.74–0.96 (mean: 0.87) of the total measurement.

Conclusion:

The proportion of wind bias on deposition based detectors is significant but lower than corrected for in some previous studies. This knowledge should improve risk and dose assessment from thoron and thoron progeny in NORM affected areas.

Figure 1: *Fen mine entrance (photo: Hallvard Haanes)*

References:

• *Haanes, H., Skjerdal, H. K., Mishra, R., & Rudjord A. L. (2021). Journal of the European Radon Association, https://doi.org/10.35815/radon.v2.6130*

Highlight writer:
Dag Markus Eide

High dose rate and low dose rate gamma exposures elicit different genotoxic and transcriptomic responses – but not all the time

Team members:
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Brede, D.A. (NMBU); Graupner, A. (Bundesamt für Strahlenforschung)

Background:
Biological effects of radiation have mainly been attributed to total dose, and the dose rate has been given much less attention. In experimental settings we see that dose and dose rate often is confounded. The Dose-Dose Rate Efficiency Factor (DDREF) was invented to emphasize the importance of dose rate. Although some regulatory agencies maintain that the DDREF should be 1, researchers have reported DDREFs of 2 and more.

Methods:
Ninety-six mice from 2 inbred strains were exposed to 3 Gy at 4 different dose rates: 2.5, 10 and 100 mGy/h γ-radiation and 1.5 Gy/min X-ray. Blood was tested for genotoxicity (micronucleus, reticulocyte count, comet). Transcriptomics was carried out in liver cells, and body weights and organ weights were recorded – all at approx. 36 hrs after exposure stop. Hypothesis free weighted correlation network analysis (WGCNA) analyses was done using all data.

Results:
Genotoxicity analysis:

- Reticulocyte counts (RET) showed a threshold response: ≤ 10 mGy/h was identical to controls, while 100 mGy/h γ and X-ray revealed a collapse in RET counts.
- Micronuclei (MN) in reticulocytes showed a log linear dose-response for all dose rates, in contrast to RET numbers. Thus, MN can identify different **dose rates** in addition to its well-known sensitivity to radiation **dose**.
- Heart weights were significantly increased in the low dose rate groups (2.5 & 10 mGy/h). Spleen weights were reduced in the 100 mGy/h and X-ray groups
- Hypothesis free gene network analysis with WGCNA identified gene modules that correlated to mouse individual phenotype (body weights, genotoxicity data) or exposure dose rate. Four gene modules were especially interesting.
- Gene expression levels forming one module correlated positively to exposure groups, RET and MN and consists of about 50 genes. This gene set shows

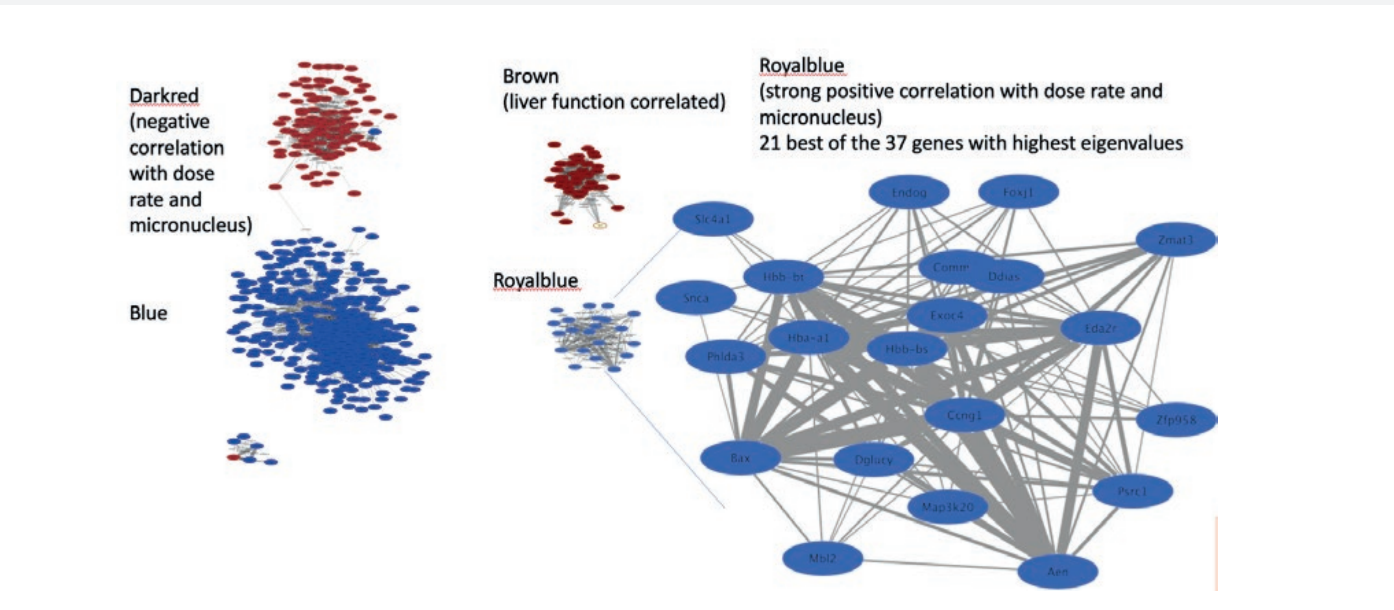


Figure 1: *Gene modules: Gene modules (clusters) of interest after WGCNA analysis of mice exposed to four dose rates of γ and X-rays*

gene set enrichment for hematopoiesis, cell reaction pathways to stress and radiation (apoptosis, P53 pathways).

- One module correlated strongly to typical liver functions. Another module showed a strong negative correlation with dose rate. A third cluster correlated to Arsenic-related traits, but without a good correlation with As-exposure.

Clustering of all 20 000 expressed genes showed a clear difference in gene expression patterns between the two inbred strains.

The gene network patterns are common to both mouse strains. Analysis of each strain separately would not give clear results, revealing the importance of sample size (from 48 to 96 mice in total, from 5 to 10 in each exposure group).

Conclusion:

Hypothesis free gene network analysis identified distinct, non-overlapping, clusters according to gene expression levels. A few of these are highly correlated to phenotypic traits as body organ weights and genotoxic responses.

Doubling the group sample size from 5 to 10 improves the specificity and sensitivity of the gene expression analysis substantially and makes sense for gene network analysis.

MN and RET numbers are excellent gene toxicity markers, capable of distinguishing dose rates after exposures. This is important when evaluating MN and reticulocyte counts for triage purposes.

Heart and spleen weight differences indicate that these organs may be sensitive to dose rate at (relatively high) doses of gamma.

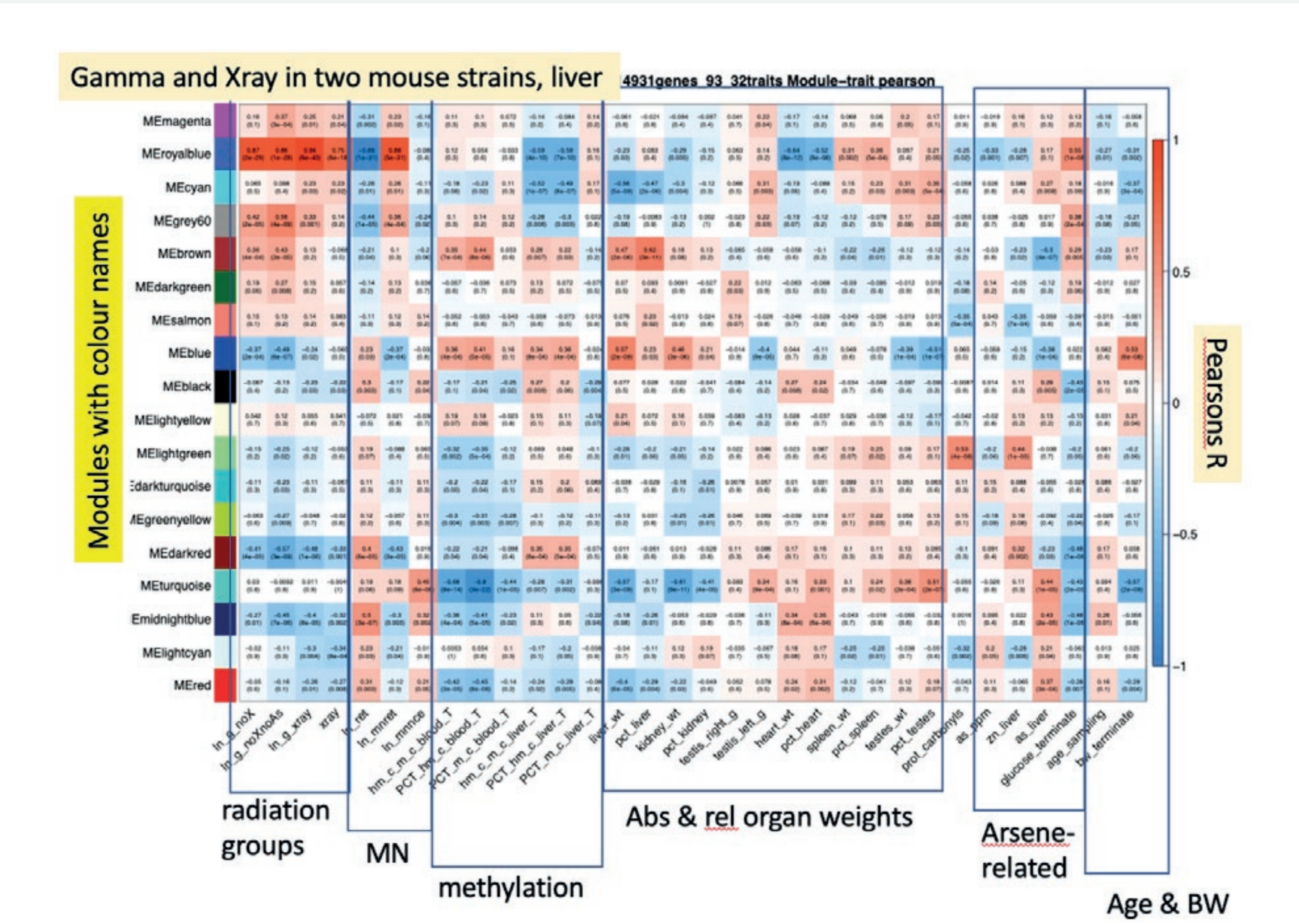


Figure 1: Heatmap of correlation coefficients for gene expression modules (horizontal) and phenotypic traits and exposure groups (vertical)

Highlight writer:
Hildegunn Dahl

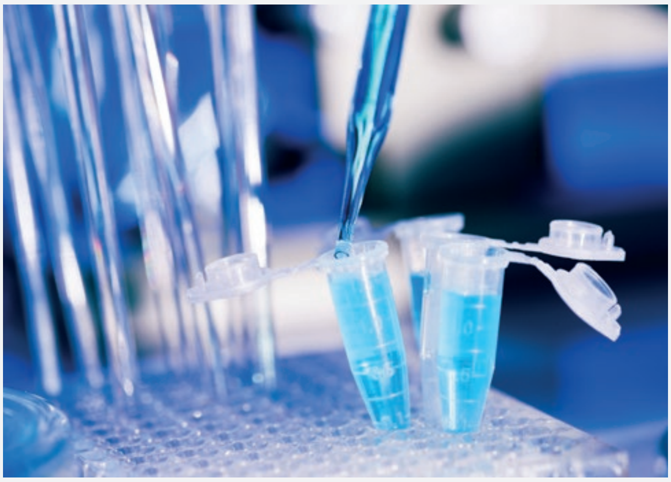
Dose-rate-dependent chromatin accessibility after exposure to gamma radiation

Team members:

H. Dahl, J. Ballangby, D.M. Eide, M.W. Wojewodzic, N. Duale, A.-K. Olsen, T. Tengs (NIPH)
A. Graupner (Bundesamt für Strahlenforschung)
D. Brede (NMBU)

Objectives:

To understand the influence of dose rate, chronic low and acute high dose rate, on genome-wide chromatin accessibility at two post-radiation timepoints.



Methods:

CBA/CaOlaHsd were exposed to chronic low (LDR 2.5 mGy, 1200h), medium (MDR 10 mGy/h, 300h) and acute high (HDR 100 mGy/h, 30h) dose rates of gamma radiation (^{60}Co, Figaro-facility). All groups received a total dose of 3 Gy, and were sacrificed one day (LDR, MDR and HDR) and over 100 days post-irradiation (LDR and HDR). Genome-wide chromatin accessibility was analysed in liver tissue DNA using the "Omni--Assay for Transposase-Accessible Chromatin" with high-throughput sequencing (Omni-ATAC-Seq). The chromatin accessibility profiles were evaluated considering: i) statistically differentially changed accessible regions (DARs); ii) occurrence of DARs across genomic elements; and iii) functional involvement of genes associated with the DARs. The chromatin accessibility profiles were also associated with the previously published[1] mRNA transcriptomic response in the same samples.

Results:

Dose-rate-dependent modulation of chromatin accessibility was prominent one day after radiation, as well as after the extended (>100 days) period. One day after exposure, all dose rate groups showed statistically different DARs compared to controls. However, the response after acute HDR was more potent than after chronic LDR and MDR. In general, the DARs identified one day after radiation. showed increased accessibility compared to controls in intronic and intergenic regions.

After the extended post-radiation period, there was no evidence of chromatin alterations after chronic LDR, whereas acute HDR induced long-term changes in the chromatin. Acute HDR led to as many DARs as one day after radiation but allocated to other genomic regions. In contrast to one day after, these DARs showed reduced accessibility and were mainly restricted to promoter regions, specifically transcription start sites (TSS). Through enrichment analysis, these genes with changed accessibility in promoter regions were found to be relevant for DNA damage response and binding of transcription factors.

Conclusion:

These data contribute to the understanding of implications of dose rate, given chronically or acute, and how it can be related for manifestation of radiation-induced molecular response relevant for the progression of long-term adverse health effects.

References:

• *Dahl H, Eide DM, Tengs T, Duale N, Kamstra JH, et al. (2021) Perturbed transcriptional profiles after chronic low dose rate radiation in mice. PLOS ONE 16(8): e0256667. https://doi.org/10.1371/journal.pone.0256667*

Public perceptions and attitudes towards management of radioactive substances in food

Highlight writer:
Yevgeniya Tomkiv

Team members:

Yevgeniya Tomkiv, Deborah Oughton (NMBU)
Wataru Naito, Kyoko Ono (AIST, Japan)

Objectives:

Experience from both Chornobyl and Fukushima accidents showed that nuclear or radiological accidents can have long-term impacts on food production systems. Restrictions on food sales, monitoring and other management strategies on the affected territories are crucial to ensure continuing production. However, the public response to radioactive contamination of food can be complex, and lack of consumer trust can lead to avoidance of even non-contaminated food. This study aimed to explore the public perceptions towards management of radioactive substances in food in order to contribute to the development of successful communication strategies.

Methods:

An online survey of 1003 respondents from all areas of Norway was conducted in March 2020.

Results:

A major proportion of the respondents felt they knew about the legal limits (67%) and how they were set (30%), but a surprisingly large proportion of them agreed with incorrect statements about what the legal limit is: 62% considered it to be a boundary between danger and safety, 68% considered it to be a boundary between whether or not food can be eaten.

Only 5% of the respondents said they thought about radioactivity when buying food and 33% indicated they were concerned about not knowing enough about food safety related to radioactive contamination. 82% of the respondents replied that they would purchase food produced in Norway and the main reasons for such decision was trust in the legal limits set by the government (75%) and preference for buying food produced in Norway (54%) (Figure 1). Only 21% of respondents thought that there could be flexible limits for radioactivity in food in different regions and for different foods and 57% supported uniform legal limits throughout the country. Similarly, only 35% of respondents agreed with the statement that food limits could be higher for the foods that are eaten only occasionally.

Conclusion:

A high level of trust to the legal limits set by government and a wish to support local producers will impact on people's willingness to purchase locally produced food in an aftermath of the accident. However, a great deal of respondents had misconceptions about the legal limits and what they represent, and did not support regional or other differences in legal limits. Post-accidental communication about management of radioactive substances in food should be ready to address these aspects.

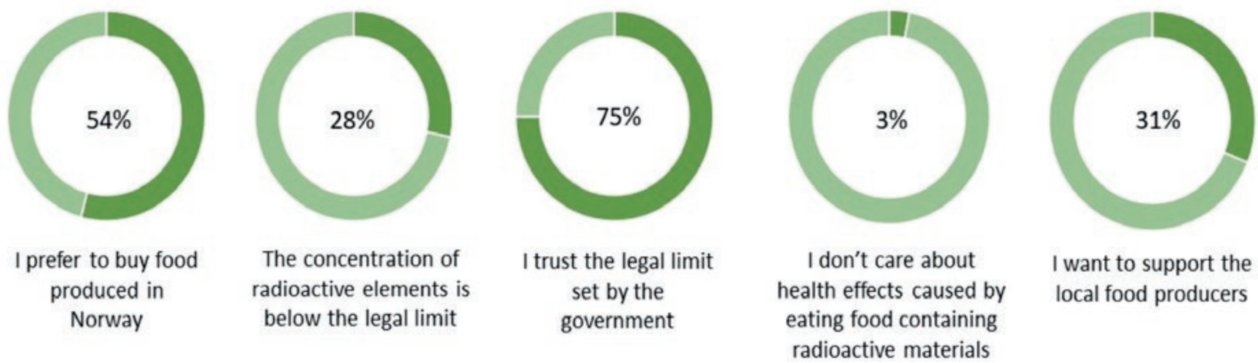


Figure 1: *Reasons for purchasing food produced in Norway if Norway was to be affected by a nuclear accident (n=819)*

International Collaboration

By Anne Liv Rudjord, Deputy Director

The year 2021 has, as 2020, 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 2021, 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. 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.

Furthermore, CERAD participated in 2021 in the collaborative European activities for arrangement of a radiation protection partnership PIANOFORTE 'Partnership for European research in radiation protection and detection of ionising radiation: towards a safer use and improved protection of the environment and human health.' This partnership was recently approved by European Commission in the HORIZON-EURATOM-2021 call NRT-01-09, will start 1 June 2022 and last five years. Together with 57 organisations from 24 different European countries, CERAD will actively contribute to partnership's research and integration activities in the coming years.

CERAD continues to be actively engaged in Arctic Council activities and contributes with 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).

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 AMS and Synchrotron facilities in Germany, France, Australia, Switzerland, Sweden and Spain as well as facilitating access to contaminated sites (e.g., Chornobyl, Fukushima). This enables and enriches CERAD's field and research activities and CERAD's publication list is a testimony to its broad international engagement.

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

With regard to UNSCEAR, in 2021 the committee published an Annex to its 2020 report *"Levels and effects of radiation exposure due to the accident at the Fukushima Daiichi Nuclear Power Station"*, that summarized new scientific and peer reviewed information, related to the levels and effects of exposure due to the Fukushima accident on March 11th 2011.

CERAD maintained its representation in IAEA activities related, revising technical safety guides, continuing work on the societal impacts of the Fukushima accident, and initiating collaboration on decommissioning and remediation of legacy sties (MAESTRI project).

Our experts work in ICRP task groups, an example being TG 99: Reference Animals and Plants Monographs, CERAD's Centre Director is a member of UNESCO's World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), and the All European Academies (ALLEA) Permanent Working Group on Ethics of Science and Technology s. 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.

CERAD has continued its support of international initiatives to develop Adverse Outcome Pathways (AOPs) through active involvement in the Radiation and Chemical (Rad/Chem) AOP joint topical group (JTG). The group was formed June 1, 2021 as part of the initiative from the High-Level Group on Low Dose Research (HLG-LDR), that is overseen by the OECD Nuclear Energy Agency (NEA) Committee on Radiation Protection and Public Health (CRPPH). The Rad/Chem AOP JTG vision is to facilitate collaboration and co-ordination between the chemical and radiation fields to promote the development of AOPs in radiation research and foster broader implementation of AOPs into hazard and risk assessment. The group, being a forum to discuss, identify and develop joint initiatives, has in 2021: 1) conducted a horizon scan-style survey to identify status and priority needs for AOP development, 2) organized a number of targeted workshops and meetings in collaboration with different scientific communities, 3) engaged journals to promote and publish AOP-relevant scientific papers, 4) executed a number of studies to demonstrate AOP development for radiation-relevant effects in wildlife and humans, and 5) initiated reviews and position papers to describe the state of science, methodological achievements or strategies to advance the use or implementation of AOPs in radiation research. The group, co-ordinated by Knut Erik Tollefsen (NIVA/NMBU, Norway), Vinita Chauhan (Health Canada, Canada) and Danielle Beaton (Canadian Nuclear Laboratories, Canada), has a 3 year mandate to continue supporting the work.

CERAD's close and fruitful collaboration with the IUR within radioecology continued through 2021. The International Conference on Radioecology & Environmental Radioactivity (ICRER) online event was organized 29 June-1 July 2021 with around 450 registered participants. CERAD is a co-organiser of ICRER and the online event provided a preview of some of the key topical issues that will be explored in more detail at the physical conference in Oslo in September 2022.

CERAD's research director was Principle Investigator for an application for a new experimental station (CheMic) at the MAX IV synchrotron facility in Lund, Sweden. He also attended the annual meeting of the U.S. Transuranium and Uranium Registries as invited guest.

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.
- A Jeol JEM2100 transmission electron microscope with a Lab6 filament and 200 kV accelerating voltage was commissioned at the NMBU Imaging Centre in 2021. It allows up to 1.2M times magnification, achieving atomic resolution (HR-TEM, high resolution TEM) and is equipped with an Oxford X-Max-80 SDD EDS detector for elemental mapping of material and tissue samples and Scanning Electron Transmission Microscopy (STEM) capabilities with detectors for bright field (BF), Dark field/High-angle annular darkfield (DF/HAADF) and back scatter (BEI) as well as quantitative Selected Area Electron Diffraction (SAED).
- For determinations at very low concentration levels, the Accelerator Mass Spectrometry (AMS) facilities at the Australian National University in Canberra, the Centro Acceleradores at the University of Seville in Spain as well as the new AMS at Czech Technical University 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, Diamond in the UK and MAX IV in Sweden (Fig. 1).
- 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

Figure 1: *Aerial view of the MAX IV synchrotron facility, Lund, Sweden (https://www.maxiv.lu.se/). Photo: Perry Nordeng, courtesy of MAX IV.*

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 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 plagued 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.

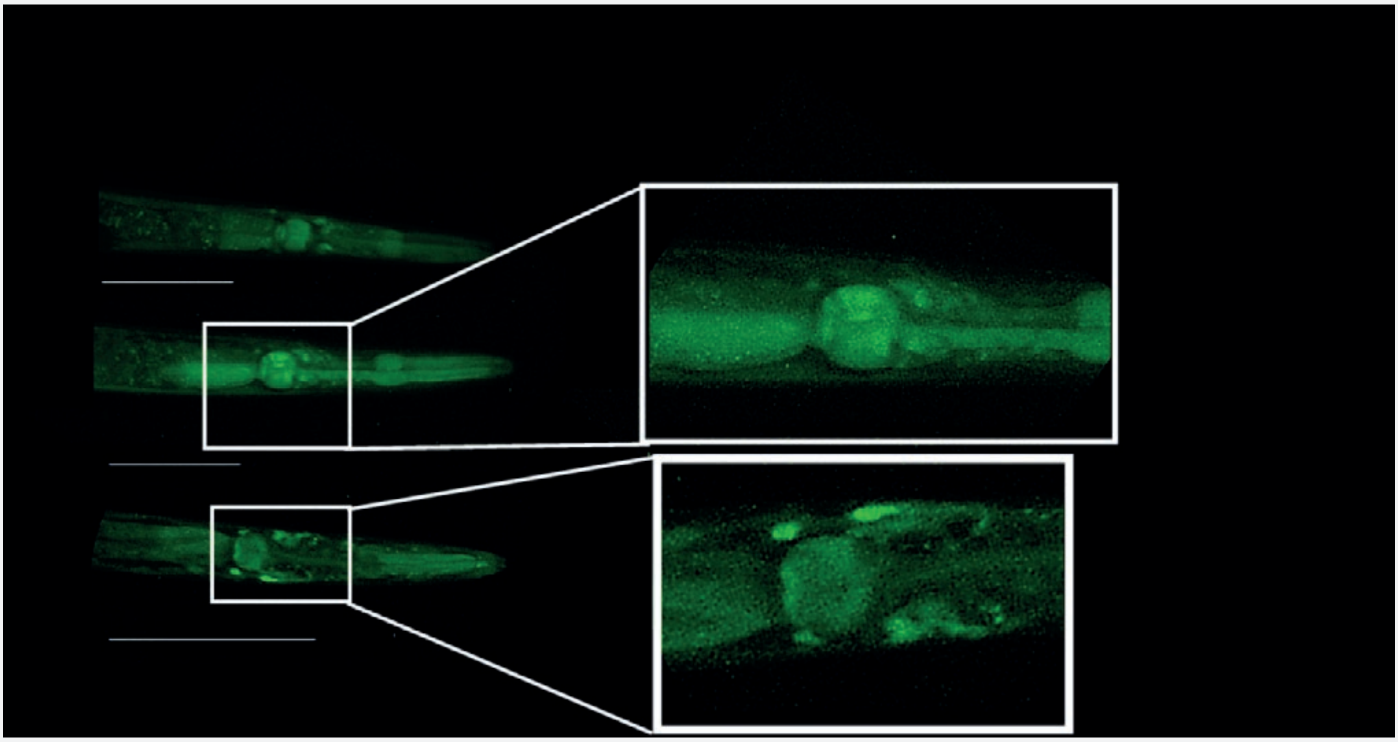


Figure 2: *Sod-1 expression in the pharynx of a control nematode (top), CeO_2 NP exposed nematode (middle), and $Ce(NO_3)_3$ exposed nematode (bottom) exposed nematode, showing an increased sod-1 gene expression in the pharynx, particularly associated with the terminal bulb and the foregut. All scale bars represent 100 µm (Rossbach et al., 2022).*

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 Zebrafish and C. *elegans, including* ratiometric biosensors and fluorescent reporter strains (Fig. 2).

Models

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

- Dispersion and Transfer Models: Advanced models of 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 ROMS/TRACMASS and ROMS/OpenDrift models 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

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. They provide important input to all CERAD research areas (RA), as investigations carried out relate to the speciation of radionuclides (RA1), mobility and transfer in the environment and bioavailability towards aquatic and terrestrial organisms (RA2) and also possible effects in the studied organisms from both radionuclides and other stressors (RA3). Thus, most results feed into the environmental risk assessment performed in RA4.

Field work campaign in the Chornobyl exclusion zone

The National University of Life and Environmental Sciences of Ukraine (NUBIP), NMBU and CERAD performed a joint field campaign in the Chornobyl exclusion zone (ChEZ), Ukraine, from the 26th to the 30th of October, 2021. A main goal of the field work was to initiate a fish telemetry study, which aims to determine the position and movement patterns of fish, and specifically how long fish spend near sediments relative to the time spent in the upper water column. Such data are needed to improve the estimates of the external dose contribution from sediments. During the field work, pike, Prussian carp and trench were caught and tagged: in total 12 fish from Lake Glubokoe and 11 fish from a small lake nearby. Acoustic receivers were placed in the lakes to record the vertical and horizontal movement of the fish. A second goal of

Figure 1: *Acoustic receivers indicated with red points in Lake Glubokoe.*

Figure 2: *Spring 2021 fieldwork at the Taraldrud NORM site (Photo: L. Skipperud)*

Figure 3: *Vefsna catchment field work. Sediment cores from Lomtjørna (left) and sampling from a boat on Nedre Flipingvatnet (right). (Photo: H-C. Teien)*

the fieldwork was to sample fish and the organisms that fish typically feed on in order to identify whether terrestrial insects constitute a source of ^{137}Cs to insectivorous fish.

Fieldwork concerning NORM sites

CERAD performed fieldwork at the Taraldrud legacy site, where acid forming alum shale was used for ground leveling work in the 1980s and 1990s. Sampling was carried out as part of a PhD project that aims to assess the possible environmental contamination from naturally occurring radionuclides in the Taraldrud area and their potential impact on local biota. The fieldwork included *in situ* fractionation of water, sampling of soil and sediment to study the mobilization and transfer of uranium and other naturally occurring radionuclides. To assess the accumulation in biota, plant samples were collected along with aquatic invertebrates.

Fieldwork concerning catchment-river transport models

CERAD, NMBU and DSA performed a fieldwork between 22nd and 27th of August 2021 in the Vefsna catchment, lakes and river Vefsna to obtain data needed to improve the development of atmospheric deposition model for ^{137}Cs and transport models covering both catchment and river transport processes. *In situ* gamma measurements were performed and soil samples collected in order to determine deposition densities that will serve as an input to catchment transport models and for validation of atmospheric modelling of fallout from the Chornobyl accident. Furthermore soil, vegetation, sediments, as well as size fractionated lake water, river water from 4 lakes were collected from the upper part of the Vefsna catchment.

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 in CERAD is to provide this future workforce. We consider networking during education crucial for future employment opportunities and encourage that students interact with research projects, potential employers and the wider radioecology community.

MSc in Radioecology

As part of our MSc program, students can specialize in the field of Radioecology in a two-year, Bologna- accredited MSc programme (120 ECTS). Apart from CERAD staff, experts from other European as well as North American institutions teach on our courses. Typical courses are Radiochemistry, Radioecology, Ecotoxicology and Assessing Risk to Humans and the Environment (see table below). All courses are taught in English. In the second year, MSc students work on research questions associated with CERAD projects.

PhD course on Environmental Radiobiology

The PhD course on 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 knowledge about the biological effects of radiation on humans, including updates on epidemiological studies. Areas covered include fundamental radiobiology, biological responses to ionising radiation, the use of biomarkers and toxicogenomics, factors linked to radiation sensitivity, non-targeted effects (bystander, genomic instability, adaptive response, etc.) and multiple stressors.

PhD and PostDoc students in CERAD

So far, 19 PhD students connected to CERAD have completed their PhD education, and of these, 2 defended their work in 2021:

- Li Xie: "Single and combined toxicity of gamma and ultraviolet B radiation in the aquatic macrophyte *Lemna minor*". PhD defence 16.04.2021.
- Ian Thomas Behnke Byrnes: "Characterization of Radioactive Particle Exposure Using Micro and Nano-Focused X-ray Techniques". PhD defence 15.12.2021.

CERAD also offers PostDoc positions and so far, 13 PostDocs have been or are still part of CERAD.

The year 2021 was another year where COVID-19 gave challenges to the progress of both PhD and PostDoc students. Restrictions meant limited access to lab facilities and some students experienced delays in their workplan. But all made some progress, and we expect that these delays will be overturned in the next year.

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 Humans and the 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
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

Li Xie

On February 16th 2021 Li Xie defended his PhD thesis “Single and combined toxicity of gamma and ultraviolet B radiation in the aquatic macrophyte *Lemna minor*” and gave the trial lecture “Eustress and Distress In Plants”. His main supervisor was Professor Knut Erik Tollefsen (NMBU/NIVA) and he was co-supervised by Professor Knut Asbjørn Solhaug (NMBU), Dr. Hans-Christian Teien (NMBU) and Dr. You Song (NIVA). The evaluation committee, consisting of first opponent Professor Ann Cuypers (Hasselt University, Diepenbeek, Belgium) and second opponent Professor Éva Hideg (University of Pécs, Pécs, Hungary), coordinated by Professor Thomas Rohrlack (NMBU) approved the thesis and recommended that Li Xie be awarded the degree Philosophia Doctor (PhD). Li is continuing his studies as a Post doc at NIVA.

Ian Byrnes

On December 15th 2021 Ian Thomas Behnke Byrnes defended his PhD thesis “Characterization of Radioactive Particle Exposure Using Micro and Nano-Focused X-ray Techniques” and gave the trial lecture “Micro and nanoscale imaging techniques of essential and non-essential element biodistribution: state-of-the-art, advantages and disadvantages”. His main supervisor was Professor Ole Christian Lind (NMBU) and he was co-supervised by Professor Dag Anders Brede (NMBU), Professor Deborah H. Oughton (NMBU), Professor Brit Salbu (NMBU) and Professor Koen Janssens (University of Antwerp). The evaluation committee, consisting of first opponent Dr. Rodolphe Gilbin (Institute for Radiological Protection and Nuclear Safety (IRSN), France) and second opponent Professor Gareth Law (University of Helsinki, Finland), coordinated by Professor Lindis Skipperud (NMBU) approved the thesis and recommended that Ian Byrnes be awarded the degree Philosophia Doctor (PhD). Ian is continuing his studies as a CERAD Post doc.

Funding and Expenditures

By Hans Christoffer Tyldum,
Management Director

The turnover for CERAD in the ninth operational year was MNOK 46.

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 13.5 in 2021. 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 all the partner institutions are estimated to about MNOK 25.

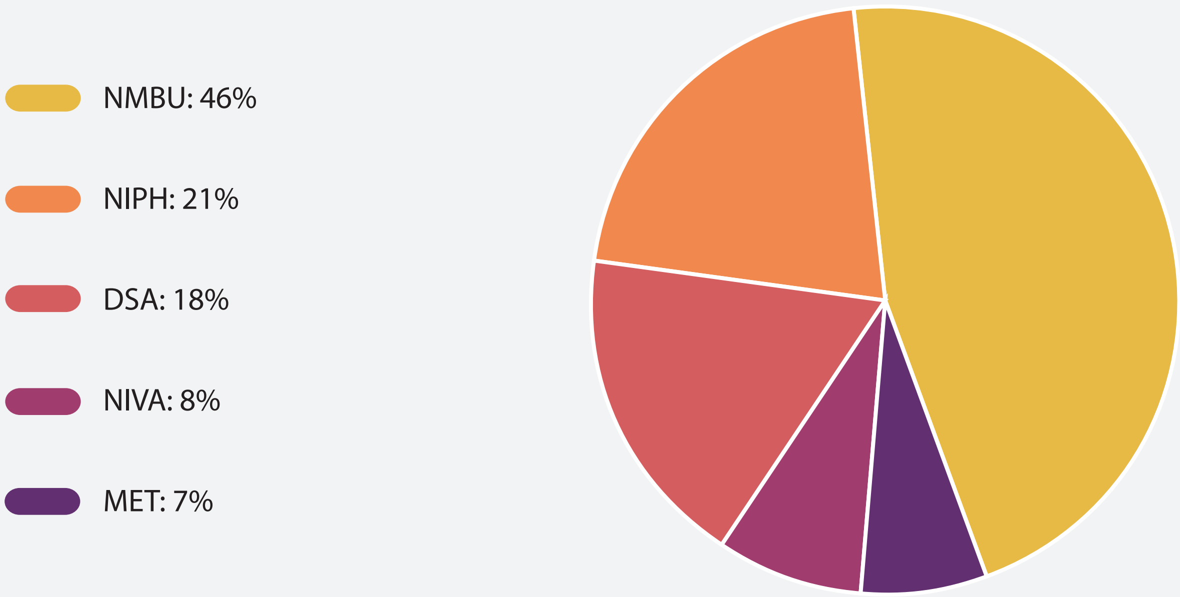
In addition, ongoing RCN and EU funded projects at NMBU and the partners attached to CERAD comes to approximately MNOK 2.3.

The expenditure is primarily connected to salaries, amounting to MNOK 38, which includes overheads covering indirect costs.

Other running expenses amounted to MNOK 8.

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

Partners' contribution to CERAD's total turnover in 2021 (based on estimates)



Annual Conference

The annual CERAD conference was organised on Zoom May 10-11th, 2021.

The conference gathered 66 participants: researchers from all partner institutions, members of scientific advisory committee, relevance advisory committee and CERAD board, and a number of invited speakers and guests. The participants presented research highlights of the past year, discussed emerging challenges and new projects.

Several guest lecturers were invited this year to discuss controversies over the effects of the ionising radiation and what it means for the research in this field and challenges that emerge with the new research directions at CERAD like decommissioning and development of Adverse Outcome Pathways frameworks.

First day of the conference was dedicated to the research highlights from RA1, RA2 and RA4 and on second day of the conference, results from the RA3 were presented. Two sessions were dedicated to the Young Scientists - 9 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.

A good tradition of joint dinner and a concert by HYBRIS, the CERAD House-band was broken in 2021 due to the pandemic restrictions. Instead, a digital social event with speeches, quiz, videos and awards was organised in the virtual space.

Photo: Participants of the session "Emerging challenges and new projects" (By Yevgeniya Tomkiv)

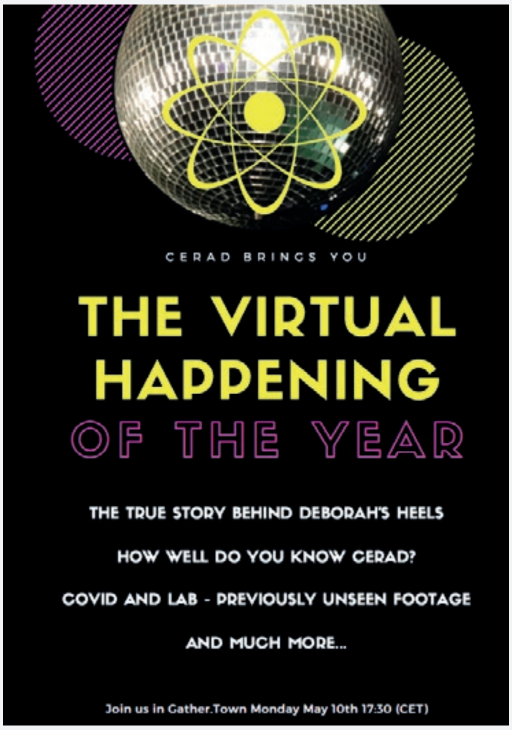


Photo: Teaser for the CERAD digital social event

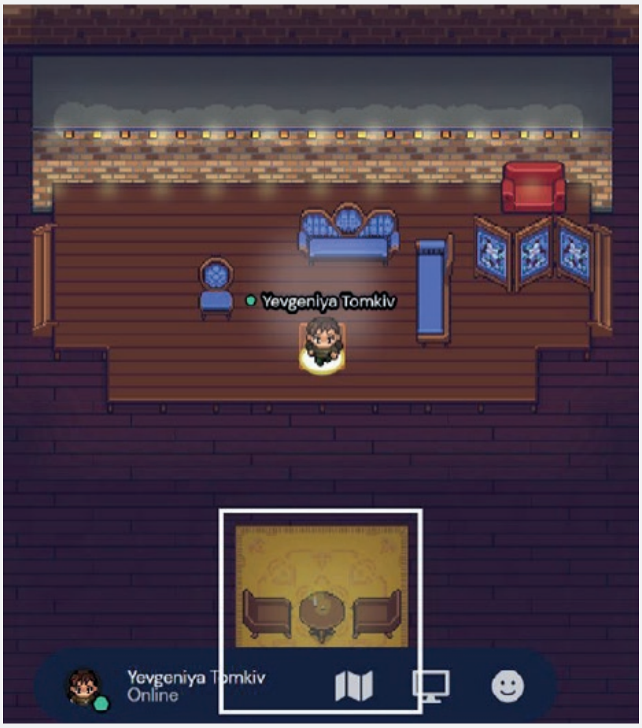


Photo: CERAD's Digital socialising space in Gather Town

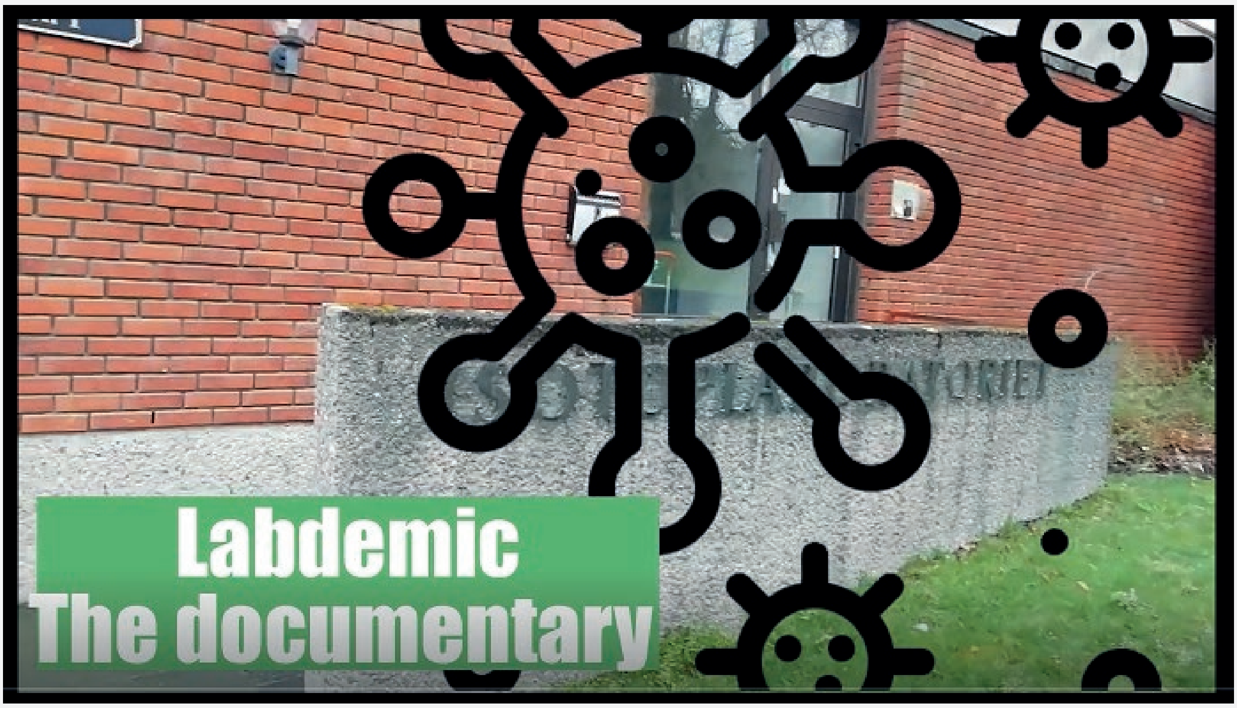


Photo: CERAD mocumentary on working in the lab during the COVID pandemic


Societal Impact

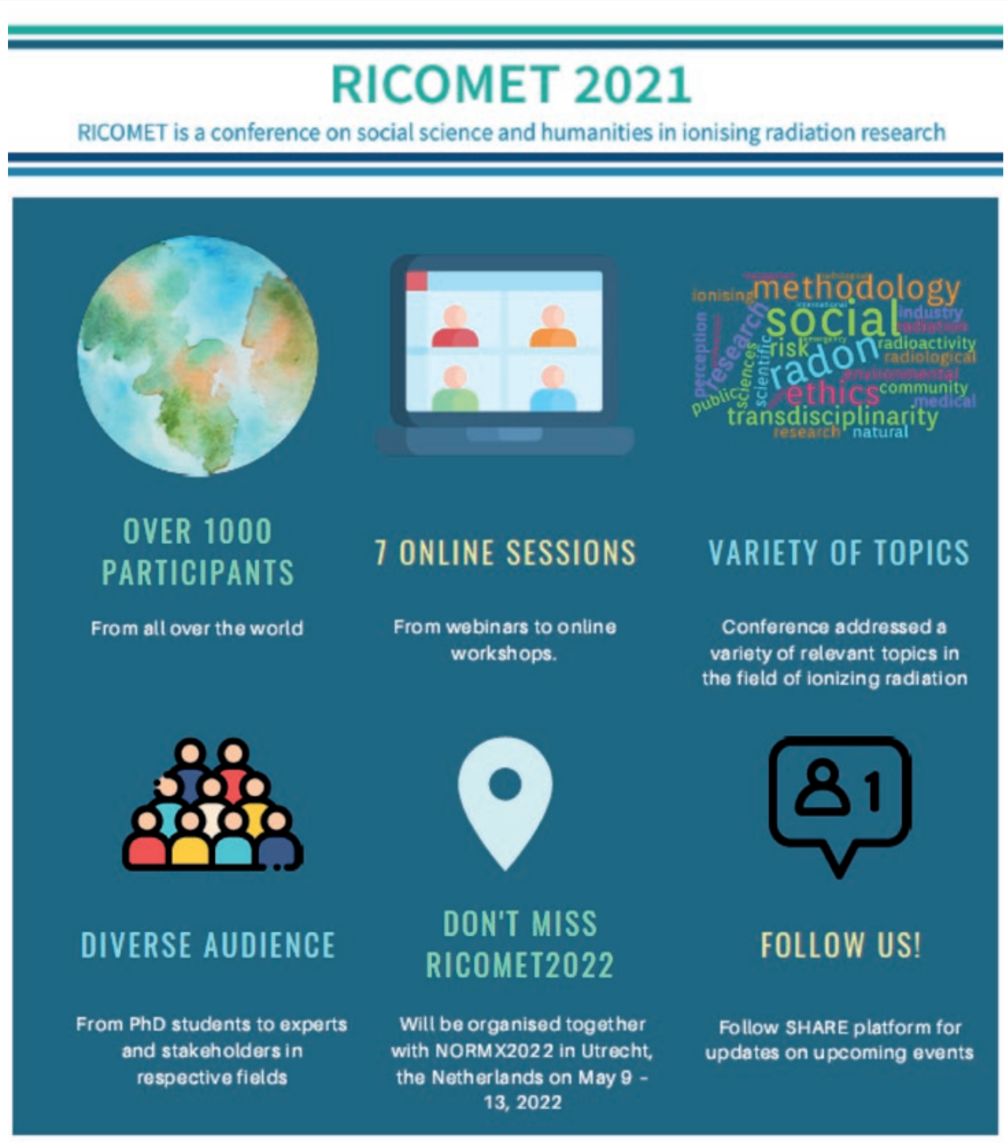
By Deborah H. Oughton, Centre Director and Yevgeniya Tomkiv, UMB4c leader

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 Chornobyl 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 for the psychosocial aspects of nuclear emergencies. In collaboration with the iClear project, CERAD has also participated in the discussions on rezoning of the Chornobyl 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 Chornobyl 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 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. Due to our expertise and experience in risk communication and stakeholder involvement, CERAD researchers have been heavily involved in the development of the handbook "Food safety following a radiation emergency: Handbook for health risk communication" for the World Health Organisation.

We are still assessing the ecological impacts of the Fukushima and Chornobyl 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



A summary of the RICOMET conference which was held online 8-10 September 2021

economic and societal consequences, through assessment of impacts on ecosystem services. In the framework of the RadoNorm project, CERAD has established a collaboration with the local community in the Gjøvik municipality and is planning a citizen science initiative there. Together with citizens, the aim is to identify the main barriers to radon remediation, and to create a project where we can tackle these barriers as a joint collaboration between citizens, local actors and researchers.

CERAD members participate in most of the European Atomic Energy Community (EURATOM) Horizon 2020 programme boards, and have been instrumental in formulating topics and text for the EU EURATOM calls, including the new PIANOFORTE EU project. CERAD was a co-founder of the platform for Social Sciences and Humanities in Ionising Radiation Research, SHARE, and Yevgeniya Tomkiv has been a member of the SHARE Bureau since 2020. CERAD was involved in organisation of the 2020-2022 RICOMET (Risk Communication and Ethics) conference series that focuses on societal aspects in various fields related to radiation. New EURATOM calls published in 2021 include communication and perception of risks and societal aspects of radiological protection. CERAD's multidisciplinary approach to research is fully in line with this focus.

Publication List

Anderson, D., Beresford, N. A., Ishiniwa, H., Onuma, M., Nanba, K., & Hinton, T. G. (2021). Radiocesium concentration ratios and radiation dose to wild rodents in Fukushima Prefecture. *Journal of Environmental Radioactivity, 226*.

Berge, E., Andronopoulos, S., Klein, H., Lind, O. C., Salbu, B., Syed, N., & Ulimoen, M. (2021). Uncertainties in short term prediction of atmospheric dispersion of radionuclides. A case study of a hypothetical accident in a nuclear floating power plant off the West coast of Norway. *Journal of Environmental Radioactivity, 233*, 106587.

Christensen, T., Johnsen, B. J., & Bruzell, E. M. (2021). Violet-blue light exposure of the skin: is there need for protection? *Photochemical & Photobiological Sciences, 20*(5), 615-625.

Clero, E., Ostroumova, E., Demoury, C., Grosche, B., Kesminiene, A., Liutsko, L., . . . Cardis, E. (2021). Lessons learned from Chornobyl and Fukushima on thyroid cancer screening and recommendations in case of a future nuclear accident. *Environment International, 146*.

Cunningham, K., Hinton, T. G., Luxton, J. J., Bordman, A., Okuda, K., Taylor, L. E., . . . Bailey, S. M. (2021). Evaluation of DNA damage and stress in wildlife chronically exposed to low-dose, low-dose rate radiation from the Fukushima Dai-ichi Nuclear Power Plant accident. *Environment International, 155*.

Dahl, H., Eide, D. M., Tengs, T., Duale, N., Kamstra, J. H., Oughton, D. H., & Olsen, A.-K. (2021). Perturbed transcriptional profiles after chronic low dose rate radiation in mice. *PloS One, 16*(8).

Gerke, H. C., Hinton, T. G., & Beasley, J. C. (2021). Movement Behavior and Habitat Selection of Rat Snakes (Elaphe spp.) in the Fukushima Exclusion Zone. *Ichthyology and Herpetology, 109*(2), 545-556.

Guedon, R., Maremonti, E., Armant, O., Galas, S., Brede, D. A., & Lecomte-Pradines, C. (2021). A systems biology analysis of reproductive toxicity effects induced by multigenerational exposure to ionizing radiation in C. elegans. *Ecotoxicology and Environmental Safety, 225*.

Hildrestrand, G. A., Rolseth, V., Kunath, N., Suganthan, R., Jensen, V., Bugaj, A. M., . . . Bjoras, M. (2021). NEIL1 and NEIL2 DNA glycosylases modulate anxiety and learning in a cooperative manner in mice. *Communications Biology, 4*(1).

Holmerin, I., Kiel Jensen, L., Hevroy, T., & Bradshaw, C. (2021). Trophic Transfer of Radioactive Micronutrients in a Shallow Benthic Food Web. *Environmental Toxicology and Chemistry, 40*(6), 1694-1705.

Hosseini, A., Brown, J. E., Avila, R., Beresford, N. A., & Oughton, D. (2021). Redesigning the FDMT Food Chain Transfer Model: Now Probabilistically Enabled and Fully Flexible. *Environmental Modeling & Assessment*.

Haanes, H., & Gjelsvik, R. (2021). Reduced soil fauna decomposition in a high background radiation area. *PloS One, 16*(3), e0247793.

Haanes, H., Skjerdal, H. K., Mishra, R., & Rudjord, A. L. (2021). Outdoor measurements of thoron progeny in a 232Th-rich area with deposition-based alpha track detectors and corrections for wind bias. *Journal of the European Radon Association, 2*.

Johansen, M. P., Anderson, D., Child, D., Hotchkis, M. A. C., Tsukada, H., Okuda, K., & Hinton, T. G. (2021). Differentiating Fukushima and Nagasaki plutonium from global fallout using Pu-241/Pu-239 atom ratios: Pu vs. Cs uptake and dose to biota. *Science of the Total Environment, 754*.

Klein, H., Bartnicki, J., Brown, J. E., Hosseini, A., Lind, O. C., Ytre-Eide, M. A., & Salbu, B. (2021). Consequences for Norway from a hypothetical accident at the Sellafield reprocessing plant: Atmospheric transport of radionuclides. *Journal of Environmental Radioactivity, 237*, 106703.

Kosmopoulos, P. G., Kazadzis, S., Schmalwieser, A. W., Raptis, P. I., Papachristopoulou, K., Fountoulakis, I., . . . Kontoes, C. (2021). Real-time UV index retrieval in Europe using Earth observation-based techniques: system description and quality assessment. *Atmos. Meas. Tech., 14*(8), 5657-5699.

Liutsko, L., Oughton, D., Sarukhan, A., Cardis, E., & Consortium, S. (2021). The SHAMISEN Recommendations on preparedness and health surveillance of populations affected by a radiation accident. *Environment International, 146*.

Martell, M., Perko, T., Tomkiv, Y., Long, S., Dowdall, A., & Kenens, J. (2021). Evaluation of citizen science contributions to radon research. *Journal of Environmental Radioactivity, 237*.

Martin, L., Kamstra, J. H., Hurem, S., Lindeman, L. C., Brede, D. A., Aanes, H., . . . Alestrom, P. (2021). Altered non-coding RNA expression profile in F-1 progeny 1 year after parental irradiation is linked to adverse effects in zebrafish. *Scientific Reports, 11*(1).

Masresha, A. E., Skipperud, L., Rosseland, B. O., G M, Z., Meland, S., & Salbu, B. (2021). Bioaccumulation of trace elements in liver and kidney of fish species from three freshwater lakes in the Ethiopian Rift Valley. *Environmental monitoring and assessment, 193*(6), 329-329.

Muruzabal, D., Sanz-Serrano, J., Sauvaigo, S., Treillard, B., Olsen, A.-K., López de Cerain, A., . . . Azqueta, A. (2021). Validation of the in vitro comet assay for DNA cross-links and altered bases detection. *Archives of Toxicology, 95*(8), 2825-2838.

Oughton, D., Liutsko, L., Midorikawa, S., Pirard, P., Schneider, T., & Tomkiv, Y. (2021). An ethical dimension to accident management and health surveillance. *Environment International, 153*.

Park, J., Yoo, E.-J., Shin, K., Depuydt, S., Li, W., Appenroth, K.-J., . . . Han, T. (2022 2021). Interlaboratory Validation of Toxicity Testing Using the Duckweed Lemna minor Root-Regrowth Test. *Biology, 11*(1), 37.

Rossbach, L. M., Oughton, D. H., Maremonti, E., Eide, D. M., & Brede, D. A. (2021). Impact of multigenerational exposure to AgNO3 or NM300K Ag NPs on antioxidant defense and oxidative stress in Caenorhabditis elegans. *Ecotoxicology and Environmental Safety, 216*.

Scheibener, S., Song, Y., Tollefsen, K. E., Salbu, B., & Teien, H.-C. (2021). Uranium accumulation and toxicokinetics in the crustacean Daphnia magna provide perspective to toxicodynamic responses. *Aquatic Toxicology, 235*.

Schmid, S., Song, Y., & Tollefsen, K. E. (2021a). AOP Report: Inhibition of Chitin Synthase 1 Leading to Increased Mortality in Arthropods. *Environmental Toxicology and Chemistry, 40*(8), 2112-2120.

Schmid, S., Song, Y., & Tollefsen, K. E. (2021b). AOPReport: Inhibition of Chitin Synthase1Leading to Increased Mortality in Arthropods. *Environmental Toxicology and Chemistry, 40*(8), 2112-2120.

Schuster, M., Tewary, G., Bao, X., Subedi, P., Hauck, S. M., Olsen, A. K., . . . Rosemann, M.

(2021). In vitro cellular and proteome assays identify Wnt pathway and CDKN2A-regulated senescence affected in mesenchymal stem cells from mice after a chronic LD gamma irradiation in utero (vol 60, pg 397, 2021). *Radiation and Environmental Biophysics, 60*(4), 689-689.

Skuterud, L., & Thorring, H. (2021). Caesium-137 in mountain flora with emphasis on reindeer's diet - Spatial and temporal trends. *Journal of Environmental Radioactivity, 231*.

Sneve, M., & Strand, P. (2021). Building optimization into the process for decommissioning, remediation of legacy sites and facilities, and management of the wastes arising: results of an international workshop. *Journal of Radiological Protection, 41*(3), S200-S215.

Svendby, T. M., Johnsen, B., Kylling, A., Dahlback, A., Bernhard, G. H., Hansen, G. H., Petkov, B., Vitale, V. (2021). GUV long-term measurements of total ozone column and effective cloud transmittance at three Norwegian sites. Atmospheric Chemistry and Physics (Print), 21(10), 7881-7899.

Teien, H.-C., Kashparova, O., Salbu, B., Levchuk, S., Protsak, V., Eide, D. M., Jensen, K. A., Kashparov, V. (2021). Seasonal changes in uptake and depuration of Cs-137 and Sr-90 in silver Prussian carp (Carassius gibelio) and common rudd (Scardinius erythrophthalmus). *Science of the Total Environment, 786*.

Turcanu, C., Sala, R., Perko, T., Abelshausen, B., Oltra, C., Tomkiv, Y., Oughton, D. H., Liland, A., Zeleznik, N. (2021). How would citizens react to official advice in a nuclear emergency? Insights from research in three European countries. *Journal of Contingencies and Crisis Management, 29*(2), 143-169.

Ulimoen, M., Berge, E., Klein, H., Salbu, B., & Lind, O. C. (2022). Comparing model skills for deterministic versus ensemble dispersion modelling: The Fukushima Daiichi NPP accident as a case study. *Science of the Total Environment, 806*.

Vazquez-Ortega, A., Perdrial, N., Reinoso-Maset, E., Root, R. A., O'Day, P. A., & Chorover, J. (2021). Phosphate controls uranium release from acidic waste-weathered Hanford sediments. *Journal of Hazardous materials, 416*.

Weyde, K. V. F., Olsen, A.-K., Duale, N., Kamstra, J. H., Skogheim, T. S., Caspersen, I. H., Engel, S. M., Biele, G., Xia, Y., Meltzer, H. M., Aase, H., Villanger, G. D. (2021). Gestational blood levels of toxic metal and essential element mixtures and associations with global DNA methylation in pregnant women and their infants. *Science of the Total Environment, 787*.

Wolf, R., & Tollefsen, K. E. (2021). A Bayesian Approach to Incorporating Spatiotemporal Variation and Uncertainty Limits into Modeling of Predicted Environmental Concentrations from Chemical Monitoring Campaigns. *Environmental Science & Technology, 55*(3), 1699-1709.

CERAD in Media

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For 35 år siden eksploderte en av de fire reaktorene i Tsjernobyl atomkraftverk, som førte til at den nærliggende byen Pripjat ble fraflyttet. Vi har mye å lære av ulykken, men ved neste kjernefysiske ulykke vil også kunnskapen fra koronapandemien kunne bli nyttig, skriver kronikkforfatterne. (Foto: Shutterstock / NTB)

Vi har noe å lære av Tsjernobyl i håndteringen av koronapandemien

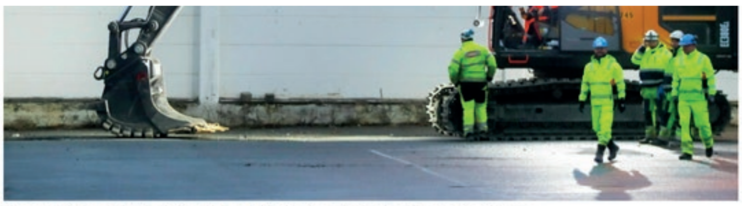
KRONIKK: Det som ble gjort i årene etter Tsjernobyl-ulykken har klare paralleller med dagens situasjon med covid-19.

Deborah Oughton
PROFESSOR OG DIREKTØR FOR SENTER FOR RADIOAKTIVITET, MENNESKER OG MILJØ (CERAD) VED NMBU OG MEDLEM AV UNESCOS VERDENSKOMMISJON FOR ETIKK I VITENSKAP OG TEKNOLOGI (COMEST)

Yevgeniya Tomkiv
POSTDOKTOR VED SENTER FOR RADIOAKTIVITET, MENNESKER OG MILJØ (CERAD) VED NMBU

https://forskersonen.no/covid19-helse-kjernefysikk/vi-har-noe-a-laere-av-tsjernobyl-i-handteringen-av-koronapandemien/1851258

vårt OSLO
Avisa for deg med ♥ for Oslo

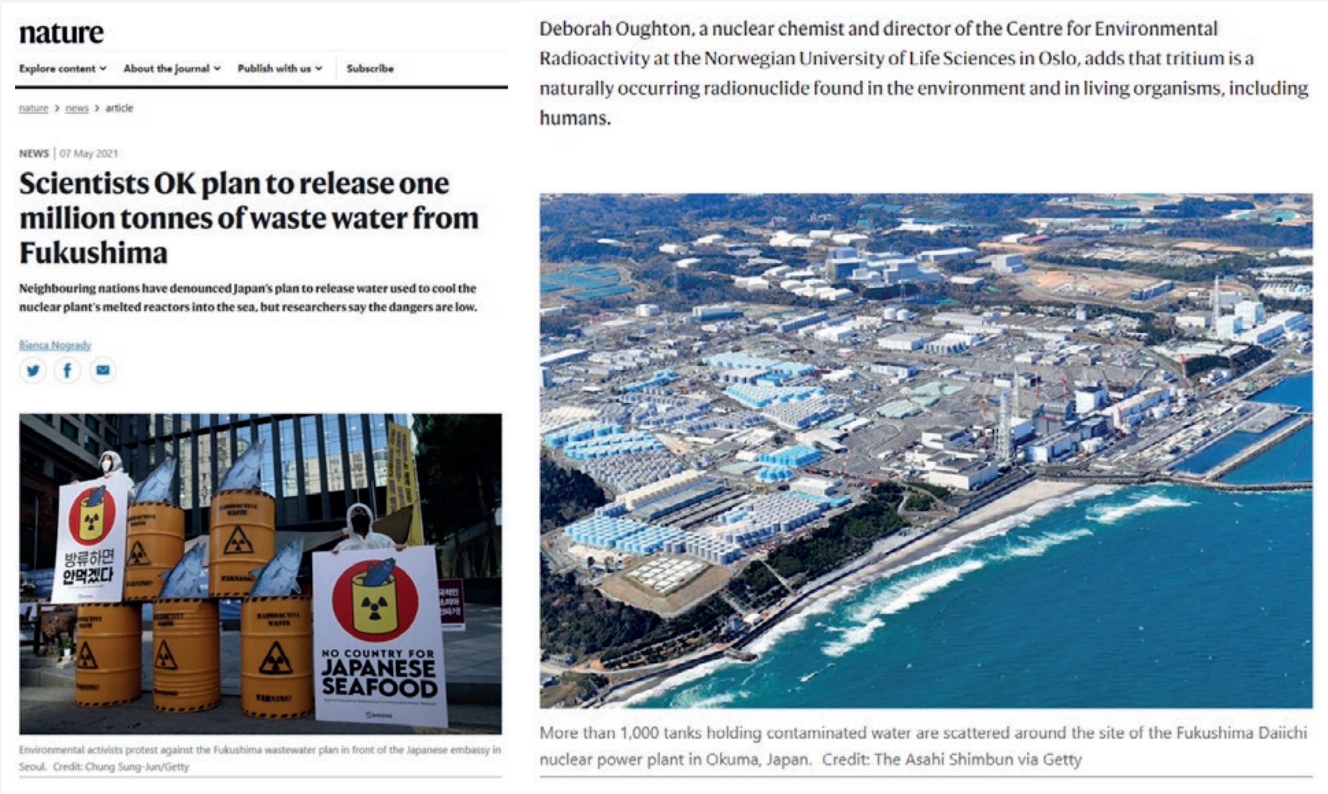


Fjerning av natrulig radioaktiv alunskifer er bakgrunnen for søknad om utslipp fra Fornebubanen. Terje Pedersen

Fornebubanen vil slippe ut radioaktivt spillvann i fjorden: - Lave mengder som ikke utgjør risiko for mennesker

Fornebubanen søker om å få slippe radioaktivt spillvann ut i Oslofjorden ved Skøyen og Lysaker. — Det er snakk om lave mengder og er tidsbegrenset. Det vil uansett aldri nå noen drikkevannskilde, sier NMBU-professor Lindis Skipperud.

https://vartoslo.no/bydel-vestre-aker-direktorat-for-stralevern-og-atomsikkerhet-dsa/fornebubanen-vil-slippe-ut-radioaktivt-spillvann-i-fjorden-lave-mengder-som-ikke-utgjor-risiko-for-mennesker/362525



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NEWS | 07 May 2021

Scientists OK plan to release one million tonnes of waste water from Fukushima

Neighbouring nations have denounced Japan's plan to release water used to cool the nuclear plant's melted reactors into the sea, but researchers say the dangers are low.

Bianca Nogrady

Environmental activists protest against the Fukushima wastewater plan in front of the Japanese embassy in Seoul. Credit: Chung Sung-Jun/Getty

Deborah Oughton, a nuclear chemist and director of the Centre for Environmental Radioactivity at the Norwegian University of Life Sciences in Oslo, adds that tritium is a naturally occurring radionuclide found in the environment and in living organisms, including humans.

More than 1,000 tanks holding contaminated water are scattered around the site of the Fukushima Daiichi nuclear power plant in Okuma, Japan. Credit: The Asahi Shimbun via Getty

https://www.nature.com/articles/d41586-021-01225-2?msclkid=344c55bfc7b011ecb-2068c078fd9d4e6

Communicating about radiation risks – a complex story

Radiation risks are a contested topic. Radiation can be found everywhere around us: in our bodies, in the ground, from outer space, it is used in medicine and variety of industries. But for many people, radiation is associated with atomic weapons or nuclear accidents. People's attitudes to risks from radiation are often very different from those of experts, which can cause conflicts and controversies. What really influences the way we feel about radiation risks and what does it mean for how we should be communicating about them?

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Yevgeniya Tomkiv
PostDoc, NMBU

https://www.pintofscience.no/pint21-oslo-thursday

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Simone Cagno, Italy - Adjunct Scientist NMBU
Jakub Jaroszewicz, Poland
Christina Søyland Hassfjell, Senior Scientist, Norway
Chloe Eastabrook, PhD student, Great Britain
Jordi Vives i Batlle, SCK, Belgium

Conferences and Workshops

CERAD Annual Conference

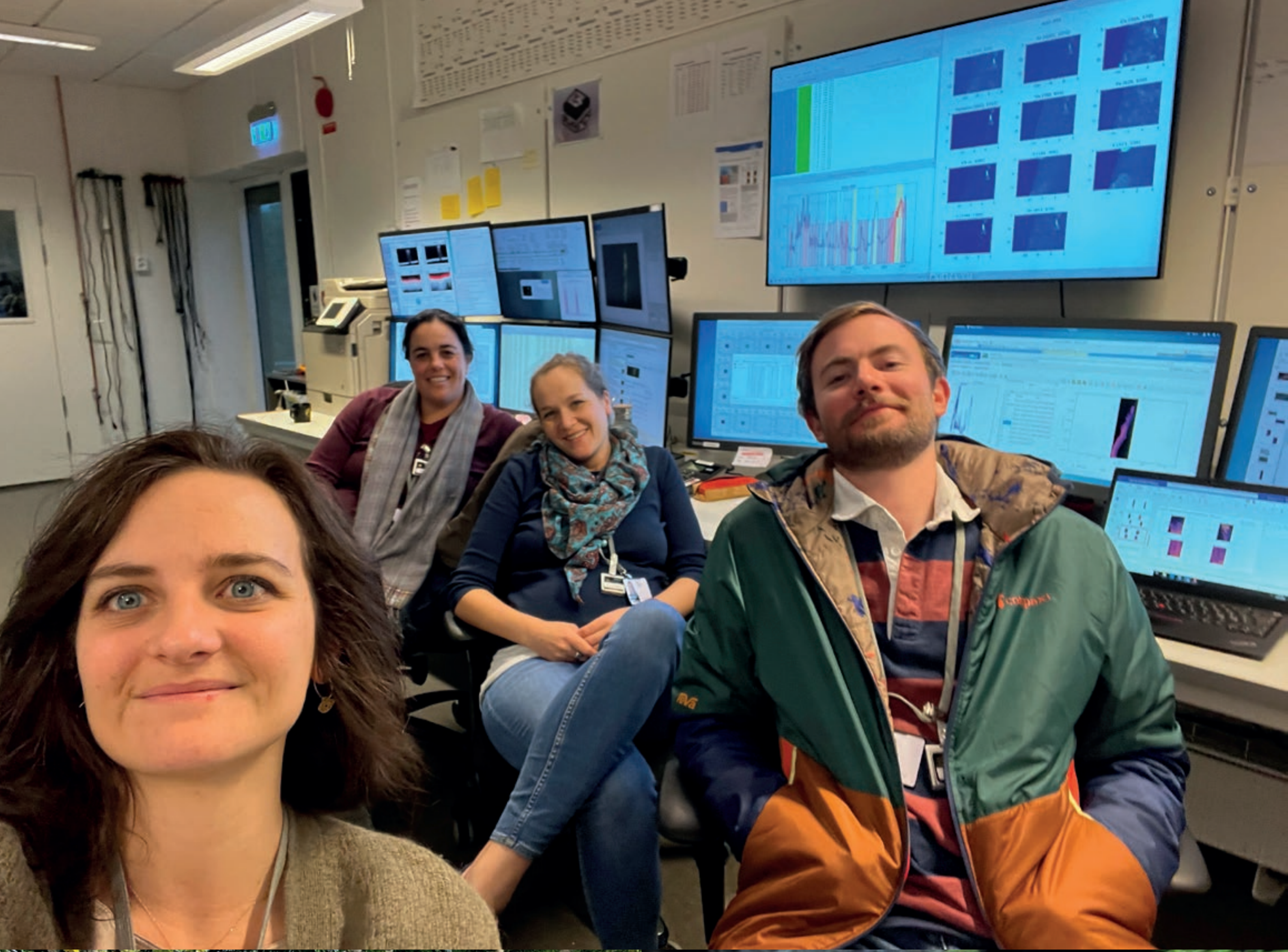
Venue: Zoom and Gather Town
May 10th-11th, 2021
Organizer: CERAD

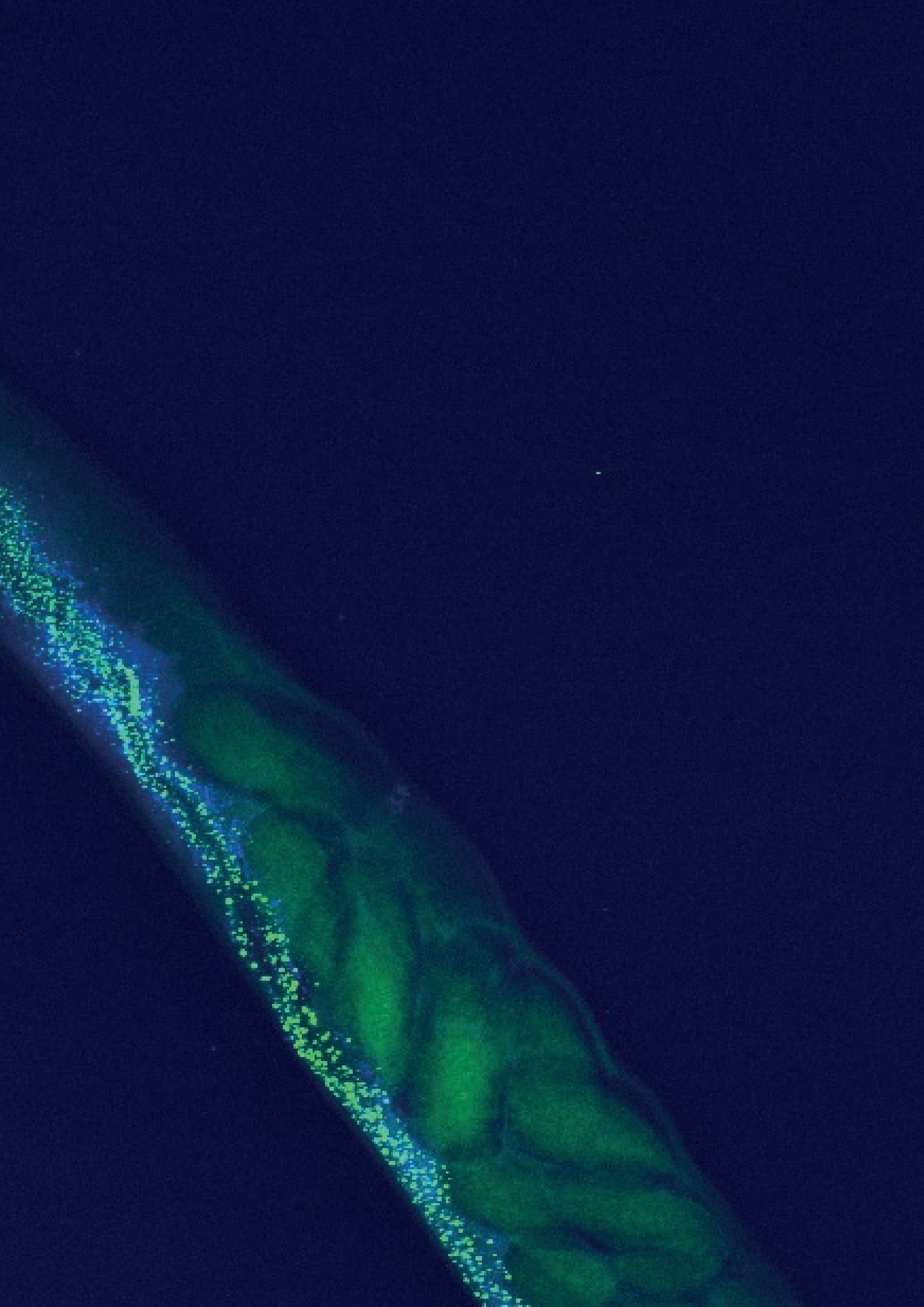
International Conference on Radioecology & Environmental Radioactivity (ICRER)

Venue: Online
29 June-1 July 2021
Organizer: IUR/DSA/CERAD

NERIS/SHARE/ALLIANCE Webinar

Considerations about offshore release of Fukushima Daiichi treated cooling water
Venue: Zoom
Friday 15th October 2021
Organizer: NERIS/SHARE/ALLIANCE by CERAD/NMBU





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Norwegian Meteorological Institute

NIPH Norwegian Institute of Public Health

NIVA Norwegian Institute for Water Research