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COMET Workshop report

Thirty years after the Chernobyl accident: what do we know about the effects of radiation on the environment?

Chernihiv, Ukraine

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Editors: **Catherine Barnett, Samuel Welch**

Contributors: Christelle Adam-Guillermin, Pål Andersson, Clare Bradshaw, Nicholas Beresford, Karine Beaugelin-Seiller, Olena Burdo, Caitlin Condon, David Copplestone, Jacqueline Garnier-Laplace, Sergey Gaschak, Anna-Lea Golz, Dmitri Gudkov, Nele Horemans, Tarja Ikäheimonen, Ari Ikonen, Mikko Kärkkäinen, Aleksei Konoplev, Catherine Lecomte-Pradines, Adelaide Lerebours, Sviatoslav Levchuk, Luke Massey, Susan Molyneux-Hodgson, Juan-Carlos Mora, Carmel Mothersill, Maarit Muikku, Kenji Nanba, Liubov Nagorskaya, Germán Orizaola, Fred Pearce, Almudena Real, Richard Shaw, Dave Spurgeon, Maryna Shkvyria, Jill Sutcliffe, Masanori Tamaoki, Eugene Tukalenko, Claire Wells, Yegor Yakovlev, Vasyl Yoschenko

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Sergey Gaschak

Christelle Adam-Guillermin

David Copplestone

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List of Acronyms and Abbreviations

CEZ	Chernobyl Exclusion Zone
ChNPP	Chernobyl Nuclear Power Plant
DCC	Dose Conversion Coefficient
DCRL	Derived Consideration Reference Level
FEZ	Fukushima Exclusion Zone
ICRP	International Commission on Radiological Protection
LD_{50}	Lethal dose (the amount of an ingested substance that kills 50% of sample).
NGO	Non-Government Organisation
OECD	Organisation for Economic Co-operation and Development
RAP	Reference Animal or Plant
SSD	Species Sensitivity Distribution

Workshop attendees

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1. Introduction

The year 2016 was the 30th anniversary of the world's worst nuclear accident at the Chernobyl nuclear power plant (Ukraine). To mark this anniversary, a workshop was held in the Ukraine to discuss what we have learnt from studies of the effects of radiation on the environment (i.e. wildlife) in the Chernobyl Exclusion Zone (CEZ), and what questions still remain. Consideration was also given to wildlife effect studies conducted in the Fukushima area of Japan following the 2011 releases from the Fukushima Daiichi Nuclear Power Plant.

The topic of the workshop was selected because of the lack of consensus on the impacts of radiation on wildlife in the CEZ (e.g. Beresford & Copplestone 2011; Møller & Mousseau 2016). There are a comparatively large number of publications which report to have observed detrimental effects of radiation on wildlife at comparatively low dose rates. To put these low dose rates into context, some studies report radiation induced effects below natural background exposure rates of wildlife in, for instance, the United Kingdom. A similar debate is beginning to evolve with respect to observations made within the vicinity of Fukushima (e.g. Beresford *et al*. 2012; Copplestone & Beresford 2014; UNSCEAR 2106).

Radiation effects studies of wildlife in the CEZ have been given considerable attention in the media, but the lack of scientific consensus on the issue is difficult to communicate to the public. Furthermore, the low dose rates at which effects are being reported raises issues for regulators, by challenging existing dose rate benchmarks used in radiological environmental impact assessments. Moreover, if substantiated, some of the studies would challenge existing radiation protection principles not only for wildlife but also for humans.

We attempted to achieve a wide spectrum of participation within the workshop with participants not only from the fields of radioecology/radiation protection but also from regulatory organisations, nuclear related industries, an NGO, the media[1], a chemical ecotoxicologist and representation from the social sciences and humanities fields. We also aimed to ensure participation of scientists from Ukraine and Belarus. A list of attendees can be found in Appendix 1. The authors of the majority of papers reporting effects at low dose rates were invited to the workshop but did not attend.

Format of the workshop and this report

We particularly wanted a diverse participant group with different views in order to stimulate a broad discussion. The presentations and abstracts which were provided by the contributors, and which are included here and on the Radioecology Exchange website, are the views of the individual authors and not of the report editors or the COMET project.

The workshop included presentations giving an overview of results from the many groups which have studied the environment with the Chernobyl Exclusion Zone (CEZ) and also those

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[1] An article has been published in *BBC Wildlife* magazine December 2016 (*Rising from the Ashes*; F. Pearce) and a second has been submitted to *Outdoor Photography* magazine.

currently working there (see Appendix 2 for the agenda). Results from some of the studies conducted in Japan following the Fukushima accident were also presented. Consideration was given to comparisons of field and laboratory effects studies for both radiation and chemical stressors; existing benchmark dose rates for radiation are based upon laboratory studies. One presentation discussed how the existing benchmark dose rates were derived. Some suggestions for best practice in field effect studies were also made. Abstracts from these presentations (as supplied by the authors) are included in Section 3 of this report. Where the presenter has agreed, their presentation is hyperlinked to the presentation title. Below each abstract are some notes from the questions and answers session after the presentation.

There were also two themed breakout sessions:

- How do we resolve the anomalies between field and laboratory studies?
- Implications of Chernobyl (and Fukushima) studies for current benchmark dose rates?

Feedback from each of the breakout sessions is presented in Section 4.

Following the presentations and discussion sessions various stakeholders (representing NGO, regulatory, industry, media, international organisation communities etc.) were invited to give their opinions on the topic and discussions of the workshop (see Section 5).

The following section of this report presents the recommendations arising from the workshop. A series of papers resulting from the workshop will be published in a special issue of the *Journal of Environmental Radioactivity* (planned for 2017/18).

Following the workshop the participants visited the CEZ, they are pictured above in front of Chernobyl reactor 4.

References

Beresford N.A., Copplestone D. 2011. Effects of ionizing radiation on wildlife: What knowledge have we gained between the Chernobyl and Fukushima accidents ? Integrated Environmental Assessment and Management, 7, 371–373.

Beresford, N.A., Adam-Guillermin, C., Bonzom, J.-M., Garnier-Laplace, J., Hinton, T., Lecomte, C., Copplestone, D., Della Vedova, C., Ritz, C. 2012. Response to authors' reply regarding "Abundance of birds in Fukushima as judged from Chernobyl" by Møller *et al*. (2012). Environmental Pollution, 169, 139-140. http://dx.doi.org/10.1016/j.envpol.2012.05.013

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UNSCEAR. 2016. Developments since the 2013 UNSCEAR report on the levels and effects of radiation exposure due to the nuclear accident following the great east-Japan earthquake and tsunami. A 2016 white paper to guide the Scientific Committee's future programme of work. United Nations Scientific Committee UNSCEAR on the Effects of Atomic Radiation. Available from: http://www.unscear.org/docs/publications/2016/UNSCEAR_WP_2016.pdf

2. Recommendations from the workshop

There are divergent results on radiation effects (for a range of species and endpoints) reported from field studies in the Chernobyl Exclusion Zone and increasingly around Fukushima. Some of these field studies are not compatible with the outcomes of laboratory studies. During the final discussion the following key points were identified with regard to making progress on understanding and addressing these issues:

- There are a large number of field studies reporting effects at dose rates which appear improbable given:
  - The reported laboratory effects data for similar species.
  - Dose rates are below no effects dose rate values (based on laboratory data) used in conservative screening assessments.
  - Dose rates are below natural background in many countries.
- The workshop participants agreed that currently the results from these field studies cannot be used in the derivation of benchmarks values for use in regulatory assessment. However, there was agreement that these data should not be dismissed, especially as some of them have photographic evidence of effects and, in some cases, mechanisms are proposed which may realistically cause damage and which could be tested; these 'inconvenient truths' need to be acknowledge, not ignored.
- The workshop recommended that studies reporting effects at low dose rates need to be independently investigated (e.g. repeating the studies although it may be difficult to persuade funding agencies of the need to do this). The workshop participants made some recommendations on important issues which need to be considered and these are listed below:
  - **Exposure** is often poorly determined. Many studies report (relatively few) dose rate meter results, often in units which are not applicable to wildlife (e.g. Sv). Use of dose rate meters may be acceptable as a marker of different contamination levels, but the limitations of their use need to be clearly stated in papers, not presented as actual exposure rates.
  - Contamination is **highly heterogeneous** in the Chernobyl Exclusion Zone and often too few measurements are made to even indicate a gradient of exposure with any confidence; there is rarely any error presented for dose rate measurements. Sufficient estimates of contamination, relative to the likely home range of the species being considered, should be made and in figures of dose rate versus parameters of effect, the error on dose rate should be presented.
  - **Internal exposure** is rarely determined and often not estimated. Internal dose rates could be determined for ^{137}Cs and ^{90}Sr at least by live-monitoring (and a few studies have done this). If it is not possible to live-monitor, then transfer values specific to the CEZ are becoming available.
  - **External dose rates** could be better estimated by fitting animals with dosimeters – these could be applicable for animals as small as large bee

species. For mammals dosimeters are available which record dose rate as a time series. However, this obviously requires recapture of a sufficient number of animals with dosimeters or some other means of collecting the dosimeters.

- If application of dosimeters is impractical then better external dose estimates could be made by determining radionuclide activity concentrations in sufficient environmental media samples from an area representing that likely to be utilised by the species of interest and an estimation of dose rate made using a **bespoke wildlife assessment model**.
- However, even if improved dose rate estimates are made it must be recognised that in some cases any effect observed may be the consequence of much higher dose rates in the past – i.e. the **exposure history** of the organism or species needs to be considered.
- The need to consider **site history** was highlighted. For instance, the highest exposure rates in most papers must have been determined in the Red Forest. Though this is often not acknowledged in papers, nowhere else in the CEZ would give rise to dose rates of this magnitude (i.e. >100 µGy h^{-1}). However, the Red Forest is an area which was coniferous forest which was killed by high radiation in 1986. It has slowly been recolonised by less radiosensitive species such as birch along with understorey vegetation. This is, therefore, now a different habitat to the rest of the CEZ and which is of low habitat quality. Furthermore, the Red Forest is relatively close to the Chernobyl NPP and hence some areas are subject to some human disturbance.
- **Statistically** some of the studies reporting effects relationships in the CEZ appear to be driven by a few influential observations which, as noted above, must be from the Red Forest given the quoted dose rates. The fact that the Red Forest is a unique ecosystem is not acknowledged in the vast majority of papers which use data from it to derive radiation effect relationships.
- The workshop recognised that the often reported statistically **'significant'** relationships do not demonstrate a causal effect; it was agreed that a significant statistical relationship does not necessarily have real world relevance. It was also noted that many of the reported significant relationships have poor R^2 values.
- A lack of proper **control sites** in some studies was acknowledged and it was recommended that future studies should have appropriate controls which may be in or out of the CEZ depending upon the context and purposes of the study.
- The workshop suggested that reviewers may often **lack the statistical expertise** to challenge papers they review (this was acknowledged by a number of participants who regularly review papers). Some advice on statistics (circulated to participants as background briefing prior to the workshop) can be found associated with this report.
- The workshop recommended that researchers **publish no-effect studies** recognising that such studies are unfortunately unlikely to be published in high

  profile journals (as studies reporting effects often are). However, it is critical that such data are made available so that they can be included in overall evaluations of risk to wildlife from ionising radiation.

- Working in the CEZ/Fukushima area is often a matter of achieving what you can on a limited budget during a limited field visit period. This was recognised as being a fact of life of working in the CEZ. However, when writing-up such studies, authors should be **clear about the limitations of their work**.
- The workshop strongly recommended that data from radiation effects studies are made **openly and freely available** – there are now a number of mechanisms whereby this can be done using 'data centres' or on-line data repositories. Making data available is a requirement of many journals and funders, though this currently is sometimes not rigorously adhered to.
- The workshop participants were of the opinion that if underpinning data from the field studies were made available a significant step would be made to addressing the disagreement on the magnitude of effects due to exposure to ionising radiation observed in the CEZ/Fukushima areas by enabling its **re-evaluation** by others.

The workshop also recommended that there was a need to be able to **link effects observed at** the **individual level** (including molecular and biomarker results) **with population level** effects, given that populations are usually the endpoint of environmental impact assessments. There is also a need to determine how to best **communicate** information to stakeholders (including the public) and influencing bodies able to **establish funding programmes**.

3. Abstracts including Questions & Answers

3.1 Is non-human species radiosensivity in the lab a good indicator of radiosensitivity in the wild?

Jaqueline Garnier-Laplace, Clare Della-Vedova, Karine Beaugelin-Seiller **(IRSN, France)**

Ecological risk assessment has globally become the basis for environmental decision-making within government and industry for chemical substances. Regarding radioactive substances, recently revised International[1] and European[2] Basic Safety Standards are pushing the development and/or the application of member state policy on environmental regulation in the field of radiological protection. Within this framework, existing derived effect benchmarks for ionising radiation and non-human species need to be more challenged in order to reinforce their credibility when used as levels of exposure considered to be safe for the environment. Actually, the derivation of such benchmarks has mainly relied on laboratory studies from a limited number of species[3]. Moreover a first comparison with field data from the Chernobyl Exclusion Zone evidenced a significant discrepancy between laboratory and field data on wildlife chronically exposed to ionising radiation[4]. This was done by comparing the range of variation of radiosensitivity of species from the Chernobyl Exclusion Zone with the statistical distribution of sensitivity established for terrestrial species chronically exposed to purely gamma external irradiation. The conclusion evidenced an apparent higher sensitivity of wildlife in the Chernobyl Exclusion Zone suggesting that organisms in their natural environmental were more sensitive to radiation (by *ca*. a factor of 8)[4]. This comparison highlighted the lack of mechanistic understanding and the potential confusion coming from sampling strategies in the field, including biased dosimetry and inadequate design to deal properly with confounding factors. An additional way to challenge benchmarks is to improve the quality/quantity of radiotoxicity data constituting the basis for a statistically-based comparison. This will be the major focus of this talk where we will demonstrate how to make the comparison more robust (i) by extending the knowledge making use of acute radiotoxicity data, (ii) by analysing the discrepancy between lab and field at the taxonomic level rather than at the ecosystem level, (iii) by identifying environmental factors modifying radiological dose-effect relationship in the field. Illustrations will be chosen for each item, the two first being in progress in the framework of an ICRP task group[5], the third one dealing with a recent meta-analysis on radiation effects on bird abundance in Fukushima[6].

References

[1]IAEA. 2014. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. General Safety Requirements Part 3. No. GSR Part 3. IAEA, Vienna, Austria.

[2]COUNCIL DIRECTIVE 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.

[3] Andersson *et al*. 2009. Protection of the environment from ionising radiation in a regulatory context (protect): proposed numerical benchmark values. J. Environ. Radioact. 100, 1100-1108.

[4] Garnier-Laplace *et al*. 2013. Are radiosensitivity data derived from natural field conditions consistent with data from controlled exposures? A case study of Chernobyl wildlife chronically exposed to low dose rates. J. Environ. Radioact. 121, 12-21.

[5] Task Group 99, ICRP Committee 5, established in 2015, proposing a work programme to gather and update basic data and guidance for the best use and practices of RAPs in support of the application of the system of radiological protection of the environment in planned, emergency and existing exposure situations.

[6] Garnier-Laplace *et al*. 2015. Radiological dose reconstruction for birds reconciles outcomes of Fukushima with knowledge of dose-effect relationships. Sci. Rep. 5, art. no. 16594.

Questions and Answers (refer also to linked presentation)

Q Are the green dots (chronic dose observed in CEZ; see presentation) incorporated in the distribution?

A No, but they fit in the correct range for some wildlife groups.

A Data on birds from Møller and Mousseau are far to left of the distribution. This suggests higher sensitivity in the field than in lab but this may be only “apparent”. See also Sergey Gaschak’s presentation for further discussion on this issue.

Q When was the study conducted and what factors did you take account of?

A July 2011, variables included in the model were traditional environmental factors (e.g. landscape type, quantity of food available to birds).

Q Did you get all the raw data from Møller and Mousseau to analyse?

A Yes, everything for every observation point.

Q In laboratory vs field studies, should we be weighting either data sets to aid comparison by e.g. a factor of 10?

A The present analysis was not conducted to derive a benchmark or any ‘protection value’. When we did such derivation under ERICA and PROTECT projects, we selected only the minimum population demography-relevant EDR_{10} value per species, fitted the SSD and then applied a safety factor on the dose rate estimated to protect 95% of species. Here we established the distribution of the variation of sensitivity per wildlife group on the basis of all the quality-checked EDR_{10} values (not only the minimum per species) obtained from laboratory; the goal being to make a comparison with EDR_{10} values from field.

Q Are you likely to use this data for ICRP activities?

A Yes.

3.2 Comparison of laboratory v's field effects for non-radioactive pollutants

Dave Spurgeon (NERC-CEH, UK)

Laboratory toxicity tests are widely recognised as key workhorses of ecological risk assessment. A range of protocols currently exist that can be used to derive concentration response data for a range of species. Whether obtained for bacteria, plants or animals, there is always a question about how well the results for any given laboratory toxicity test represent effects occurring for different species, under variable environmental conditions, for exposure temporally variable, cumulative and combined exposure in the field. In their classic paper on the potential use of species sensitivity distribution, Van Straalen and Denneman (Ecotox. Environ. Saf. 1989 18, 241-51) already recognised that the use statistical model based on laboratory toxicity data to generate environmental quality standard designed to protect a certain percentage of species in natural communities would be flawed if the data used to build these models was not field relevant. They listed 8 factors that could cause different in observed effect between lab and field. Four were identified that could lead to greater field effects. These were: 1) exposure may be under sub-optimal environmental conditions in the field, but rarely is in the lab; ii) in the field, organisms may be exposed to mixtures of stressors; iii) adaptation to one stressor may entail ecological cost when faced with another stressor; and, iv) in the field, exposure is long-term compared to short-term in lab. A further four factors were identified that could cause effects to be less in the field than in the lab. These were: 1) in the field, biological availability may be lower than in lab tests, ii) in the field ecological compensation and regulation mechanisms may occur; iii) evolutionary change may allow populations to adapt to high concentrations; and, iv) contamination is heterogeneous in the field, but homogenous in the lab.

In the intervening years since the publication of the Van Straalen and Denneman paper, ecotoxicologist have gone a long way to understanding which of the factor may be the most important for defining the relationship between lab and field toxicity. Many studies have investigated the toxicity of chemical under different field relevant environmental conditions. These have shown that variables can indeed increase toxicity. However, some conditions have been shown to have little influence or even to mitigate effects. For mixtures, models to describe and predict effects have been developed. These have shown that additive is a reasonable starting point for joint assessment, although this is not always the case especially where detoxification pathways and mechanisms of effect interact. Adaptation has been shown to occur. However, this has been found to be chemical and species dependent and indeed can even be absent in some cases. One of the major areas of research has been on differences in bioavailability between laboratory and field tests. For metals in particular, the form of addition to laboratory test systems have been shown to represent a worst case, with high bioavailability to toxic free ion forms. This evidence has led to the development of approach that can counter such effects both experimentally and during risk assessment. Finally the development of physiological models has greatly improved our understanding of how difference in exposure time affect toxicity. This relates not just to progression of effects in a single generation studies, but also to a growing body of evidence for the prevalence of multigenerational effects and their possible impacts.

Questions and Answers (refer also to linked presentation)

Q Failure to recover when a pollutant is removed has parallels to low-dose genomic instability have you looked at that?

A Not yet, we currently have a proposal in to study further. Failure to recover, could indeed reflect transgenerational effects related to transfer of genomic instability. This is an important topic to fully understand effects on biota. In our study we only know what happened at the end of five generations and for the chemical we considered. We think that more data are needed in this area.

Comment from floor - A characteristic of genomic instability is that results are the same at every generation so in five generations the results would always the same. My suggestion would be to look at mitochondria for the answer.

Q Did you look at different forms of Zn at different sites?

A No conducted crude measurements of availability and speciation.

Comment from floor - It may have an effect.

Q LD 50 – would you advise people to look at point at which it becomes stable?

A Have not considered it, do not know the answer. When putting together species sensitivity distributions, should take time scales into account (e.g. 96 h v 120 h studies). Some in favour of replacing LD_{50}s with no-effect concentrations. With a long-enough exposure time they are the same value but would wipe out existing data allowing species-sensitivity distributions. Something flawed is perhaps better than a ‘perfect nothing’.

Q When you measure the LD_{50} is important.

A If you can continue to monitor your species for a longer period of time then do so. It is a compromise with how much effort this is to do versus disturbance but at least you know something about the trajectory over time.

Comment from floor - Multi-generational studies need to be conducted.

Q Is there a need for new standards?

A The community believes there is. There are starting to be multi-generational tests brought forward for standardisation by the OECD for organisms such as fish and Daphnia.

Q How do ‘chemicals’ deal with low concentration effects endpoints?

A No simple answer, not easily identified. Risk assessors do not want omics data as it is too complicated to explain. There are papers published dismissing biomarkers as not linked to population dynamics and therefore being pointless. We would like to implement some biomonitoring data but if biomarkers were easy we would have them for cancer.

3.3 An overview of field effects studies in the Chernobyl Exclusion Zone

Nick Beresford[1], David Copplestone[2], Tom Scullion[1,2], Jim Smith[3], Marion Scott[4] ([1]NERC-CEH, UK, [2]University of Stirling, UK, [3]University of Portsmouth, UK, [4]University of Glasgow, UK)

In the initial aftermath of the 1986 Chernobyl accident there were detrimental effects recorded on wildlife, for instance:

- Mass mortality of pine trees over c. 6 km^2 close to the NPP
- Reduced seed production in pine trees over a larger area
- Reductions in soil invertebrates
- Likely death of wild mammals (low numbers were recorded in autumn 1986)

Twenty-five years after the Chernobyl accident there is no consensus on the longer-term impact of the chronic exposure to radiation on wildlife in the area around the NPP from which people were evacuated in 1986. Reconciling this lack of consensus is one of the main challenges for radioecology. With the inclusion of environmental protection in, for instance, the recommendations of the ICRP, we need to be able to incorporate knowledge of the potential effects of radiation on wildlife within the regulatory process (e.g. as a basis on which to define benchmark dose rates).

In this paper we will review some of the papers reporting effects on wildlife from the Chernobyl Exclusion Zone. We will structure this on the basis of different organism types and for each we will present the differing results and discuss the potential reasons for this. To illustrate some points we will present some novel results from on-going studies.

We will also briefly discuss related post-Fukushima research and make recommendations for the future.

Questions and Answers (refer also to linked presentation)

Q Spread on the Czrijej *et al*. (2010) colony forming units on feather data is high.

A Yes.

Q Have you only done a simple regression on bait lamina data (provisional data not included in the linked presentation)?

A Yes, for now. We also have soil samples available for measuring e.g. organic matter, pH, radionuclide contents etc..

Q I am not doubting that there are concerns on the methodology, but the results (in the papers reviewed) are demonstrating effects.

A Main issue is with misinterpretation of data, using p-value as an indicator of effect. Variation is often not well explained in some studies, for many people the reported effects seen at low dose rates do not make sense in the real world e.g. effects would be seen at UK background dose rates. This could just be due to misinterpretation of data but we need to find out the reasons why discrepancies are being seen.

Comment from floor – For defending e.g. ERICA screening dose rates at inquires, we need to work together to get consistent conclusions.

Q Problems with basic experimental design e.g. lots of weight on the Red Forest, must take into account human disturbance, history, etc.

  A Good to see recommendations on that topic come out of this meeting.

Q Problems with reviewing some of the papers appear not to have been considered by experts in our field, e.g. dose rate is reported in various units. There are also methodological problems, statistical problems, and some experiments are small. It is important to see the raw data.

  A Review process needs people with statistical knowledge, some reviewers are often unable to evaluate the statistical information. Papers published in higher impact journals do not generally get reviewed by radioecologists. In the review process we need to get the "right" people to review papers.

Q Did you speak to Marian Scott about the use of linear versus non-linear models?

  A Yes, in all areas of toxicology dose response curve shape is a well discussed; hormetic v linear v non-linear.

Comment from floor - Need to have a justified reason to use more complex model. Non-linear model used by choice within the chemical field.

Q Is it just external dose reported?

  A Yes, often, in different units.

Comment from floor - That is the flaw in these papers.

Comment from floor - There are effects perhaps not at the current dose rates as reported but we need to work together to understand the studies/results.

3.4 Characterization of the radiation effects on wildlife inhabiting contaminated area and influence of the dose estimate

Christelle Adam-Guillermin, Catherine Lecomte-Pradines (IRSN, France)

Several years after the major nuclear accidents occurring at Chernobyl and Fukushima, studies conducted on the fauna and flora chronically exposed to radiation often led to contradictory conclusions. The purpose of these in situ studies was to understand and predict the consequences of the long term exposure to ionising radiation on the native populations and in fine on the structure and development of the ecosystem. However, publications relating to species of invertebrates, vertebrates and plant, report either no effect, or varying intensity of effects on development, growth, behaviour and reproduction. The differences between species in radiation sensitivity and adaptive capacities over generations can partially explain these results. Furthermore, the lack of consistency on the observed long-term impact of radiation on wildlife can be endorsed by the heterogeneity in the methods used for the dose rate estimates, which may introduce a bias in the comparison of the results. Indeed, most studies only reported external dose rates and did not consider the contribution of all radiation types (including alpha, beta and gamma emitters). Moreover, to establish robust dose-effect relationships the contribution of internal contamination to the total dose rate absorbed by wildlife must be considered, according to the mode of life of the organism (e.g. ingestion, inhalation, dermal absorption). This highlights the complexity of the studies to correctly understand the effects induced by the chronic exposure to radiation and the benefit that would be provided by a multidisciplinary approach, including an accurate dose estimate, to draw robust conclusions on the environmental consequences of a nuclear accident.

Questions and Answers (refer also to linked presentation)

Q Can you provide clarification of the numbers of bird boxes used in Fukushima compared to those used at Chernobyl?

A We used 123 nest boxes in Fukushima (but did not perform any study in Chernobyl). Almost half of them were occupied.

Q Did you use replicates of nest boxes at each site?

A No, but there were lots of boxes at each site.

Q The R^2 on the plasmatic carotenoid levels slides shows a lot of scatter (see linked presentation). What factors were included?

A All controlling factors were integrated in the site using general linear mixed models.

Q So you did not look at the controlling factors individually?

A No

Comment from floor - I think it would be interesting to look at these data by removing each factor one by one to perhaps reduce the scatter.

3.5 Effects of long-term radiation exposure on aquatic biota in lentic ecosystems within the Chernobyl Exclusion Zone

Dmitri Gudkov[1], Natalia Shevtsova[1], Natalia Pomortseva[1], Elena Dzyubenko[2], Andrian Yavnyuk[3], Maria Balandina[4], Valentin Shukalevich[1], Alexandr Nazarov[5] ([1]Institute of Hydrobiology of the NAS of Ukraine; [2]G. Skovoroda Pereyaslav-Khmelnitsk State Teacher Training University; [3]National Aviation University; [4]T. Shevchenko National University of Kiev; [5]State Specialized Enterprise “Ecocentre”)

Self-purification of the lentic water bodies in the Chernobyl exclusion zone (CEZ) is extremely slow processes and though of the 30 years, past after the Chernobyl NPP accident in 1986, the ecosystems of the majority of lakes, dead channels and crawls possess high level of radioactive contamination of all the components. During 1998-2015 we studied dynamics and bioavailability of the main dose-forming radionuclides in components of lake ecosystems as well as effects of long-term radiation exposure on aquatic biota within the CEZ. The absorbed dose rate for hydrobionts of the researched water bodies was registered in range from 1.3 mGy year^{-1} to 3.4 Gy year^{-1}. It is determined that the rate of chromosomal aberrations in the roots of the helophyte plants of the most contaminated lakes on average in 2-3 times and in cells of the pond snail embryos in 4-6 times exceeding the spontaneous mutagenesis level, inherent to aquatic organisms. Leukogram analysis of peripheral blood of fish showed the decrease of part of lymphocytes, responsible for the implementation of immunological reactions. At that it is registered increase in the number of granulocytic elements (neutrophils and pseudoeosinophils), responsible for phagocytic function and involved in allergic and autoimmune reactions. Along with changes in leukograms an increased level of morphological damages of erythrocytes (deformation of nucleus and cell membrane, nucleus and cytoplasm vacuolization, pyknosis and lysis of cells, forming of microcytes, schistocytes, double nucleus cells and micronuclei) was determined, which is generally for pray fish in 4-12 times and for predatory fish in 7-15 times higher than in fish from reservoirs with background levels of radioactive contamination. Analysis of the viability of the seed progeny of the common reed at germination in the laboratory showed that in gradient of absorbed dose rate from 0.03 to 11.95 cGy/year for parental plants in lakes, there is a reduction in technical germination (from 93 to 60%), germination energy (from 91 to 30%) and seed viability (from 54 to 38%). At the same time significantly increased the number of abnormalities of seed seedlings: necrosis of roots (from 1.3 to 14.7%); disturbance of gravitropism (from 2.6 to 17.0%); damages of organogenesis (from 4 to 24%) and disturbance of chlorophyll synthesis (from 0 to 2%). Hereby the long-term radiation exposure of aquatic biota in lakes within the CEZ causes reactions, showing the damage of important biological systems. The special significance may acquire cytogenetic and genetic effects resulting from disorders of the genome stability with high probability of appearance in the form of increased mutation rates, decreased fertility and loss of the most sensitive species. Cumulative radiobiological processes can last for many generations allowing currently assume the possibility of incomplete realization of the long-term effects of irradiation. Against the background of the discernible welfare of aquatic biota population in the CEZ, the radiation-induced lesions of biological systems of hydrobionts at different levels of organization could pose a real threat to the manifestations of the negative effects of long-term radiation exposure in the future.

Questions and Answers

Q Did you consider the influence of other stressors such as differing natural histories (industrial areas v's remote) of water bodies?

A Yes we also studied heavy metals, pesticides and surfactants as well as basic anion-cation composition of the water in each of the water bodies. Overall the effect of these was not found to be significant. Thus we consider radionuclides are a key factor in studied water bodies within the CEZ.

Comment from floor - You have studied also the impact of acute radiation on the same parameters for molluscs in the laboratory conditions. So now you have a good opportunity to compare the effect of long-term and acute exposure, which is one of the main topics of this workshop.

A Yes

3.6 *Assessment of radiation effects in birds breeding in Red Forest area (2003-2005): problems of research approaches and interpretation of the results*

Sergey Gaschak (Chornobyl Center, Ukraine)

This ecotoxicological study was initiated by in 2003 and initially led by Møller & Mousseau (published 2007) in order to get a sample of breeding birds chronically exposed to radiation with a range of the external doses from 'background' up to 100–200 µSv hr^{-1} (max values in natural habitats during that period). It was supposed to sample blood, sperm, feathers, eggs etc. to assess biological effects. Breeding success was also to be assessed and compared to radiation. More than 200 nest-boxes (NB) were put up in the 'Red Forest' (RF) in 2003 (dose rates 5–167 µSv hr^{-1}), and the study took place in 2003–2005. There was no 'control' site outside of Chernobyl exclusion zone (CEZ) with a 'semi-control' site (C) being established in the CEZ in 2005: 70 NB, 0.9–2.4 µSv hr^{-1}. Habitats in the RF are mainly represented by sparse young birch reforestation (where mature pine plantations were killed in 1986), remains of older birch undergrowth, some alder/aspen areas, some dry and wet grassy clearings, there are some mature pine plantations in marginal sub-lethal areas. Habitats of C site are mature pine plantations with deciduous undergrowth. Occupation of NB as a result of radiation impact was not considered initially, and was not taken into account in the study design. However it became a main point discussed in the article published by Møller & Mousseau (2007). The main conclusion was: 'birds prefer to breed in sites with low radioactivity with a stronger effect in flycatchers than in tits'.

We did not share or support these conclusions. Collaboration in framework of this study ceased in 2004. However in 2004-2005 we continued it independently including additional establishment of a semi-control site, collecting data on egg morphology, ^{90}Sr and ^{137}Cs live-monitoring in adult birds and nestlings, and studies of blood. Here we will talk only about the main, in our opinion, misleading conclusions of the Møller & Mousseau (2007) paper. In our view the reported study replaces comprehensive analysis of the habitat quality by formal and non-transparent mathematical computations, and in this way actually ignores habitat factors. Any bird species chooses habitats according to their biological preferences and demands. The RF which comprises sparse birch forest with a number of glades *a priori* offered distinct and poorer conditions for tree-dwelling birds compared with the mature coniferous, mixed or deciduous woodlands at other study sites. Without the NB there were almost no birds resident in the RF. Poorness of conditions in areas impacted by high doses causes the 'illusion' of radiation determined depletion of the bird population. Almost all breeding species are migrants including the most abundant GT and PF, and in theory have equal initial conditions in concern of experience to radiation. The great tit is more flexible in choice of habitats and occupies appropriate holes several weeks earlier than PF. Data analysis showed that the first nests of GT appear in wet birch forest with undergrowth, and the last – in dry pine plantations. Breeding success as a difference between number of laid eggs, hatched and fledged nestlings does not have any significant relation with radiation or habitat conditions. Mortality of eggs and nestlings was caused by human activity in the most of cases, with some predation. However variability of clutch size significantly grew with radiation. Also, elongation index of eggs shortened following radiation - they became more spherical. The birds breeding in the RF conditions had more abnormalities in blood cells compared with the control group. Thus these observations indicate different kinds of radiation stress in migratory birds arriving in RF for breeding. However, at conditions 20-25 years after the accident it did not cause significant depression of reproduction. This study was not able to give reliable answers due to simplified design, lack of samples, absence of some data (e.g. age of females), and ignoring natural history of local conditions and birds. A long-term study using pairs of identical habitats with distinct radiation conditions could better investigate this problem.

Questions and Answers (refer also to linked presentation)

Q I know flycatcher habitats very well. Normally they like mature forests; it also migrates, arriving later than the great tit. In Belgium it looks for nesting places, choosing those that have been left by the great tit.

> **A** I do not exclude the effect of migration, but in our experience flycatchers removed a clutch of great tits eggs by building a nest over theirs, despite there being a large choice of empty nest sites; they chose not to use those boxes for unknown reasons (the author sent a supplementary response to this question after the workshop – see below).

Q Is it possible to put small dosimeters on a ring and to retrieve it later by recapturing the bird?

> **A** In theory yes. At least in respect of adults during the breeding season. But after, likely a very low recapture rate. Birds in this study were re-captured in same nest many times in the same season. Contamination levels were measured throughout season in these birds, levels measured did not always correspond to that of their neighbours. Birds did not always goes back to the same nest box area the following year.

Q As the breeding period is quite long, at least in Japan (how long is it in Ukraine?), it could give interesting information on exposure.

> **A** Very roughly: great tit - mid-April until mid-end of May if they have only one clutch, and until mid-end of June if two clutches. Flycatcher - from end of April until the beginning of May for nesting with 5-6 weeks on the nest if one clutch. As usual birds which have two clutches are not so numerous. However some birds have even three clutches. I am not familiar how long the birds stay at the breeding area. When nestlings leave the nest they for a certain time roam together with their parents. But if they leave the area or keep to it – I do not know. However, I guess that they may be there for at least two months. I am talking about great tit and pied flycatcher. Definitely some other species stay there much longer or even all year long, and some species for shorter periods.

Supplementary information subsequently supplied by the author in response to questions at the workshop

In the case of the Red Forest area and adjoining locations the birds have access to: mature pine forest, sparse birch reforestation and some dense deciduous forest (aspen, oak, alder and birch). The next boxes were deployed in these habitats. There are not too many natural tree holes, this is a normal fact for pine forest and relatively young deciduous trees (most of the tree in the Red Forest were only 15-20 year old at the time of the study). In opposite to rather flexible great tit which are ready to nest almost everywhere the pied flycatcher definitely avoids areas of sparse reforestation. In a 'control' pine forest with good undergrowth the species competed with each other. In the Red Forest they also occupied boxes in an areas of pine forest which survived after the accident (i.e. the ‘sub-lethal band’). Very few flycatchers occupied nest-boxes in the ‘lethal area’.

Flycatchers arrive in the CEZ *c*. 3-5 weeks later than great tits. Tits occupy nests when there are no leaves on trees whilst flycatchers mostly nest when trees are in leaf. Tits already have clutches by the time flycatchers are nesting.

Our observations show flycatchers do not always look for vacant nest-boxes, there are several examples when they built nests above clutches of great tits (and by this way forced the great tits out of the nest box); we have seen no instances of great tits doing this in nest boxes occupied by flycatchers.

During one breeding period (April-June) we recaptured the same birds several times. But 'remote' recapturing was rare. Only one great tit was recaptured on the same area in the next year. The fact of 'exclusive' recapturing is not so strange, many species normally do not return back in the same hole.

In our region great tits as well as pied flycatchers are migrants. The difference is how far they migrate. Flycatchers - very far, tits - not very. However very few birds (great tit) keep the same location all year long. Migration over hundreds of kilometres is not rare (one bird marked in Poland was recaptured in Red Forest). They normally gather in settlements with more rich conditions for the winter period. Local forests can maintain few birds in winter.

Contamination of birds depends on where they collect food. According to our data sometimes birds were remarkably 'cleaner' than plot around the nest, and vice versa. Contamination of the body depends on contamination of food, and rate of uptake/depuration of radionuclides. Small birds have relatively fast radionuclide biological half-lives and that is why change of foodstuff contamination causes rather fast change of internal contamination. Birds which return back in Red Forest after a year do not have their previous radionuclide 'burden', they lost this soon after departure the previous year.

3.7 Effects of radiation on the health of fish from Chernobyl

Adelaide Lerebours[1], Dimitri Gudkov[2], Liubov Nagorskaya[3], Jim Smith[a] ([1]University of Portsmouth, UK; [2]Institute of Hydrobiology, Ukraine; [3]Applied Science Center for Bioresources of the National Academy of Sciences of Belarus, Belarus)

Fish are considered as the most radiosensitive aquatic species and have been highly exposed in freshwater systems at Chernobyl, and in both freshwater and marine systems at Fukushima. Although the biological effects of acute exposure to radiation have been extensively studied, little is known about the effect of long-term chronic exposure of organisms exposed in the natural environment.

A few studies have highlighted some anomalies in the reproductive system of fish after several generations post-accident (over two decades), despite the continuing decrease of ^{137}Cs specific activity. However, the data, whilst informative, were qualitative and quantification of the observed effects is still lacking. At the molecular level, it is well established that ionising radiation induces DNA damage, but only a few studies have investigated DNA damage in relation to radionuclides in the environment.

In the present work, we wanted to assess whether three decades of direct and multi-generational exposure to radiation from the Chernobyl accident was significantly affecting the genetic material and the reproductive system of freshwater fishes in their natural environment. Perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) were collected from 7 lakes located inside and outside the Chernobyl Exclusion Zone (CEZ) that represent a gradient of contamination.

The results revealed that fish from the CEZ are still highly contaminated with ^{137}Cs and ^{90}Sr. A biomagnification phenomenon was observed for ^{137}Cs with an activity concentration 2-3 times higher in perch than in roach. ^{90}Sr activity concentrations were similar between the two species and a gradient of activity was observed as follows: Glubokoye > Yanovsky > Cooling Pond. The general health condition of the fish, assessed by the presence of external and internal sign of disease and calculation of the index conditions, didn't significantly vary between fish from control and contaminated lakes. The micronucleus test, reflecting the loss of genetic material from the nucleus of blood cells, didn't reveal any damage in contaminated fish. Finally, the histological analyses of the female reproductive system demonstrated a significant difference between the maturation stage of the gonads of perch and roach. Female perch from lakes inside the CEZ displayed a higher proportion of immature eggs than fish from reference or low contaminated lakes and this is more pronounced than for the roach.

As a whole, our work highlights that, 30 years after the accident, the fish are in good general health condition, however, the exposure levels are still considerable and significant effects on the reproductive system especially in perch are evident.

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Questions and Answers

- **Q** Did you select fish by age, size?
  - **A** Yes.
- **Q** Contamination of fish is age dependant, this has been well published.
  - **A** Yes bigger fishes are more contaminated as they are older, for Cs it is really important.
- **Q** You state that you measured the size of the fish and their age at each lake, were there differences between them?
  - **A** We have no statistics yet for the age but they were the same size across the lakes.

3.8 Current state and objectives of research of large carnivores in the exclusion zone

Maryna Shkvyria[1], Denis Vishnevsky[2], Yegor Yakovlev[1] ([1]Schmalhausen Institute of Zoology NAS of Ukraine; [2]Chornobyl Ecological Centre, Ukraine)

The Exclusion zone is a unique area due to protection status, the nature management, a cross-border disposition, fauna complexes. Moreover the status of Exclusion zone as key transboundary territory– ecological corridor and future Biosphere reserve creation needs monitoring of dynamic situation. Large predators of European forests are species-indicators of forest ecosystems conservation. Research and development of recommendations for the management of these species communities are extremely important because of current level of the environmental transformation.

Researches of large carnivores have been realized during 2003-2016. Methods were used: route accounting (the final route length was 700 km), tracking, mapping of denning sites, phototraps accounting, collection and analysis of feces and prey carcasses; helminthological studies – full or partial dissection and MacMaster technique of helminth egg flotation of feces.

Territorial structure of wolf packs was studied. Seven den sites were mapped. The study of food showed a small share of anthropogenic food in the diet. The number is 40-50 specimen. Founds of lynx were recorded and the number is estimated about 15 specimen. Brown bear founds are occasional (tree marks, tracks, shots), no breeding was recorded. Main points of human-carnivores coexistence are connected with fear of damage and attacks, and lack of education for locals and employees to create positive image of wildlife in Zone (Shkvyria & Vishnevskiy, 2012).

The role of anthropogenic influence on Biological Signal Field (BSF) characteristics of the wolf was studied in comparison with results obtained from Białowieża National park (Poland). It was found that there was no significant dependence on the characteristics of the territory and the differences between the behaviour of wolves in studied territories and the main factors which govern the character of wolf activity are not the level of the anthropic load and hunting pressure, but periods of the life cycle and spatial structure of groups (Shkvyria & Yakovlev, 2016).

Since the beginning of the study based on the materials obtained during an autopsy and study of feces of wild animals (wolves, foxes and lynx) we were recorded such species of helminths: *Alaria alata*, *Ancylostoma* sp., *Thominx* (=*Eucoleus*) *aerophilus*, *Spirometra* sp., *Toxocara canis*, *Toxocara mystax*, *Dirofilaria immitis*, *Macracanthorhynchus catulinus*, *Trichocephalus* (=*Trichuris*) *vulpis* (Yakovlev *et al*., unpublished data).

Two species – *Canis lupus lupus* and *Lynx lynx* are characterized by stable number and territorial structure. Perspectives of *Ursus arctos* is not clarified.

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Questions and Answers (refer also to linked presentation)

Q 40-50 wolves were identified and 48 were killed?

> **A** About 40 wolves were killed in the zone and neighbouring territories illegally last year by helicopter. If you count wolves at the traditional time, in winter (usually this includes the mating season and it is also the hunting season) you will count the minimal number present (because many wolves could be killed prior to this time). Usually in the Ukraine, the count is conducted in January and after the count is finished hunting continues, but new wolves can come into the territory so the number during January-March will be more or less right; but it is a seasonal number. If you count all year you will get different numbers, the number with pups, or a maximum late autumn number when the pups are grown and sub-adults from previous years and adults gathering into a pack before beginning their winter hunts on large ungulates. We counted wolves all year and as such can give information about the average pack size which is 5-7 wolves in pack (but cannot provide the minimum or maximum). So, if we have seven den sites we estimate about 50 wolves in the zone (including singles) which is the average number of wolves in Ukrainian part of the zone.

3.9 Complex radiobiological investigations of small rodents from the Chernobyl Exclusion Zone

Olena Burdo, Alla Lypska, Olena Sova, Natalia Ryabchenko (Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kyiv)

Radionuclide contamination of large areas caused by the Chernobyl disaster has set a number of important radioecological and radiobiological problems. One of the most important is the science-based forecast for the combined impacts of radiation factors on biota and human.

Chernobyl exclusion zone (ChEZ) is a unique natural testing ground allowing research of the processes occurring in natural populations under the effects of ionizing radiation. Due to wide dissemination, close contact with the upper layers of contaminated soil and high reproduction rate, rodents are commonly used as bio-indicator species in radioecological and radiobiological research.

Purpose of this research - to investigate radiation-induced changes in the blood system of bank voles from the ChEZ using the complex of hematologic, cytogenetic and morphophysiological parameters.

Hematological study of quantitative parameters shown statistically significant difference in the total content of leukocytes and erythrocytes in the peripheral blood of animals from contaminated areas and reference group. It was manifested both in increasing and decreasing of average values comparatively reference levels in different years of observation. For example, number of bone marrow cells during 2012 and 2013 years increased by 40%, while in 2015 - decreased by 40%; the number of white blood cells and red blood cells was reduced throughout the period of study 20% and 70% in 2015, respectively.

Our study has shown that in the remote period after the Chernobyl accident elevated levels of genetic and cytotoxic damage in bone marrow of small rodents' generations from contaminated areas are still observed against the lability of the studied markers. It is shown that during years of observation frequency of binucleated and micronucleated kariocytes, apoptotic cells exceeded spontaneous levels in ~ 4; 3 and 2 times, respectively.

These changes are the result of the prolonged irradiation. It caused significant violations in processes of bone marrow cells' proliferation and differentiation. Up to 30% of the analyzed reticulocytes were micronucleated a lot. The tendency to decrease of their levels with time after the accident was marked. Increased levels of bone marrow cells with pathological features were accompanied by activation of their apoptotic elimination. It should be noted dose-response biological effects were not revealed.

Levels of ^{137}Cs and ^{90}Sr accumulation in the body of rodents from the ChEZ were estimated; their high lability during the time after the accident and inter-individual and were found. Radiation doses and structure of radiation loads on small rodents from contaminated sites are determined. During the years after the accident contribution of external and internal radiation in total absorbed dose were changed, indicating significant contribution of incorporated ^{90}Sr and ^{137}Cs.

Qualitative changes in hematopoiesis of animals from the ChEZ manifested in the disturbance of bone marrow cell maturation. Malfunction of hematopoiesis foci formation in liver and spleen was also found. Major changes were registered in erythroid lineage. High level of genotoxic and cytotoxic effects in bone marrow was observed.

Differences between the reference and the exposed groups were found by the study of morphological parameters of voles internal organs, confirming the activation of the physiological stress in the exposed animals.

The observed complex biological changes appear as the result of chronic combined exposure, complex compensatory and adaptive processes in natural populations of small rodents from the ChEZ.

Questions and Answers

- **Q** Are there any further studies planned?
  - **A** Yes, the data we have means we need to study more. 2014 was a hard winter. Something other than the high level of radioactivity is the reason for differences being observed e.g. lake drying up over time, abiotic factor or perhaps in 2015 we did not capture the same population.

3.10 A study of radiation effects on ecosystem and wildlife in areas affected by the Fukushima accident

Masanori Tamaoki (Fukushima Branch, National Institute for Environmental Studies, Japan)

Our research group has been carried out some research projects for environmental disaster after FDNPP accident. Those include research for direct or indirect impacts of radiation on wild organisms and ecosystems in Fukushima. Here, I introduced following three topics carried out in my institute. (1) To evaluate DNA damage caused by radiation to the Japanese field mouse (*Apodemus speciosus*), mice were captured from a highly radiation dose site (Fukushima) and two lower radiation sites (Toyama and Aomori). The accumulation of oxidative stress marker (8-OHdG) was determined. The mice collected from Fukushima showed higher accumulation of 8-OHdG in testis than those from lower radiation sites. However, there was no difference in gene diversity among difference radiation dose sites. These suggest that germ cells of the mice living in highly radiation dose area were suffered oxidative stress but DNA damage was reduced by endogenous anti-oxidative or DNA repair systems. (2) To evaluate DNA repair followed by DNA damage with irradiation, transgenic plants that can detect homologous recombination activity induced by double strand break of DNA were generated. The plants were grown on contaminated soil for 30 days. Thereafter, estimation of frequency of DNA repair in plants was carried out. The result showed that DNA repair frequency was increased with increase of dose of irradiation. In addition, the transgenic plants showed that that DNA damage was mainly occurred from external exposure of gamma-radiation from contaminated soil. (3) To detect effects of evacuation, monitoring project of terrestrial biodiversity such as mammals, insects, birds and frogs was started from 2014 in Fukushima. The aim of the project is to yield information on the biodiversity and ecosystem effects of large-scale and long-term evacuation of the Fukushima area. In the project, a total of 48,081 insects and spiders were sampled from the 47 sampling sites. Most were *Hymenoptera* and *Diptera* (16,583 and 20,082 individuals, respectively). In total, 46 taxonomic and caste groups were found at more than 5 sites and were used in the subsequent analyses. The abundance of Carpenter bees was lower within the evacuation zone than outside, whereas those of most of the other collected taxa, including pollinators, were higher or not different. Considering previous studies of insects and radiation levels in the evacuation zone, it is unlikely that the radiation has acutely damaged the bee population. Alternatively, a potential cause of the reduced population density of the carpenter bee in the evacuation zone might be a reduction in the numbers of flowers of garden plants following the evacuation.

Questions and Answers (refer also to linked presentation)

- **Q** The staining of 8-OHdG in testis was only detected in sperm cells? How about in other cell type?
  - **A** Correct. Staining of 8-OHdG was not detected in the epididymis.
- **Q** How do you incorporate the effects from the decontamination activities in your ecological model, when it was carried out relatively quickly?
  - **A** Currently, I have no idea how to incorporate it (the decontamination activities) in our ecological models. But, we also try to detect evidence of decontamination activities in our satellite monitoring. It can be useful to know the ecological impact of decontamination activities.

3.11 Morphological abnormalities in Japanese red pine in Fukushima zone

Vasyl Yoschenko, Kenji Nanba (Fukushima University, Japan)

Japanese red pine (*Pinus densiflora* Siebold & Zucc.) is one of the most widely spread tree species in the forest ecosystems of the Fukushima zone. After the Fukushima accident this species extensive also colonizes the abandoned former agricultural fields and other areas adjacent to the forests. This species is closely related to Scots pine that is the main forest species in the Chernobyl zone.

High radiosensitivity of the coniferous species is a well-known fact. In the Chernobyl zone the extremely high doses of acute radiation in April 1986 resulted in formation of the lethal damages to the populations of Scots pine growing in the vicinity of the ChNPP (Kozubov and Taskaev, 2002). Our observations (Yoschenko *et al.*, 2011) showed that the comparable low rates of chronic radiation created morphological changes in the young pine trees. The most common morphological abnormality was cancelling the apical dominance. Frequency of this abnormality was high at the dose rates that can be also found in the Fukushima zone.

In 2014 we found the same abnormalities in the populations of young trees of Japanese red pine in the Fukushima zone. Also, similar abnormalities were reported in other coniferous species in the Fukushima zone (Watanabe *et al.*, 2015). At the same time, we have not observed any morphological abnormalities in the mature pine trees. The lethal damages to the coniferous species even in the vicinity of the FD1NPP have not been yet reported.

In 2015-2016 we studied the morphological abnormalities in 8 young populations of Japanese red pine exposed to the different levels of chronic radiation. The probability of cancelling the apical dominance increased from the level 0.11-0.14 in the two less irradiated populations to 0.5 and 0.9 at the absorbed dose rates of approximately 14 and 25 $\mu Gy\ h^{-1}$, respectively.

Most of the observed abnormalities appeared in the second whorl after the beginning of exposure. No new abnormalities were observed in the fifth whorl. This temporal pattern is similar to those reported for Scots pine in Chernobyl and for Japanese Fir in Fukushima.

Further detailed studies are necessary for interpretation of the observed temporal pattern and, in general, for explanation of the mechanism of the morphological abnormalities.

The study has been published see: Vasyl Yoschenko, Kenji Nanba, Satoshi Yoshida, Yoshito Watanabe, Tsugiko Takase, Natsumi Sato, Koji Keitoku. Morphological abnormalities in Japanese red pine (*Pinus densiflora*) at the territories contaminated as a result of the accident at Fukushima Dai-Ichi Nuclear Power Plant. Journal of Environmental Radioactivity, 165, 2016, 60-67. http://dx.doi.org/10.1016/j.jenvrad.2016.09.006

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Questions and Answers

None

3.12 How were the current benchmarks used in radiological assessments derived?

Almudena Real (CIEMAT, Spain)

The actions to be taken to adequately protect the environment against the detrimental effects of ionising radiation have to be commensurate with the overall level of risk to non-human biota. To judge the level of risk, the estimated dose rates received by animals and plants need to be compared with some form of numeric criteria, a benchmark (predefined dose rate value).

A variety of aspects can influence the final value of the derived benchmark, including: the aim of the application of the benchmark (i.e. application as screening value or as legally binding criteria or standards), the protection goals of the assessment (species, populations, communities, ecosystems, etc.), the data on radiation-induced biological effects considered (type of exposure, biological endpoints, etc.), and the derivation method used (expert judgement, assessment (safety) factor, statistical extrapolation techniques).

Benchmark values have been proposed by several international organizations (UNSCEAR, ICRP, IAEA), countries (UK, USA, Canada) and research projects (ERICA, PROTECT), although not all of them have used the same methodology, application purpose, interpretation of the data, and protection goals, to derive these values.

Regarding the methodologies used to derive benchmark values, these include from the use of varying degrees of expert judgement, to the application of formalized methodologies consistent with those used within chemical risk assessment.[1,2,3,4]

The talk will describe the different approaches (methodology, protection goals, quality and quantity of the data, etc.) used by the different groups to derive benchmark values for the radiation protection of the environment. The strengths and weaknesses of the different approaches will be discussed.

The different numerical values proposed by different organizations, countries and scientific projects will be presented and, when possible, compared. The benchmark values derived will be collated with the natural background dose rate values and with the values of dose rates leading to observed effects in animals and plants.

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Questions and Answers (refer also to linked presentation)

Q Do you think that datasets exist within in the FREDERICA database that have obtained data during the same experiment to quantify at the same time both mutation effects (in germinal cells) and reproduction effects in order to examine whether any correlation could be evidenced?

A Maybe yes, but I do not know. I think fish, mammals and terrestrial plants have more information (not only endpoints but also dose rates). I would have to go to FREDERICA and check.

Comment from David Copplestone: As the FREDERICA database manager it might be easier for me to look for the datasets that show both mutation effects (in germinal cells) and reproduction effects offline; I can probably do that quite quickly in the database.

3.13 Estimating radiological exposure of wildlife in the field

Karine Beaugelin-Seiller[1], Jacqueline Garnier-Laplace[1], Nick Beresford[2] ([1]IRSN, France, [2]NERC-CEH, UK)

The assessment of the ecological impact due to radionuclides at contaminated sites requires estimation of the exposure of wildlife in the field, in order to correlate radiation dose with known radiological effects. The robust interpretation of such field data asks for great care in sampling designs, in consideration of possible confounding effects (e.g. from the tsunami at Fukushima) and in an accurate and relevant quantification of radiation doses to biota. Generally, in field studies the exposure of fauna and flora has been characterised through measurements of the ambient dose rate or activity concentrations in some components of the environment, and only rarely in the exposed organisms themselves. The use of such data does not allow the establishment of a robust dose-effect relationship for wildlife exposed to ionising radiation in the field. Effects of exposure to radioactivity depend on the total amount of energy deposited into exposed organisms, by adding doses (or dose rates) for all radionuclides and pathways.

Realistic dose estimation needs to reflect the entire story of the organisms of interest during their whole exposure period. This talk describes the process of identifying and collecting all the related information that will allow answering “W” questions (Which organisms are exposed, Where, When and hoW). Some parameters are well known to influence the dose (rate): the organism life stage, its ecological characteristics (habitat, behaviour…), the source term properties (e.g. emitting facilities, nature of radiation), etc.. The closer the collated data are to the ideal data set, the more accurate and realistic the dose (rate) assessment will be. This means characterising each exposure pathway (internal and external), the activity concentration in each exposure source, the time each organism spends in a given place, as well as the associated dose coefficients or the data required for their assessment. Most often, the only available information is the activity concentration per radionuclide in some abiotic components of the exposed ecosystem. The data set has to be completed such that it tends as much as possible to the ideal, making ecologically plausible assumptions.

The whole process of data collation in view of dose reconstruction is illustrated for Japanese birds exposed to radioactive deposition following the Fukushima accident, from the work done by Garnier-Laplace *et al*. (2015), notably on the basis of ecological data gathered by Møller *et al*. (2015 a&b).

With respect to the Chernobyl Exclusion Zone we will also consider variability under field conditions, availability of relevant datasets and options for better estimating internal and external doses received by wildlife.

References

Garnier-Laplace, J. *et al*. 2015. Radiological dose reconstruction for birds reconciles outcomes of Fukushima with knowledge of dose-effect relationships. Sci. Rep. 5, article no. 16594.

Møller, A. P. *et al.* 2015a. Cumulative effects of on interspecific differences in response of birds to radioactivity from Fukushima. J. Ornithol. 156, 297-305.

Møller, A. P. *et al.* 2015b. Ecological differences in response of bird species to radioactivity from Chernobyl and Fukushima. J. Ornithol. 156, 287-296.

Questions and Answers (refer also to linked presentation)

Q How did you use the biochemical composition of soil in dose estimations?

A Effects of exposure to ionizing radiation are linked to the energy produced by the particles that are absorbed by the exposed organism. The transport and deposit of energy in matter depends on the density of this matter. Then assessing the dose coefficient in a given situation requires to know the composition of the target organism as well as that for all the exposure sources (in this case soil).

Q Have you looked at what the likely difference in density is on DCC's?

A During the IAEA projects EMRAS and MODARIA[2], we investigated some physical parameters that may influence the DCCC values in situations of external exposure, such as soil density, contamination profiles in soil and sediment and the effect of the soil water content. This last study is partly and indirectly related to changes in density (more water in soil in place of air means a slightly higher density, from 1.3 to 2.2). A set of alpha, beta, and gamma emitters were selected in order to cover the range of possible emission energies. The values of their external DCCs varied generally within a factor 1 to 1.5 with the soil water content, except for beta emitters that appeared more sensitive (DCCs within a factor of about 3).

Q I did not see tritium in your presentation?

A This comment concerns the figure related to the contribution of the different radionuclides in the NPP source term to the internal exposure of ERICA reference organisms, this is dominated by C-14 and Ag-110m for most organisms (see presentation). Generally, for humans, the ingestion pathway is dominated by C-14 and H-3. The question proposer was surprised by the absence of H-3 among the highest contributors to the dose rate. The legend was too small to see that H-3 was indeed included. In our scenario, tritium appears as the fifth or sixth contributor, after C-14, (Ag-110m for invertebrates), Cs-137, Cs-134 and Co-60.

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[2] See: (i) Vives i Batlle, J., Balonov, M., Beaugelin-Seiller, K., Beresford, N.A., Brown, J., Cheng, J-J., Copplestone, D., Doi, M., Filistovic, V., Golikov, V., Horyna, J., Hosseini, A., Howard, B.J., Jones, S.R, Kamboj, S., Kryshev, A., Nedveckaite, T., Olyslaegers, G., Pröhl, G., Sazykina, T., Ulanovsky, A., Vives Lynch, S., Yankovich, T. and Yu, C. 2007. Inter-comparison of absorbed dose rates for non-human biota. Radiat. Environ. Biophys., 46, 349-373. http://dx.doi.org/10.1007/s00411-007-0124-1; (ii) Beaugelin-Seiller, K.2016. Effects of soil water content on the external exposure of fauna to radioactive isotopes. J. of Environ. Radioact., 151, 204-208.

3.14 *The PROBA database*

Kashparov Valeriy, Levchuk Sviatoslav (Ukrainian Institute of Agricultural Radiology of NUBIP of Ukraine)

The results of works in the near exclusion 30-km zone of ChNPP accident are compiled on the CD 'Radioactive contamination of the 30-km zone' released by UIAR [http://www.uiar.org.ua/BD/bd.htm]. The CD contains the following data: a complete set of maps of terrestrial contamination with ^{90}Sr, $^{239+240}$Pu, ^{238}Pu, ^{241}Pu, ^{241}Am, ^{144}Ce, ^{154}Eu and soil properties (raster images in jpg-format and thematic layers in MapInfo (*.wor)); databases of the experimental information on radioactive contamination of the territory "SAMPLE" [1] and on physical–chemical characteristics of the fuel particles "HOT PARTICLES" [2] in the Microsoft Access (*.mdb); estimates of radionuclides inventories in the 30-km Chernobyl zone the major publications of UIAR (*.pdf); etc. The CD is run under the Microsoft Internet Explorer version 4.0 or higher. This CD contains the information and materials, which are not being a subject of commercial use.

Database "SAMPLE" contains the characteristics of the soil sampling points (geographic coordinates, landscape description, dose rate), values of the terrestrial density of radionuclides contamination (^{90}Sr, ^{134,137}Cs, ^{154}Eu, ^{238}, $^{239+240}$Pu), values of exchangeable and associated with fuel particles fractions of ^{90}Sr, principal agrochemical characteristics of soil (soil type, Hr, pH, content of K_2O, Ca, P_2O_5, organic matter).

References

1. Kashparov, V.A., Lundin, S.M., Zvarich, S.I., Yoschenko, V.I., Levtchuk, S.E., Khomutinin, Yu. V., Maloshtan, I.N., Protsak, V.P. 2003. Territory contamination with the radionuclides representing the fuel component of Chernobyl fallout. The Science of the Total Environment, 317, 1-3, 105-119.
2. Zhurba, M., Kashparov, V., Ahamdach, N., Salbu, B., Yoschenko, V., Levchuk, S. 2009. The "hot particles" data base. Radioactive Particles in the Environment, NATO Science for Peace and Security Series C: Environmental Security. Eds. Oughton, D., Kashparov, V. Springer, Netherlands, p. 187-195.

Comments from speaker - PROBA means sample in English and soil samples are available if anybody wants access to them.

Questions and Answers (refer also to linked presentation)

Q How do people access the database if they want to use it?

A The law has recently changed allowing the PROBA database to be distributed on request. However, the Help function will only work with an old version of MS Access which may be rectified in the future.

4. Breakout Discussion Sessions

Two breakout sessions were held to consider the following questions:

- How do we resolve the anomalies between field and laboratory studies?
- Implications of Chernobyl (and Fukushima) studies for current benchmark dose rates?

Participants were randomly split into four groups for these sessions with the group participants being varied between the sessions. Each group had a facilitator and a rapporteur. The facilitator within each group led the discussion whilst the rapporteur recorded it (providing the basis of the notes below) and communicated back to the workshop in a plenary session. The feedback below provided is that prepared by the breakout group rapporteurs and it has not been edited other than for English readability. Note this reflects the discussions in the groups and not recommendations from the workshop in general; Section 2 should be consulted for workshop recommendations which are in part based on the breakout group and subsequent plenary discussions.

As a preliminary to breakout group discussions an independent summary of the presentations was prepared and given (by Clare Bradshaw (Stockholm University)) and this has been reproduced below.

This summary is based ONLY on the presentations given at the COMET workshop. There is a lot more data in the literature and additional reviews on Chernobyl studies have been published (e.g. Geras'kin *et al.* 2008).

This not an exhaustive summary of all results presented in all presentations, but rather an overview of some of the results for which dose rates estimates were available.

Dose rates (DR) given are based on a range of different types of estimates (everything from hand held dosimeters 1m above the ground to detailed external and internal dose rate measurements and calculations). So they may not be directly comparable – the values are simply taken as given in the presentations (and converted to µGy h^{-1} where necessary). Where people have directly compared external gamma dose rates and calculated total dose from internal and external there is generally a factor of 2-10 difference (e.g. Garnier-Laplace, *et al*. 2016; Beresford *et al*. 2008).

Remember: DRs change with time (because of changes in contamination levels and organism age/size).

History of exposure/dose may be important (though these things rarely considered) (see Yoschenko abstract and presentation above).

Dose rate bands (e.g. DCRL* or other benchmark)	**A selection of effects mentioned in workshop presentations**
<0.1 mGy d^{-1} **(<4 µGy h^{-1})** **or** **<10 µGy h^{-1}**	Møller & Mousseau+ (2013) small mammal tracks (0.01-100 µSv h^{-1} but measured on ground, external only): negative effect on abundance (R^2=0.31). But skewed by three highest dose measurements (100 µSv h^{-1} (Red Forest???, which is a very different ecosystem). *Deryabina et al.*+ (2015): up to 5 µGy h^{-1}, elk and wolf tracks – no effects except possibly more wolves in CEZ. Cultivable bacteria on bird feathers decrease with dose up to 2.9 µSv h^{-1} (but although significant (p = 0.024), R^2 = 0.07) (Czirjak *et al.*, 2010). Møller & Mousseau (2009) – 0.1-10 µGy h^{-1} – large reductions in bees, butterflies etc. But dose rates in range of background… Fukushima butterflies: LD_{50} larvae = 1.9Bq (= 8 µGy h^{-1} = lower than NEDR and background). Previous studies in lab – LD_{50} were >1Gy (Hiyama *et al*. 2014 / Copplestone & Beresford 2014). *Gudkov et al.* - Reeds: frequency of chromosomal aberrations in cells of root meristems higher in the CEZ lakes (0.7-14 µGy h^{-1}) than Pripyat River (0.25 µGy h^{-1}). Seed viability, germination etc. decrease with increasing dose rate (0.03-12 µGy h^{-1}).
0.1– 1 mGy d^{-1} **(4–40 µGy h^{-1})** **0.24 mGy d^{-1}** **(10 µGy h^{-1})**	*Burdo* - bank voles in CEZ. External gamma dose rates: Control site – 0.001 – 0.002 µGy h^{-1}; two contaminated sites Dityatki 0.2 – 0.22 µGy h^{-1}, and Janiv 5.5-14 µGy h^{-1}. A number of cytogenetic and genotoxic markers, in particular those to do with bone marrow cell maturation had higher frequencies at one or both of Dityatki/Janiv. Bonzom *et al*. (2016): Increase in litter mass loss with increased dose External dose rate: 0.2 – 29 µGy h^{-1}, total dose rates 23-150µGy h^{-1}. Mousseau *et al.* (2014): up to 100 µSv h^{-1} - decrease in litter loss (and increase in litter thickness over same range). Up to 6 µGy h^{-1} – no effect (Jones 2004 PhD Nottingham). Lecomte-Pradines *et al*. (2014): Nematodes. External dose rates 0.2-22 µGy h^{-1}, TDR = up to c. 220µGy h^{-1}. No effect of radiation or any

	other measured factor on Shannon diversity. Specific nematode indices (Maturity index, NCR) were positively affected by TDR (and also by pH and orgC). Reduced relative abundance of bacterial vs fungal feeding nematodes. Up to 31 µGy h^{-1}: no difference in taxon richness in aquatic invertebrates. (Murphy *et al*. 2011). Stenalski *et al*. (in prep) Antioxidants in tit nestlings in Fukushima. Up to 30µGy h^{-1}, TDR = 10x ambient, and varied with age. Decrease in various parameters (antioxidant status, carotenoids and triglyceride) with TDR (huge scatter in data but 'site' considered as a random factor in the analysis and had no effect). No effect on breeding parameters or MN. *Lerebours*: Roach and perch from CEZ lakes. TDR in 3 most contaminated sites was 190-390 µGy d^{-1} (=8-16 µGy h^{-1}). No effect on micronuclei, or on most health condition indices (Fulton Index condition, hepatosomatic index, gonadosomatic index disease and injury, parasites). In three most contaminated lakes, more immature eggs in perch despite fish being similar size and age. *Tamaoki*: Captured mice at Fukushima site with 20.33 µSv h^{-1} site and two ref sites (0.05, 0.1 µSv h^{-1}). Total exposure to the testes exceeds ICRP benchmark (0.25-0.55 mGy d^{-1}). 8-OHdG and DNA repair enzyme OGG1 in testes (but not in epididymis) were elevated in Fukushima. Effect decreased with time (as has dose rate). *Yoschenko et al*. (2011) loss of apical dominance in Scots pine, CEZ: EDR_{10} = 0.9µGy h^{-1}, EDR_{50} = 40µGy h^{-1} Møller & Mousseau (2007): Areas in and near Red Forest with 5-200 µSv h^{-1} and 5-7 µSv h^{-1} "birds prefer to breed in sites with lower activity" But *Gaschak's* interpretation and further data do no support this – "does not depend on radiation" – more to do with habitat. Great tit eggs become more spherical with increased radiation (up to 90 uSv h^{-1}) and variability of clutch size increased in same range (Gaschak).
1 – 10 mGy d^{-1} (40 – 400 µGy h^{-1})	*Beresford*: new data from bait lamina. Preliminary data - up to 240µSv h^{-1} general decrease but R^2 0.05, p<0.15. *Gudkov*: Fish leucograms (various measures) at 2 contaminated sites (c. 300 µGy h^{-1}) showed effects that they related to radiation.

	Erythrocyte deformities (e.g. micronucleus) in fish blood from 3 contaminated lakes (DR c. 10-300 µGy h^{-1}). Lymnaea snails – embryo chromosomal aberrations and frequency of dead cells and phagocytic cells highest in 4 CEZ lakes with DR 35-400 µGy h^{-1}. No effect below 0.3 µGy h^{-1} (Gudkov *et al.*)
10-100 mGy d^{-1} (400 – 4000 µGy h^{-1})	*Gudkov et al*. CEZ: Bottom dwelling fish – up to 300 µGy h^{-1} (Glubokoye lake most contaminated) No morphological damage could be related to radiation Small mammals in Red Forest: Gy h^{-1} exposures. Varying conclusions on effects of genetic diversity but general conclusion probably that no loss of genetic diversity, no chromosomal or micronucleus effects, no adaptation? (Baker *et al*. *Gaschak*) Up to 1000 µGy h^{-1}): four invertebrate taxa showed both positive and negative effects (Bezrukov *et al*. 2015) – but big spread in the data.

*Derived Consideration Reference Level (see ICRP Publication 108[3]);

+Where citation appears in italics it refers to abstracts and associated presentations above, where not in italics these are references cited in presentations – most often that of Beresford *et al*. (Section 3.3)

Other comments

Importance of habitat came up in many talks (e.g. Sergey Gaschak, Maryna Shkvyria, Masanori Tamaoki) including changes in landscape/habitat due to human evacuations and also the human impacts on wildlife. For instance:

- In Fukushima, wild boar more common in evacuated areas, carpenter bee less common (lack of horticulture?), other bees and wasps, beetles more common (more small flowers there now?) (Fukasawa *et al*. 2016; Yoshioka et al. 2016).
- In CEZ, the Red Forest is a very different habitat to other areas.

References

Geras'kin, S.A., Fesenko, S.V., Alexakhin, R.M. 2008. Effects of non-human species irradiation after the Chernobyl NPP accident. Environment International, 34, 880-897. http://dx.doi.org/10.1016/j.envint.2007.12.012

Garnier-Laplace, J., Geras'kin, S., Della-Vedova, C. Beaugelin-Seiller, K., Hinton, T.G., Real, A., Oudalova, A. 2013. Are radiosensitivity data derived from natural field conditions consistent with data from controlled exposures? A case study of Chernobyl wildlife

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[3] http://www.icrp.org/publication.asp?id=ICRP%20Publication%20108

chronically exposed to low dose rates. Journal of Environmental Radioactivity, 121, 12-21, http://dx.doi.org/10.1016/j.jenvrad.2012.01.013

Beresford, N.A., Gaschak, S., Barnett, C.L., Howard, B.J., Chizhevsky, I., Strømman, G., Oughton, D.H., Wright, S.M., Maksimenko, A., Copplestone, D. 2008. Estimating the exposure of small mammals at three sites within the Chernobyl exclusion zone - a test application of the ERICA Tool. Journal of Environmental Radioactivity, 99, 1496-1502.

Fukasawa, K., Mishima, Y., Yoshioka, A., Kumada, N., Osawa, T. 2016. Mammal assemblages recorded by camera traps inside and outside the evacuation zone of the Fukushima Daiichi Nuclear Power Plant accident. Ecological Research, 31, 493-493.

Yoshioka, A., Mishima, Y., Fukasawa, K. 2015. Pollinators and other flying insects inside and outside the Fukushima evacuation zone. PLOS ONE, 10, e0140957.

4.1 Feedback from Breakout Session 1: Are there anomalies between laboratory and field studies, what can we learn from non-radioactive pollutants?

Feedback from Group One

Laboratory versus field

- Laboratory studies are too simplistic
    - e.g. in laboratory studies cannot take into account of important variables like food availability

How to fill the gap between laboratory and field studies?

- By using modelling tools
    - But studies observing no effects are often not published
- By using robust biomarkers of stress
    - But we still observe a difference between laboratory and field studies
- By applying microcosm/mesocosms
    - Used for chemicals - but too costly so abandoned
    - How could it help to fill the gap between laboratory and field studies?
    - How would you incorporate the data into models?
    - Could be used for multi-species studies
- Lower dose/longer term exposure
    - Need access to the low dose exposure facilities
- Low versus high dose
    - A good experiment could consist of comparing two experiments with the same total dose but different dose rates
- By identifying the ecological factors influencing the sensitivity of the study species
- It would have been very valuable to have data on the biomonitoring of some organisms before the accident

- By doing more mechanistic studies to determine the genetics and adaptation resulting from indirect/direct effects
- By taking into account the exposure history of organisms in the assessment of the dose

So extrapolation between laboratory and field should be possible by either using models and/or experimental improvements.

Is it worth doing some laboratory experiments highlighting some important effects observed in the field at very low doses?

- Yes it deserves to be checked. This can be done under laboratory conditions with our own tools.

Feedback from Group Two

Laboratory versus field

- Results can be compared, taking into account limitations and different conditions. We do not know all the conditions in the field, nor all the variables. The laboratory is more controllable, but not realistic. We may misinterpret the field test results, because we do not know all the affecting variables.
- Differences in laboratory and field test results - to have results within an order of magnitude, that's fine. That's life!
- Systematic differences/biases? Nothing obvious. Comparing data from different studies and sites is useful. Possibility to see new effects and their possible explanations more clearly.
- What you can learn from non-radioactive studies? Get your exposure right! Most of the laboratory tests have been done using external radiation, not that many use internal contamination. Better evaluation of radiation doses in the field is needed. Try to find new techniques for dose measurements. Doses to organs? Are they important in an individual and/or at population level?
- Chronic exposure - should we make longer experiments? Yes, if possible! Jacqueline Garnier-Laplace methodology (see presentation above) seems to work for 'transferring' acute results to chronic.
- Limited number of species for laboratory tests. Now we are studying mainly small, short-lived animals. Are the results valid for bigger, longer living animals?
- We should be able to select the species relevant for the environment studied. We should keep the freedom/flexibility to study what (and how) scientists think is important/interesting/needed in order to have good science. Studies should not be too specific, standardized.
- We should be quicker! We are missing valuable/irreplaceable time for studies because of the organisational inertia and political reasons. Though naturally, in early phase the bias is on humans and radiation protection issues.

Key points:

- Both laboratory and field experiments are needed, just keep in mind the limitations.
- Differences in laboratory and field test results - to have results within an order of magnitude, that’s fine. That’s life!
- Exposure right.
- Chronic tests.
- Studies should not be too specific, but need relevant species, methods.
- Multiple stressors.

Feedback from Group Three

The numerous laboratory experiments and field observations provide enough results for the laboratory/field comparison. The discrepancies between the results of the field and laboratory observations can be caused by the following reasons:

- Inaccuracy of the dosimetric assessments in the field:
    - heterogeneity of deposition. Especially important for the large animals which migrate over large areas and thus can be exposed to the different external dose rates in the different periods;
    - seasonal patterns of radiation exposure (changing of diet for animals, seasonal variations of the radionuclide activity concentrations in plants or their organs, etc.);
    - the incorporated radionuclide concentrations in the organisms (organs) should be used rather than their concentrations in soil (to estimate internal exposure);
    - in the field conditions the organisms usually are exposed to the chronic radiation that changes in time. The observed effects should be related to certain moments (often in the past) when they first occurred. Needs (a) to identify the moment when the initial changes happened, and (b) to calculate the dose rates in the past. For (b), the dynamics of the radionuclides bioavailability in the past must be taken into account (e.g. due to the changes of their physical-chemical forms, migration etc.);
    - non-uniform distribution of the incorporated radionuclides in larger organisms.
- Influences of factors other than radiation (e.g. chemical contamination etc.) in the field
- Natural variability of radiosensitivity in the studied populations
- Difference of the effects in various populations in the field can be linked not only to radiation exposures but also to genetic differences. We do not have the same population at different observation sites
- Dynamics of genes (gene flows) in the studied populations in the field

In general, we suggest that the laboratory experiments can give the qualitative information necessary for understanding the possible effects in the field. In most cases, absence of the major disagreements between the results of the laboratory experiments and field observations should be considered as a good result.

Feedback from Group Four

In Group four, we discussed different aspects of the comparisons between field and laboratory studies on radioecology, but first, we all agree that there are clear discrepancies between the two environments, something otherwise common in all aspects of experimental biology.

- Laboratory estimation of the effects of radioactivity in organisms are more precise, but less realistic that field studies. If our goal is to estimate the potential impact of radioactive substances in organisms in order to estimate radioactive safety levels (i.e. benchmarks), laboratory studies would give us a more robust estimation, but if our goal is to estimate the effects of radioactivity in natural ecosystems we definitely need more and better field studies.
- One alternative that we discussed during the session was the need for developing more field-controlled studies (e.g. mesocosms), in which it would be possible to conduct experiments under more realistic settings while still controlling most of the variables affecting the final results. This approach should be encouraged within the radioecology community.
- Another basic assumption that was discussed is that the choice between laboratory and field studies is clearly dependent on the study species, with larger organism and species with longer life spans (e.g. vertebrates) more suitable for field studies, while smaller organisms while shorter life cycles (e.g. bacteria, *Arabidopsis*, invertebrates) may be more adequate for laboratory experiments.
- One important aspect that was discussed regarding field experiments was the need for a more accurate dosimetry. Many previous field studies conducted in radioactive areas such as the Chernobyl Exclusion Zone lack of an adequate evaluation of radiation levels, which makes the interpretation and evaluation of these results very challenging. This is a crucial point that needs to be improved in order to move forward with field studies in radioecology.
- Everyone also agreed that we should make better use of the research experience with non-radioactive pollutants, trying to identify the main solutions used in this field to deal with confounding factors when conducting field studies.
- There was also a final plea for a more thorough use of the information already accumulated in field studies over the last years (especially since the Chernobyl accident), in particular with the possibility of re-calculation of dosimetry values from reported studies.

4.2 Feedback from Breakout Session 2: Implications of Chernobyl (and Fukushima) studies for current benchmark dose rates

The same format was followed as for breakout session one, however the four groups contained different people with different rapporteurs.

Feedback from Group One

Are there implications of the current studies?

- Most of the new information implies no effects below the benchmarks.
- The Møller and Mousseau group have published around 90 papers showing effects below the benchmarks, but they are mainly mutations. They should be taken into account.
- The last published revision of the FREDERICA effects databases was done in 2010, there are six years of publications which should be included in the database. It is not only to incorporate newly published data from the refereed literature but also to include available data from the grey literature and published in different languages (not English).
- But, what are the relevant effects which should be considered in deriving the benchmarks? Reproduction for maintaining the populations, while the effect of chromosomal damages on populations is not clear. It is difficult to correlate damages in the DNA with effects at the individual level.
- The benchmarks can be made more robust. Those derived in the ERICA and PROTECT projects[4]are appropriate as a generic benchmark. But they have problems in their application to different species. If we have more information for specific wildlife species groups we would have better data to derive wildlife group benchmarks.
- Studies should be focused on reproduction, fertility and fecundity endpoints and those wildlife groups less studied, when possible.

Have the current benchmarks being challenged by the newly published data?

- There are some publications challenging them, but maybe they do not pose a scientifically credible challenge. Dose rates for some of these papers need to be re-calculated and there is a need to reproduce some of the field studies.
- IRSN did re-calculate doses from some Møller and Mousseau papers, and then the resultant doses were not the same as those originally reported (difference by a factor of 2 to 10).
- Every calculation can be discussed as the selection of the factors is subjective and it has tremendous uncertainties difficult to quantify. There is a lack of information, for instance, on the behavior of animals in the ecosystem, their movements etc.
- Studies should not be focused on more complex organisms although they are more sensitive. All the ecosystem must be protected. In ICRP in addition to the sensitivity, exposure conditions should be included (e.g. trees do not move).
- There is a lot of work going on which will produce new data in the near future. How can they be included in the databases in order to improve the benchmarks?

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[4] See Anderson et al. (2009) http://dx.doi.org/10.1016/j.jenvrad.2009.05.010

- "Field studies show that field conditions are more sensitive than controlled laboratory studies."
- Should we decrease the benchmarks based on the laboratory experiments using a safety factor? In fact they are too conservative and we do not need to make them more conservative.
- Microdosimetry could improve our knowledge on how radioactivity affects the DNA and damage it. Monte Carlo calculations might help interpretation; the approach is used in the calculation of dose conversion coefficients
- We need to improve the quantity of internal dose data. Laboratory experiments are not realistic for internal dose. For example, injections are commonly used in laboratory internal exposure studies, discrepancies induced by using injection of radionuclides depends greatly on the radionuclides being studied.
- We use critical organs in the definition of Sievert for humans, but absorbed doses (Gy) for wildlife. Is it necessary or even possible to adopt an approach similar to Sv?
- Doses are calculated for the whole organism. Should they be calculated for some organs?
- What kind of practical mechanisms can be used if you are above the benchmarks? It is not practical to use them in existing situations, but in prospective calculations for planned releases. There could be justifications for being above the benchmarks in planned exposure situations (e.g. economic, social).
- ICRP 124 shows how DCRLs should be used for the different exposure situations. What is needed? Can RAPs be used? Should some specific organisms be used in specific exposure scenarios?
- Even if you have the perfect field study designed and performed (all confounding factors, all contaminants, all species in the ecosystem, etc.) and you finally obtain a perfect dose response curve, how would it affect the derivation of the benchmarks? The same organisms in different conditions, would produce different radiation effects curves because of the different conditions of exposure. The selection of the data would affect the derivation of the benchmark. Radiation is only one factor affecting the effects which can be different in different conditions.
- Relating the dose effects with natural variability should be important.
- Sufficient numbers of samples is important to define natural variability and to improve the statistics of the studies. Economic and time restrictions should be taken into account. Can field studies be reproduced/replicated? It is almost impossible.

Feedback from Group Two

I began with an accuracy warning: This is a journalist's report (the rapporteur for this session was one of the media representatives). As we know, they can go wrong.

- We were very cautious of the potential of the existing body of knowledge from field studies in Chernobyl and Fukushima to be turned into new or radically revised benchmarks. There are too many uncertainties about the actual observed effects, and also about the real doses which could be very different from estimates based on ambient levels.

- Benchmarks must, as now, be based mainly on laboratory studies, and strongly controlled field studies. But there is an evident growing disparity between field and laboratory studies that makes it ever harder to defend existing baselines. Trust in benchmark “safety levels” is breaking down in the public sphere. That is especially true given public discussion of high profile (if sometimes hard to believe) studies, such as those from Mousseau and Møller. Regulators are in a dilemma and existing benchmarks can be hard for them to defend.
- We badly need replication and re-analysis of field findings from Chernobyl and Fukushima, especially the outliers that challenge existing benchmarks. We also need access to the large amounts of “no effects” data, which often goes unpublished. As with research into the efficacy of pharmaceuticals, without “no effects” data, metastudies are hopelessly flawed.
- We need a lot more field research in general, in order to better inform the laboratory studies on which, as we agreed, baselines needed to continue to be based.
- But we also need better laboratory studies. There were many glaring gaps in existing laboratory research that often undermined their findings. These included a failure to assess internal as well as external doses; unrealistically short timescales for administering radiation that do not remotely reflect the real world; and generally unrealistic conditions.
- We discussed whether environmental benchmarks could benefit from greater cross-fertilization with human health research. There are major differences, of course, including in goals. But perhaps, especially at the level of genetics and examining mechanisms of harm, there is scope for cross-fertilization.
- We asked what benchmarks are for. To guide remediation after accidents? For regulation of industry? For waste disposal? Maybe there is sometimes incompatibility and inconsistency in benchmarks because data come from – or are designed for -- one activity, but end up being used for another.
- In conclusion we felt that, among regulators and the public, there was a growing sense that field data did not fit either laboratory data or benchmarks, and that this gap was a present threat both to the credibility of science and to nuclear industries. The problem is we do not currently have the data to fix it. That, of course, was why the workshop was being held.

Feedback from Group Three

Credibility of field studies revealing biological effects at very low doses was discussed. These results may be an issue for nuclear industries regarding the dose threshold (benchmark) for the protection of the environment especially for sensitive species.

- As a result, it was agreed that at the moment there are no reliable field data challenging current benchmark dose rates.

- To strengthen the reliability of field studies it was recommended to widely use new tools of GPS coupled dosimetry of mammals in contaminated areas both of Chernobyl and Fukushima.
- Representatives of regulatory bodies requested a simpler approach to the tools/standards to use, by using for instance one dose limit for all the species instead of several corresponding to different biological groups. But ecologists disagreed because of the different sensitivity of species which is important to consider.
- Finally, it was suggested to take into account the past history of contamination for the current effects observed. This may help to refine the dose at which the effects occur in the field.
- It was also mentioned that education in the field of dose assessment and effects on non-humans should be enhanced.
- There are field sites other than the CEZ and Fukushima such as Mayak, Savanah River and Uranium industry sites which have a long term contamination.

Feedback from Group Four

We did not need to answer this question as the summary presented by Clare Bradshaw (see above) had already done it.

Quite a large amount of the ecological data comes from one group of scientists, so it is important to consider the validity of these data. That said we have to assume studies were conducted in good faith. Comments are relevant to both the Fukushima and the CEZ field studies. One of the challenges is the fact that we are comparing different species in the laboratory and field. This will not be a problem if the laboratory species were to provide a representative distribution of sensitivity for the species in the field. But maybe they will not as they are the species we can work with in the laboratory which are more adaptable and so possibly more tolerant to stress.

There are some issues relating to how we protect the environment within a context of human exposure and what the interaction between the two is.

Human influences on the Chernobyl system cannot be ignored as they may affect some of the results.

How credible are the field studies

- Many of the field studies are credible. Many are conducted by people in the room, including within the COMET project, and have been done in good faith to the best level possible. Science has to get better both at supporting and accepting study repetition. This is a general issue that is undermining public trust in scientists.
- There needs to be a requirement in the field to make the data from studies open and this needs to be constantly reinforced. It is in the remit of journal editors to support the field and make data open, as well as the field itself to continually publicise and look to develop the tools to support it. Researchers are reluctant to do this – because they are lazy and secretive often, but these are not defensible reasons.

- There are some concerns with the data about the strength of correlation and the underlying models that are used. There were concerns about the dosimetry IRSN has modified this for some previously reported studies.
- Is there a need for a set of criteria that should be used? For example, a given effect size, a given level of correlation. Some fields have banned the use of p values in favour of effect sizes or correlation or just sanity checking if data/findings are believable.
- There is also something to consider about the way that data are reported. In some cases physicists have done a good job when they have found odd results to be more community engaged in understanding what is happening rather than going straight for the big news story.

Are current benchmarks challenged by the field study results?

- Yes. They are because some lower level effects are seen. Some of these are molecular so there is the inevitable question how these lower organisation level effects may relate to higher level effects. Is the change in mutation likely to affect populations in radioecology and indeed in any other field? Need long-term studies to reconcile this, but this is not really the reality of funding so it makes it difficult to make the link between observed effects and what the results of changes mean in the long-term.

What should we do if they benchmarks being challenged?

- Efforts to improve the dosimetry (both internal and external exposure) may explain that doses are being underestimated in some of the field studies.
- This needs careful communication as this is context dependent. Need to say something about the extent of challenge in relation to the specific concern that a regulator or the public may have. The interaction between the community and the public needs to be carefully considered. Trust in government and scientists is very important in being able to help people understand what risk will mean.

What improvements (if any) in study design are needed?

- Conducting long-term monitoring is a better way to fully understand trends than to just do a number of further one of field studies. This needs long-term support for annual or decadal studies which is certainly not the way that the funding is provided at the moment. How do we resolve this?
- Can we automate monitoring? For example remote sensing, camera traps, eDNA etc. are all ways of collecting data that might be able to be done at lower cost than sending people out to do comprehensive surveys. Archiving is important. Repositories are needed to curate data.

5. Comments from Stakeholders

Note: all presenters during this session were given the opportunity to submit an abstract following the meeting.

5.1 Regulator perspective

Pål Andersson (SSM, Sweden)

- RAPs and benchmarks are needed and they are a good way of working.
- There is nothing in legislation stating there is a requirement to be below benchmarks.
- The use of benchmarks is important, they are mostly sound, but more study is needed.

5.2 Regulator perspective

Tarja Ikäheimonen (STUK, Finland)

- Benchmarks are a good starting point but not are not generally accepted.
- Missing more research.
- Missing knowledge of effects.
- Missing tools.

5.3 Chernobyl and Fukushima, Non-Government Organisation (NGO) perspectives

Jill Sutcliffe (UK)

NGOs have played a key role in issues to do with radiation, wildlife and health[5]. The Low Level Radiation and Health Conference was started by members of the public in 1985 and aims to bring the latest research in an accessible form to a wider audience. The Chernobyl Children International group, including the UK – based organisation, has provided respite care for children, amounting to over 1 million visits to Europe including not only recuperative time away from the contaminated area but also medical treatment. It began in 1991 when Adi Roche, Ireland, responded to an appeal from doctors for aid when she received a fax "*SOS appeal. For god's sake, please help us get the children out*" (Pers Comm: Linda Walker, Chernobyl Children, UK). In 2010, the Declaration of Basel called for a worldwide ban on uranium mining/processing (www.nuclear-risks.org and others). In 2013, a book of CEZ photographs by Gerd Ludwig was published and symposium was held in New York in 2013 to examine health and ecological impacts (Caldicott, 2014).

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[5] The Low Level Radiation and Health Conference initially considered the impacts of radiation on wildlife at their 7th conference held in Bristol in 1991; and with other groups marked the anniversaries of the nuclear accidents in March 2016 in London +Manchester (presentations on websites of NFLA, Manchester CND and Chernobyl Children, UK).

As to health impacts Greenpeace and PSR/IPPNW[6] have followed the local populations in and around Chernobyl and evaluated the associated scientific peer reviewed papers. “These demonstrate a rise in **cancer,** not only thyroid, but also leukaemia, breast cancer etc.; a rise in **non-cancer diseases** (exceeds the cancer cases) such as endocrinological diseases (Basedow, Hashimoto, Diabetes) and lens diseases. In addition, **Genetic effects** including congenital malformations, a rise in perinatal mortality and stillbirths.”

“Populations affected include the **Clean-up workers**: where there has been a 20% increase in cancer (Okeanov, 2004), in ALL and C lymphatic leukaemia (Zablotska et al, 2012), thyroid cancer (Kesmiene et al, 2012); in the Gomel region, Belarus: the cancer rate has increased by 55.9 % and in Belarus overall: by 40% (Okeanov et al. 2004). Increases in **breast cancer** have been recorded in contaminated areas Gomel + Mogilov (Belarus) and Chernigov, Kiev, Zhytomir (Ukraine), (Pukkala et al. 2006).”

“In contaminated areas of Ukraine the increases in childhood **leukaemia** are significant where contamination was > than 10 mSv (Noshenko, 2010); and in Belarus (A. Körblein 2013) for babies in the first year after Chernobyl with an increase in number of **brain tumours** in children under 6 (Ukraine) which is a 5.8 fold increase (Orlov, Sharevsky, 2002)” (IPPNW, 2016).

Recommendations:

- Estimation of health effects on humans and wildlife can only be as accurate as baseline data.
- Need to set up CHERF Chernobyl Effects of Radiation Foundation which should have happened immediately after the accident (and/or extend RERF in Japan for Fukushima) and be ready for the next accident.
- Funding is needed for scientific effort to document range of biological consequences.
- Need to appreciate “inconvenient truths” – after all, the first paper on thyroid cancer (at Chernobyl) had to be fought for to be published whereas now that battle is not mentioned.

References

Caldicott, H. editor, 2014. Crisis Without End, the Medical and Ecological Consequences of the Fukushima Nuclear Catastrophe. Adapted from the Symposium held at the New York Academy of Medicine, March 11-12, 2013.

Flowers, B. 1976. *Nuclear Power and the Environment* (PDF) (6th ed.) London: Royal Commission on Environmental Pollution.

Ludwig, G. 2013. Photographer National Geographic Magazine. The Long Shadow of Chernobyl, Four chapters: Victims, Pripyat, The Zone and Reactor 4 and Mikhail Gorbachev essay. Lammerhuber, Austria.

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[6] Greenpeace TORCH reports 2006+16, Dr Ian Fairlie; PSR/IPNW reports and conversations (Dr Angelika Claussen).

IPPNW, 2016. 30 Years of Living with Chernobyl, 5 Years Living with Fukushima, Health effects of the nuclear disasters in Chernobyl and Fukushima. Reports by Physicians for Social Responsibility/International Physicians for the Prevention of Nuclear War, Berlin, Germany.

5.4 Industry perspective

Ari Ikonen (BIOPROTA)

- For proceeding in repository programmes, the essential question is whether we are confident enough that it is safe to take the next steps. This applies also to the rationales for the radiation protection of the biota.

- Considerable work to apply biota dose assessment approaches to radioactive waste disposal has readily been done in the BIOPROTA framework, but communication of the results to wider audiences could be enhanced. The IAEA MODARIA II programme would seem a potential forum for this since it incorporates both biota assessment issues (working group 5) and the upgrade of the BIOMASS-6 overall assessment methodology for the waste disposal (working group 6).

5.5 Industry perspective

Mikko Kärkkäinen (Posiva Oy, Finland)

- Need to consider long timelines.

5.6 Media perspective

Fred Pearce (New Scientist magazine)

- Stated that present at the workshop to look at the interplay between science, social impact and the politics of radiation. He is currently writing a book entitled *Nuclear Landscapes*.
- Radiophobia – do we suffer from it? How does the public deal with it?
- Fukushima – initial efforts stopping people eating food worked well but efforts to move people back seem to be going less well.
- Creating infrastructure and getting science right is the only way to gain public trust.
- How do we deal with scientific uncertainty in an environment of real fear? Normal for scientists, but corrosive in public sphere.
- Shocked by how little we know 70 years post the Manhattan project.
- Scientists should always be aware of the social context of where they are working.
- I hope I can be part of the solution and deliver truth.

5.7 Media perspective

Luke Massey (Wildlife photographer)

- Luke was present at the workshop prior to a visit to the CEZ he wants to work with radioecologists in the Zone to tell a proper story. His work focuses on conservation issues, science, and reconnecting people with nature. Having grown up in a generation who played PlayStation games shooting wolves in Pripyat he now wants to show the public something different.

5.8 View from ICRP C5

Almudena Real

- Since 2005 the ICRP has considered it is important to put in effort to the situations that require it.
- There are three main ICRP publications[7] related to protection of the environment, Publication 108 developed the concept of Reference Animals and Plants (RAPs) with Publications 114 and 124 expanding upon this context.
- DCRLs, taking into account other factors, let us know where we can focus our efforts.
- Need a framework to demonstrate the environment is protected, however limited resources available, so need to focus. We have the beginning of the framework – biology, dosimetry, effects.
- The term 'Severe Effects Level'– is widely used in chemical industry.
- Application: Even in emergency situation after humans evacuated, we could begin to consider wildlife, as this may be needed for public communication.

Comment from the floor - Disagree with Almudena's comment, you do not want to plan to cause deleterious effects.

5.9 Science perspective

David Copplestone

- Planned exposure system will remain – being below the DCRL lower band should still be the target.
- You can go into the DCRL band, but you need to justify it.
- It is important that we, as scientists, make sure our data are available to everyone.
- Need to publish 'no effect' data.
- There is a problem with the peer review process. Reviewers do not always understand. I do not know how we fix it.
- Statistical rigor with full explanation should come into the papers.
- Good p-values do not mean causative relations in the real world.
- You need to think about how you design your study to address a question.
- Baker and Chesser wrote in 'Growing up with Chernobyl' - *Beautiful theories are often ruined by ugly facts* – be objective (it is not easy).
- Do everything we can to be as objective as we can – look at the data e.g. dosimetry.
- Make sure you understand the history of your site.
- Scientists must have a single agenda – the truth.

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[7] http://www.icrp.org/publications.asp

- Extraordinary results require extraordinary evidence.
- Take medical data into account – radioactive materials are important there too.
- Need to be certain of low level of effects.
- If the data are ‘the data’ then we will need to deal with it and have confidence in it.
- Be prepared to be unpopular and uncomfortable.

5.10 Comments on research in CEZ

Sergey Gaschak

- My experience is a lot of research groups that come to the Zone do not understand radiation, the CEZ and its diverse nature.
- Need a competent choice of methodology, questions, etc. and to be a sceptic.

6. Acknowledgements

We would like to thank all attendees for their active participation in the workshop. We would also like to thank Svetlana Chesnokova (Chornobyl Center, Ukraine) for her help in organising and running the workshop.

Appendix 1 – Workshop attendees

Name	**Organisation, Country**
Christelle Adam-Guillermin	IRSN, France
Pål Andersson	Swedish Radiation Safety Authority, Sweden
Cath Barnett	NERC-CEH, UK
Clare Bradshaw	Stockholm University, Sweden
Nick Beresford	NERC-CEH, UK
Karine Beaugelin-Seiller	IRSN, France
Olena Burdo	National Academy of Sciences of Ukraine, Ukraine
Caitlin Condon	Oregon State University, USA
David Copplestone	University of Stirling, UK
Jacqueline Garnier-Laplace	IRSN, France
Sergey Gaschak	Chornobyl Center, Ukraine
Dmitri Gudkov	Institute of Hydrobiology of the NAS of Ukraine
Anna-Lea Golz	Stockholm University, Sweden
Nele Horemans	SCK-CEN, Belgium
Tarja Ikäheimonen	STUK-Radiation and Nuclear Safety Authority, Finland
Ari Ikonen	EnviroCase, Ltd., on behalf of BIOPROTA, Finland
Mikko Kärkkäinen	Posiva Oy, Finland
Aleksei Konoplev	Fukushima University, Japan
Adelaide Lerebours	University of Portsmouth, UK
Sviatoslav Levchuk	NUBiP, Ukraine
Luke Massey	http://www.lmasseyimages.com/
Susan Molyneux-Hodgson	University of Sheffield (now University of Exeter), UK
Juan-Carlos Mora	CIEMAT, Spain
Carmel Mothersill	McMaster University, Canada
Maarit Muikku	STUK-Radiation and Nuclear Safety Authority, Finland
Kenji Nanba	Fukushima University, Japan
Liubov Nagorskaya	National Academy of Science, Belarus
Germán Orizaola	Uppsala University/Stockholm University, Sweden
Fred Pearce	New Scientist Magazine, UK
Almudena Real	CIEMAT, Spain
Richard Shaw	BGS, UK
Dave Spurgeon	NERC-CEH, UK
Maryna Shkvyria	Schmalhausen Institute of Zoology NAS, Ukraine
Jill Sutcliffe	Low Level Radiation and Health Conference
Masanori Tamaoki	National Institute for Environmental Studies, Japan
Eugene Tukalenko	Taras Shevchenko National University of Kyiv, Ukraine/University of Jyväskylä, Finland
Sam Welch	NERC-CEH, UK
Yegor Yakovlev	Schmalhausen Institute of Zoology NAS, Ukraine
Vasyl Yoschenko	Fukushima University, Japan

Appendix 2 – Agenda

Date/Time	**Item**	**Presenter**
29th August 2016		
16:00	Meet Borispol airport Kiev (latest flight arrival 15:30)	
19:30	*Registration and meeting*	
20:30	*Dinner*	
30th August 2016		
08:45	Welcome, aims, outputs, etc.	Sergey Gaschak (Chernobyl Center, Ukraine) & Nick Beresford (NERC-CEH, UK; COMET)
Session: How do we resolve the anomalies between field and laboratory studies? Chair: David Copplestone		
09:15	Is non-human species radiosensivity in the lab a good indicator of radiosensitivity in the wild?	Jacqueline Garnier-Laplace (IRSN, France)
09:45	Comparison of laboratory v's field effects for non-radioactive pollutants	Dave Spurgeon (NERC-CEH, UK)
10:15	Breakout sessions: are there anomalies between laboratory and field studies, what can we learn from non-radioactive pollutants? *Coffee available*	
11:30	Report back from Breakout sessions	Rapporteurs
12:15	*Lunch*	
Session: Research in Chernobyl and Fukushima Zone Chair: Jacqueline Garnier-Laplace		
13:15	An overview of field studies in the CEZ and FEZ	David Copplestone (Univ. of Stirling, UK) & Nick Beresford (NERC-CEH, UK)
14:00	Characterisation of the radiation effects on wildlife inhabiting contaminated area and influence of the dose estimate	Christelle Adam-Guillermin (IRSN, France)
14:30	Effects of long-term radiation exposure on aquatic biota in	Dmitri Gudkov (Institute of Hydrobiology, Ukraine)

	lentic ecosystems within the Chernobyl Exclusion Zone	
14:50	Assessment of radiation effects in birds breeding in Red Forest area (2003-2005): problems of research approaches and interpretation of the results	Sergey Gaschak (Chornobyl Center, Ukraine)
15:10	*Break: Coffee*	
15:30	Effects of radiation on the health of fish from Chernobyl	Adelaide Lerebours (University of Portsmouth, UK)
16:00	Current state and objectives of research of large carnivores in the exclusion zone	Maryna Shkvyria (Schmalhausen Institute of Zoology, Ukraine)
16:20	Complex radiobiological investigations of small rodents from the Chernobyl Exclusion Zone	Olena Burdo (Institute for Nuclear Research, Ukraine)
16:40	A study of radiation effects on ecosystem and wildlife in areas affected by the Fukushima accident	Masanori Tamaoki (National Institute for Environmental Studies, Japan)
17:10	Morphological abnormalities in Japanese red pine in Fukushima zone	Vasyl Yoschenko (Fukushima University, Japan)
17:40	*Opportunity for open discussion*	
	Close	
19:30	*Workshop dinner*	
31st August 2016		
Session: Implications of Chernobyl (and Fukushima) studies for current benchmark dose rates Chair: Christelle Adam-Guillermin		
08:45	How are current benchmarks used in radiological assessments derived?	Almudena Real (Ciemat, Spain)
09:15	Summary of *Session: Research in Chernobyl and Fukushima Zone*	Clare Bradshaw (Stockholm University, Sweden)

09:30	Breakout session: Implications of Chernobyl (and Fukushima) studies for current benchmark dose rates	
11:00	*Coffee available*	
11:15	Report back from Breakout sessions	Rapporteurs
Session: What next for field studies in Chernobyl? Chair: Sergey Gaschak		
12:00	Estimating radiological exposure of wildlife in the field	Karine Beaugelin-Seiller (IRSN) & Nick Beresford (NERC-CEH)
12:40	The PROBA database	Valery Kashparaov (NuBiP, Ukraine)
13:00	*Lunch*	
14:00	*Session: Thoughts from the research users & discussion* Chair: Nick Beresford	
	Regulator perspective	Pål Andersson (SSM, Sweden)
	Regulator perspective	Tarja Ikäheimonen (STUK, Finland)
	NGO perspective	Jill Sutcliffe (UK)
	Industry perspective	Ari Ikonen (BIOPROTA)
	Industry perspective	Mikko Kärkkäinen (Posiva Oy, Finland)
	Media perspective	Fred Pearce (New Scientist)
	Media perspective	Luke Massey (Wildlife photographer)
	View from ICRP C5	Almudena Real (ICRP C5)
	Science perspective	David Copplestone
15:30	*Break: coffee*	
16:00	Open discussion and way forward/outputs from the workshop	Chairs: Christelle Adam-Guillermin, David Copplestone, Nick Beresford, Sergey Gaschak
17:00	*Close of workshop*	
18:00	*Optional: walking tour*	
Free for Dinner (i.e. nothing arranged!)		
1st September 2016		
07:45	Optional trip to the CEZ then Borispol	
08:30	Leave for Kiev airport (if not taking CEZ trip)	