Estimating radiological exposure of wildlife in the field

Karine Beaugelin-Seiller\textsuperscript{1}, Jacqueline Garnier-Laplace\textsuperscript{1}, Nick Beresford\textsuperscript{2}

\textsuperscript{1}IRSN / CEH\textsuperscript{2}
Objectives

- What do we want to know?
  quantifying **effect of exposure** in the field for actual organisms
Objectives

• What do we want to know? Effect of exposure
• What do we know?
  – Exposure ($\mu$Sv.h\(^{-1}\), Bq.m\(^{-2}\), Bq.L\(^{-1}\)...)
  – Effect: benchmarks ($ED(R)_x$, PNEDR, DCRLs...)

COMET workshop • *Thirty years after the Chernobyl accident* ...Ukraine 30-31 August 2016
Objectives

- What do we want to know? Effect of exposure
- What do we know? Effect benchmarks
- What do we need to assess?
  - A somewhat realistic comparable endpoint: the dose (rate) experienced by exposed organisms
Objectives

- What do we want to know? Effect of exposure
- What do we know? Effect benchmarks
- What do we need to assess? Realistic dose(rate)
- The way to proceed: dose reconstruction
Dose assessment & ERRA

- “Retroprocessing” the well established scheme

1. Define the conditions for the potential wildlife exposure
2. Benchmarks definition for radiotoxicity
3a. Concentrations (Bq/L or Bq/kg)
3b. Dose rates (µGy/h)
4. Comparison exposure/effects

Exposure analysis
- (pathways, transfers, dosimetry)

Problem formulation

Risk characterisation
- Effects analysis
  - (dose-response relationships, reference levels)
The exposure analysis

- Additivity!
  - Total dose (rate) to each organism ‘o’

\[
\text{internal dose rate} + \text{external dose rate} = \text{total dose rate}
\]

\[
EDR(o) = \sum \sum \text{OF}. DC_{\text{ext}}(RN, o). [RN]_{\text{medium}}
\]

\[
IDR(o) = \sum \sum \text{DC}_{\text{int}}(RN, o). [RN]_o
\]
The exposure analysis

- Parameters to consider
  - Organism life stage
  - Organism habitat/behavior

Aquatic bird (e.g. brown dipper)

« Aerial » bird (e.g. carrion crow)

Terrestrial bird (e.g. skylark)
The exposure analysis

- Parameters to consider

![Bar chart showing exposure analysis for different bird types](image)

**Aquatic bird (e.g. brown dipper)**
- Internal contribution
- External contribution

**Aerial bird (e.g. carrion crow)**
- Internal contribution
- External contribution

**Terrestrial bird (e.g. skylark)**
- Internal contribution
- External contribution

*too far from soil source – no external contribution (only considered pathway for eggs)*
The exposure analysis

• Parameters to consider
  – Organism life stage
  – Organism habitat/behavior
  – Radiation « quality »/organism/habitat
The exposure analysis

- Parameters to consider

![Diagram showing internal and external contributions of different emitters to exposure analysis.

**α emitters**

- **241Am**
- **238Pu**

**Rat**

**Earthworm**

**Internal contribution**

**External contribution**
The exposure analysis

- Parameters to consider

\[ \begin{array}{c|c|c}
\alpha & \text{Rat} & \text{Earthworm} & \text{Rat} \\
& \text{\( ^{241}\text{Am} \)} & \text{\( ^{238}\text{Pu} \)} & \\
\beta & \text{Rat} & \text{Earthworm} & \text{Rat} \\
& \text{\( ^{137}\text{Cs} \)} & \text{\( ^{90}\text{Sr} \)} & \\
\gamma & \text{Earthworm} & \text{Rat} & \\
& \text{\( ^{60}\text{Co} \)} & & \\
\end{array} \]

- Internal contribution
- External contribution
The exposure analysis

- Exposure analysis
  - NPP authorized releases
The exposure analysis

- Exposure analysis
  - Upstream in the nuclear cycle
The problem formulation

- Hazard identification and characterisation

Hazard

- Radionuclide inventory:
  - Qualitative
  - Quantitative
  - Exhaustive

Exposure pathways

Targets

γ emitters
α emitters
β emitters

All RNs potentially present

Bq released
Bq.cm⁻²
Bq.kg⁻¹
The problem formulation

• Target identification & characterisation

Hazard

- Radionuclide inventory:
  - Qualitative
  - Quantitative
  - Exhaustive

Exposure pathways

Targets

- Target inventory:
  - RAPs/ROs/actual

  - Characteristics
    - «shape»
    - behaviour

Tier?
Local knowledge?

Equivalent ellipsoid?
Habitat (OF)?
Diet (CR)?
The problem formulation

- Characterisation of target exposure to hazard

**Hazard**
- Radionuclide inventory:
  - Qualitative
  - Quantitative
  - Exhaustive

**Exposure pathways**
- Pathway inventory:
  - External
    - Air?
    - Soil?
    - Vegetation?
    - Etc.
  - Internal
  - Duration

**Targets**
- Target inventory:
  - RAPs/ROs/actual
  - Characteristics
    - « shape »
    - behaviour
The problem formulation

- From the real world…
The problem formulation

• ...to its conceptualization

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>Deposit</th>
<th>Deposit</th>
<th>Deposit</th>
<th></th>
<th>X</th>
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<tbody>
<tr>
<td></td>
<td>Deposit</td>
<td>Deposit</td>
<td>Deposit</td>
<td></td>
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<tr>
<td></td>
<td>Forest soil</td>
<td>Root</td>
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<td></td>
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<td>transfer</td>
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<td>transfer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Bank soil</td>
<td>Root</td>
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<td>Root</td>
<td>X</td>
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<td></td>
<td></td>
<td>transfer</td>
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<td>transfer</td>
<td></td>
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<tr>
<td></td>
<td>Grass</td>
<td></td>
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<td>X</td>
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<td></td>
<td>Sediment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td></td>
<td>Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Summary: answering the “w” questions

- **Who/what** is exposed?
- To **which** source-term?
- **Where**?
- **When**?
- **How**?
The ideal data set?

- External exposure

Which organism, which source(s)?

- Bq/kg wet mass
- Bq/m³
- Bq/L
The ideal data set?

- External exposure

When?

Bq/m³

Bq/kg wet mass

Bq/L

Bq/kg wet mass

Bq/kg wet mass

Bq/kg wet mass
The ideal data set?

- External exposure

How?

Bq/m³

Bq/kg wet mass

Bq/kg wet mass

Bq/kg wet mass

Bq/kg wet mass

Bq/L

Thickness H & composition %
The ideal data set?

- External exposure: summary
  - Relevant exposure scenario(s)
  - For each scenario:
    - Activity concentration of each radionuclide in each source
    - Fraction of time spent in these exposure conditions
    - $DC_{ext}$
      - Tabulated
      - Calculated
    - Geometry and composition of sources (→ organisms)

Location of each individual

http://water.usgs.gov/ogw/bgas/spectral_gamma/
The ideal data set?

- External exposure
- Internal exposure: the winning formula

\[ D_{\text{int}} = \text{Bq/kg wet mass, whole body} \]

Spectrum courtesy of D. Orjollet, IRSN
### The ideal data set?

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<td>Any external source (Bq/kg or Bq/L, wet mass)</td>
<td>Each individual (Bq/kg wet mass, whole body)</td>
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<td>Fraction of time spent in a given exposure situation</td>
<td>Required for organisms feeding in different habitats</td>
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<tr>
<td>Source composition</td>
<td>Any external source</td>
<td>Species</td>
</tr>
<tr>
<td>Source dimension</td>
<td>Thickness of any external source</td>
<td>Equivalent ellipsoid</td>
</tr>
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<td>For any external source</td>
<td>No meaning</td>
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How to do better: an actual case

- Dose reconstruction for birds in Japan

  - Available data set

- Ambient dose rate
- Census data (bird species-57- and their abundance)
- Some meteorology & landscape descriptors

- Soil radioactive contamination data
**How to do better: an actual case**

- **Dose reconstruction for birds in Japan**

  - Available data set
    - Ambient dose rate
    - Census data (bird species-57- and their abundance)
    - Some meteorology & landscape descriptors
    - Soil radioactive contamination data
  - Objective: to reconstruct dose rates to animals to explain observed effects on bird abundance and diversity.
Dose reconstruction for birds in Japan

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</tr>
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<tbody>
<tr>
<td>Activity concentration for each radionuclide</td>
</tr>
<tr>
<td>Association of each census point (⚫) with the nearest soil sampling point (Japanese survey, color points) different for Cs isotopes (134=137) and $^{131}$I</td>
</tr>
</tbody>
</table>

- Occupancy factors
- Source composition
- Source dimension
- Distance to source

How to do better: an actual case
How to do better: an actual case

- Dose reconstruction for birds in Japan

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<tr>
<th>Occupancy factors</th>
<th>Terrestrial birds =&gt; two locations (on soil/At a given distance from soil – e.g. nest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little swift (0,1)</td>
<td></td>
</tr>
<tr>
<td>Eurasian skylark (1,0)</td>
<td></td>
</tr>
<tr>
<td>Crow (0.5, 0.5)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>birds</th>
<th>On soil</th>
<th>At distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘aerial’</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>‘terrestrial’</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>others</td>
<td>x</td>
<td>1-x</td>
</tr>
</tbody>
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Source composition
Source dimension
Distance to source
How to do better: an actual case

- Dose reconstruction for birds in Japan

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| **Occupancy factors** | Terrestrial birds => two locations (on soil/At a given distance from soil – e.g. nest)  
| **Source composition** | Soil (1.7 g.cm⁻³)  
| **Source dimension** |  
| **Distance to source** |  

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>26.00</td>
</tr>
<tr>
<td>Al</td>
<td>7.40</td>
</tr>
<tr>
<td>Fe</td>
<td>4.20</td>
</tr>
<tr>
<td>Mg</td>
<td>2.10</td>
</tr>
<tr>
<td>Na</td>
<td>2.40</td>
</tr>
<tr>
<td>C</td>
<td>0.18</td>
</tr>
<tr>
<td>Ca</td>
<td>3.30</td>
</tr>
<tr>
<td>H</td>
<td>0.96</td>
</tr>
<tr>
<td>K</td>
<td>2.30</td>
</tr>
<tr>
<td>N</td>
<td>0.03</td>
</tr>
<tr>
<td>S</td>
<td>0.11</td>
</tr>
<tr>
<td>P</td>
<td>0.11</td>
</tr>
<tr>
<td>O</td>
<td>51.00</td>
</tr>
</tbody>
</table>

How to do better: an actual case
### How to do better: an actual case

- **Dose reconstruction for birds in Japan**

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<tr>
<td>Source composition</td>
<td>Soil (1.7 g.cm$^{-3}$ and elemental composition)</td>
</tr>
<tr>
<td>Source dimension</td>
<td>20 cm thick (conservative estimate of the contaminated layer from Chernobyl observations)</td>
</tr>
<tr>
<td>Distance to source</td>
<td></td>
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How to do better: an actual case

- Dose reconstruction for birds in Japan

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</tr>
<tr>
<td><strong>Source dimension</strong></td>
<td>20 cm thick</td>
</tr>
<tr>
<td><strong>Distance to source</strong></td>
<td>Nest location</td>
</tr>
<tr>
<td>Great reed warbler (0.5 m)</td>
<td></td>
</tr>
<tr>
<td>Little swift (10 m)</td>
<td></td>
</tr>
<tr>
<td><strong>Nest location</strong></td>
<td></td>
</tr>
<tr>
<td>birds</td>
<td>distance</td>
</tr>
<tr>
<td>‘terrestrial’</td>
<td>0</td>
</tr>
<tr>
<td>others</td>
<td>From 0.5 to 10 m</td>
</tr>
</tbody>
</table>
## How to do better: an actual case

- Dose reconstruction for birds in Japan

<table>
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<th>Activity concentration for each radionuclide</th>
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<tr>
<td>CRs = f(diet or species) with diet = [herbivorous, omnivorous]</td>
<td></td>
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<table>
<thead>
<tr>
<th>birds</th>
<th>Cs</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>herbivorous</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>omnivorous</td>
<td>0.57</td>
<td>0.4</td>
</tr>
<tr>
<td>White-cheeked starling</td>
<td>0.174 (data for another species of the same genus)</td>
<td>0.4</td>
</tr>
<tr>
<td>Japanese trush</td>
<td>0.0517 (data for another species of the same genus)</td>
<td>0.4</td>
</tr>
<tr>
<td>Great tit</td>
<td>0.559 (data for this species)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occupancy factors</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Source composition</td>
<td></td>
</tr>
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# How to do better: an actual case

- Dose reconstruction for birds in Japan

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<tr>
<td>Activity concentration for each radionuclide</td>
<td>CRs = f(diet or species) with diet = [herbivorous, omnivorous]</td>
</tr>
<tr>
<td>Occupancy factors</td>
<td>No need (feeding in the terrestrial ecosystem only)</td>
</tr>
<tr>
<td>Source composition</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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**How to do better: an actual case**

- Dose reconstruction for birds in Japan

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<tbody>
<tr>
<td>Occupancy factors</td>
<td>No need</td>
</tr>
<tr>
<td>Source composition</td>
<td>Organic matter (1.1 g.cm(^{-3}))</td>
</tr>
<tr>
<td>Source dimension</td>
<td></td>
</tr>
<tr>
<td>Distance to source</td>
<td></td>
</tr>
</tbody>
</table>

### Source composition

- **C, 19.00**
- **O, 63.00**
- **Na, 0.26**
- **Mg, 0.04**
- **K, 0.22**
- **Fe, 0.01**
- **Ca, 1.40**
- **P, 0.63**
- **S, 0.64**

---

**Internal exposure**

**Activity concentration for each radionuclide**

**Occupancy factors**

**Source composition**

**Source dimension**

**Distance to source**
### How to do better: an actual case

- Dose reconstruction for birds in Japan

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<tr>
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<td>Source composition</td>
<td>O.M. (1.1 g.cm(^{-3}) and elemental composition)</td>
</tr>
<tr>
<td>Source dimension</td>
<td>Equivalent revolution ellipsoid deduced for each species from body mass and length</td>
</tr>
</tbody>
</table>

#### Source dimensions

- **Gold crest**
  - Body mass (g): 5.7
  - Body length (cm): 4.9
  - Short axis (cm): 1.4

- **Northern Goshawk**
  - Body mass (g): 1024.5
  - Body length (cm): 35.5
  - Short axis (cm): 7.2

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*COMET workshop • Thirty years after the Chernobyl accident ...* Ukraine 30-31 August 2016
### How to do better: an actual case

- Dose reconstruction for birds in Japan

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<td>Uniform contamination of the ellipsoid</td>
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How to do better: an actual case

- Dose reconstruction for birds in Japan

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<td>Nest location</td>
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Want to know/discuss something more? Please ask…

........... then a little from Nick
Thinking about how exposure is estimated in the field

- Often using dose rate meters (at ground surface) reporting in $\mu\text{Sv/h}$
  - Sometimes relatively few measurements (e.g. 2-3 per 100 m transect)
Deposition in CEZ – is highly variable

The map of the 30-km Chernobyl zone terrestrial density of contamination with cesium-137 (on 1997)
So need to consider home ranges

Estimating soil contamination in home ranges of different species
Variable at small scale as well

![Map of Chernobyl exclusion zone with radiactivity levels in kBq/kg for Cs-137 and Sr-90.

Medium site: 13-120, 2-61
High site: 28-210, 7-170
Low site: 2.24, <1-6

Chernobyl NPP

30-31 August 2016

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Variable at small scale as well

28 kBq/kg Cs-137

210 kBq/kg Cs-137

200 m

30.035000 30.036000 30.037000 30.038000 30.039000 30.040000
51.380000 51.380500 51.381000 51.381500 51.382000 51.382500

COMET workshop • Thirty years after the Chernobyl accident ...Uk
Variable at very small scale as well

Dose changes 3-fold
Estimating dose – by measurement

(TLD (LiF:Mg,Cu, P))

(RPLD)

Instadose 2

COMET workshop • Thirty years after the Chernobyl accident ...Ukraine 30-31 August 2016
TLD (bank vole) v’s dose meter

µGy/h

Dose meter reading

TLD

0 10 20 30 40 50 60 70

0 10 20 30 40
Site specific transfer data

- Will be made available as published datasets:
  - small mammals, passerine birds, amphibians, some reptiles, plants insects

The Chernobyl Exclusion Zone Observatory site

The Chernobyl Exclusion Zone (CEZ) is one of the most radioactively contaminated sites in the world. Established shortly after the accident in 1986, the CEZ was initially the area within the 30 km radius around the Chernobyl Nuclear Power Plant. Over the last 25 years the borders have expanded. The Ukrainian area (approximately 2600 km²) contains forests, abandoned farmlands, wetlands, flowing waters, standing waters, deserted villages and urban areas. The Belarusian area (approximately 2160 km²) consists mainly of swamps, marshes and peat-bogs where forest land occupies about one half of the territory; areas not forested are mostly former reclaimed agricultural lands and meadows. The CEZ is relatively flat (approximately 100-200 m above sea level). The Pripet River, a main tributary of the Dnieper, runs through the zone for about 80 km which has maximum flow rates exceeding 5,000 m³ s⁻¹ (range: 600 to 2,200 m³ s⁻¹). The climate is temperate-continental with the growing period beginning around mid-April and ending in late October; snow cover remains for about 60 days, with significant deviations in some years.

The most important radionuclides (which were originally present as particles in a range of sizes) include:

- $^{137}$Cs, $^{90}$Sr, $^{241}$Am, Pu-isotopes and U-isotopes

http://www.radioecology-exchange.org/
Transfer parameters for ICRP reference animals and plants collected from a forest ecosystem

C. L. Barnett · N. A. Beresford · L. A. Walker · M. Baxter · C. Wells · D. Copplestone

Dataset
Element and radionuclide concentrations in representative species of the ICRP's Reference Animals and Plants and associated soils from a forest in north-west England

This resource is made available under the terms of the Open Government Licence

http://doi.org/10.5285/e40b33d4-6559-4557-bd55-10e196e6e5ea

This dataset presents the results of an initial sampling exercise conducted at a terrestrial site in north-west England in summer 2010. The following samples of terrestrial Reference Animals and Plants (RAPs) were obtained from an area of circa 0.4 km squared: Molinia caerulea (ICRP RAP Wild Grass defined as Poaceae); Picea sitchensis (ICRP RAP Pine Tree defined as Pinaceae); Apis spp., Bombus spp., Nomada spp. (ICRP RAP Bee defined as Apoidea); Apodemus sylvaticus (ICRP RAP Rat defined as Muridae); Earthworms (species in the Family Lumbricidae as defined for the ICRP RAP Earthworm); Deer (belonging to the Family Cervidae (i.e. the ICRP RAP Deer)). Soil samples were also collected from throughout the sampling area. All samples were analysed for multiple elements using ICP-MS/ICP-OES and most for gamma-emitting radionuclides. Results have been used to derive biota-soil concentration ratios. The ICRP have published their framework for radiation protection of the environment (ICRP Publication 108). This describes the use of RAPs as the basis for their framework. The RAPs are generalised to the taxonomic level of Family. Publication 108 presented dose coefficient values for the selected RAPs and also reviewed data on the effects of ionising radiation to suggest Derived Consideration Reference Levels for each RAP. In summer 2010 the ICRP released a further report on their protection framework for consultation. This report presented transfer parameter values (organism-media concentration ratios) for Reference Animals and Plants. The report also raised the possibility of identifying a series of sites where samples of each Reference Animal and Plant, and their different lifestages, could be collected and analysed. It was suggested that the resultant data would constitute a set of reference values analogous to approaches used by the ICRP for human radiological protection.

Publication date: 2013-12-31
Often a journal/funder requirement but not enforced:

The entire data set is reported in Appendix 1. Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2012.10.025.
Often a journal/funder requirement BUT:

The entire data set is reported in Appendix 1. Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2012.10.025.

Appendix 1. Abundance of mammals and effect size of the relationship between abundance and background radiation (z transformed Pearson product-moment correlation coefficient) recorded during 161 line transects around Chernobyl in February 2009.

<table>
<thead>
<tr>
<th>Species</th>
<th>Latin name</th>
<th>Abundance</th>
<th>Effect size (z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox</td>
<td><em>Vulpes vulpes</em></td>
<td>147</td>
<td>-0.490</td>
</tr>
<tr>
<td>Wolf</td>
<td><em>Canis lupus</em></td>
<td>70</td>
<td>0.089</td>
</tr>
<tr>
<td>Hare</td>
<td><em>Lepus europaeus</em></td>
<td>49</td>
<td>-0.364</td>
</tr>
<tr>
<td>Mouse</td>
<td><em>Apodemus sp.</em></td>
<td>45</td>
<td>-0.087</td>
</tr>
<tr>
<td>Squirrel</td>
<td><em>Sciurus vulgaris</em></td>
<td>43</td>
<td>-0.141</td>
</tr>
<tr>
<td>Red deer</td>
<td><em>Cervus elaphus</em></td>
<td>23</td>
<td>-0.210</td>
</tr>
<tr>
<td>Przewalski’s horse</td>
<td><em>Equus przewalskii</em></td>
<td>21</td>
<td>-0.075</td>
</tr>
<tr>
<td>Roe deer</td>
<td><em>Capreolus capreolus</em></td>
<td>13</td>
<td>-0.194</td>
</tr>
<tr>
<td>Moose</td>
<td><em>Alces alces</em></td>
<td>12</td>
<td>-0.022</td>
</tr>
<tr>
<td>Wild boar</td>
<td><em>Sus scrofa</em></td>
<td>11</td>
<td>-0.138</td>
</tr>
<tr>
<td>Marten</td>
<td><em>Martes foina</em></td>
<td>9</td>
<td>-0.011</td>
</tr>
<tr>
<td>Stoat</td>
<td><em>Mustela erminea</em></td>
<td>2</td>
<td>-0.133</td>
</tr>
</tbody>
</table>
Why bother?

From a series of ‘Letters to Editors’
Environmental Pollution 2012

we note that Beresford et al. have not published any of their Chernobyl data.
Why bother?

From a series of ‘Letters to Editors’
Environmental Pollution 2012

we note that Beresford et al. have not published any of their Chernobyl data.

Many of the issues we have with field effects studies would be resolved if data were published
Thank you