Institution: University of Stirling		
Unit of Assessment: 14. Geography and Environmental Studies		
Title of case study: Creating global evidence-based radiological protection for the environment		
Period when the underpinning research was undertaken: 2010 to present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
David Copplestone	Professor	09/2010 to present
Matthew Tinsley	Senior Lecturer	09/2004 to present
Katherine Raines	Research Fellow, then Lecturer	09/2015 to present
Period when the claimed impact occurred: January 2014 to Dec 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Radioactive wastes are discharged from permitted sites such as hospitals, research facilities, nuclear power stations and through decommissioning activities. Successful protection of the environment requires accurate assessment of the impact of **every permitted site** on wildlife; Stirling research makes this possible, having:

Impact 1: developed the ERICA (Environmental Risk from Ionising Contaminants management and Assessment) software tool and Noble Gas Calculator, which are **the most widely used environmental radiological assessment tools internationally**.

Impact 2: built capacity and resilience in organisations that have **implemented ERICA in regulatory and industrial contexts in over 20 countries** (including Australia, Brazil, Canada, Egypt, Japan, UK) reducing risk to business and bringing cost and time-saving benefits.

Impact 3: underpinned the International Commission on Radiological Protection (ICRP)'s recommendations that form the **basis of standards, legislation and practice worldwide;** these recommendations now include environmental protection.

2. Underpinning research

The International Commission on Radiological Protection (ICRP) is the independent body upon which the United Nation's International Atomic Energy Agency (IAEA) and every nation that uses radioactive materials base their radiological protection regulations. ICRP initiated a landmark shift in direction in 2007 by extending the scope of radiological protection to the environment, where previously it had only been concerned with humans. Policy advice, radiological assessment tools and the underpinning data required to demonstrate radiological environmental protection were all lacking, and major research was therefore required. Stirling researchers have been at the forefront of much of this research, conducted in partnership with researchers in the UK and internationally.

Stirling research has been essential to the development of the most widely used **radiological assessment tool, ERICA** (Environmental Risk from Ionising Contaminants management and Assessment) (see **Impact 1**). Version 1.2 of the ERICA tool was released in November 2014 and relied upon updates described in **R1,** the most important being a major revision to the concentration ratio (CR) data underpinning the tool (CRs are used to predict the transfer of radionuclides into wildlife and allow the calculation of internal doses to wildlife). The revised data were compiled in an online database (the Wildlife Transfer Database: www.wildlifetransferdatabase.org/) that Copplestone was instrumental in establishing (**R2**). This database is the primary source of CR data for wildlife globally and is used in UN IAEA and ICRP publications. It tackled the greatest source of uncertainty in wildlife dose assessments by reducing uncertainty, significantly, from four orders of magnitude to less than one. It also underpins the CR data for the new ICRP 'Reference Animals and Plants' (RAPs) that form the basis of the international framework to demonstrate radiological protection of the environment.

Use of CRs to predict radionuclide transfer is one part of the dose assessment. The second is the calculation of the dose from radionuclides present in the environment (external dose), or present in the body of an organism (internal dose). Stirling research has generated dose coefficients (**R3**) for the RAPs that convert the activity concentrations in the media/organism to a dose rate. The

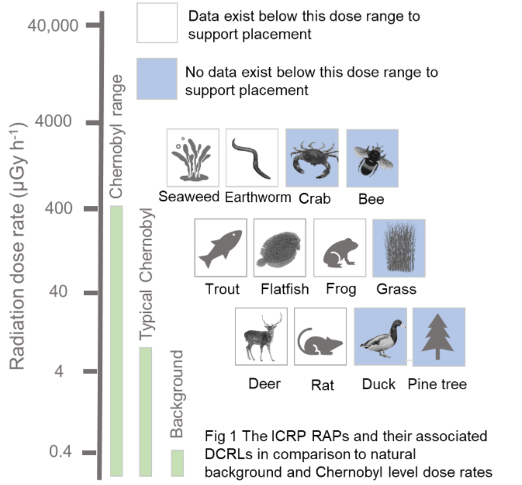

Fig 1 The ICRP RAPs and their associated DCRLs in comparison to natural background and Chernobyl level dose rates

third part of dose assessment requires information on the effects of ionising radiation to establish benchmark values for evaluating the risk of exposure to wildlife. Stirling research contributed to the ICRP defining Derived Consideration Reference Levels (DCRLs) for this purpose (**R4**), based on the known effects of radiation on wildlife species represented by the RAPs, to determine if the results of a dose assessment are likely to cause an impact. To be effective, DCRLs must be based on robust scientific evidence to build confidence in the ICRP framework. However, this evidence base on radiation effects on wildlife is limited. To address this knowledge gap, an experimental radiation facility has been built at Stirling and used to research ionising radiation effects at dose rates relevant to the DCRLs. Using this radiation facility, Stirling research demonstrated that, at dose rates found in the Chernobyl exclusion zone and levels below the currently recommended DCRL (Figure 1), bumblebee queen production was significantly impaired, providing the scientific evidence for changing the internationally recognised DCRL benchmark for future radiological protection of the environment assessments (**R5**).

Complementing the ERICA tool was the development of a separate **radiological dose assessment tool** – the Noble Gas Calculator (**R6)**. This research allowed the calculation of external doses from radionuclides released to the atmosphere in a plume, as, for example, many nuclear power stations release noble gases in significant quantities (~85% of the activity released).

Complex radiological assessment tools such as ERICA and the Noble Gas Calculator require the provision of guidance and training to build competence, capacity, and resilience within the nuclear and non-nuclear sectors to ensure that the tools can be used effectively. Copplestone's broad body of research, which includes **R1-6**, has facilitated knowledge exchange, and transfer of advice and guidance to organisations through the provision of specific, tailored training (see **Impact 2**).

In **R4**, Copplestone and co-authors **shaped recommendations and guidance** (see **Impact 3**) from the ICRP on the use of the RAPs to demonstrate the protection of the environment by focusing on how to apply the DCRLs in radiological dose assessments in a regulatory context.

3. References to the research

The body of research upon which this case study is built was supported by a NERC grant (NE/L000369/1) to Copplestone & Tinsley, and a NERC fellowship (NE/S006311/1) to Raines. Please note that the *Annals of the ICRP* publications are reviewed by two critical reviewers, then the ICRP Main Commission members, before a global public consultation is undertaken.

R1 Brown JE, Alfonso B, Avila R, Beresford NA, **Copplestone D**, Hosseini A. (2016) A new version of the ERICA tool to facilitate impact assessments of radioactivity on wild plants and animals. *Journal of Environmental Radioactivity*. 153, 141-148. https://doi.org/10.1016/j.jenvrad.2015.12.011

R2 Copplestone D, Beresford NA, Brown J, Yankovich T. (2013) An international database of radionuclide concentration ratios for wildlife: development and uses. *Journal of Environmental Radioactivity*. 126, 288-298. https://doi.org/10.1016/j.jenvrad.2013.05.007

R3 Ulanovsky A, **Copplestone D**, Vives i Battle J. (2017) Dose coefficients for non-human biota environmentally exposed to radiation. ICRP Publication 136. *Annals of the ICRP.* 46(2). https://doi.org/10.1177/0146645317728022

R4 Pentreath RJ, Lochard J, Larsson C-M, Cool DA, Strand P, Simmonds J, **Copplestone D**, Oughton D, Lazo E. (2014) Protection of the Environment under different Exposure Situations. ICRP Publication 124. *Annals of the ICRP*. 43(1). https://doi.org/10.1177/0146645313497456

R5 Raines KE, Whitehorn PR, **Copplestone D**, **Tinsley MC**. (2020) Chernobyl-level radiation exposure damages bumblebee reproduction: a laboratory experiment. *Proceedings of the Royal Society B: Biological Sciences*, 287, 20201638. https://doi.org/10.1098/rspb.2020.1638

R6 Vives i Battle J, Jones SR, **Copplestone D.** (2015) A method for estimating Ar-41, Kr-85, Kr-88 and Xe-131m, Xe-133 doses to non-human biota. *Journal of Environmental Radioactivity*. 144, 152-161. https://doi.org/10.1016/j.jenvrad.2015.03.004

4. Details of the impact

Significantly driven by our research activities (e.g. **R1-3, 6**), the need to demonstrate protection of the environment from ionising radiation is now firmly established within ICRP recommendations and UN IAEA basic safety standards and associated guidance. Our specific impacts have been:

Impact 1: Development and use of the ERICA Assessment Tool and Noble Gas Calculator

Internationally, ERICA is the most widely used tool of its type in the world (Figure 2), being recommended by environmental regulators (e.g. **C1**, **C2**, **C3**, **C4**) and used in major nuclear markets such as France, Japan and the UK. It is used to test whether current radiological environment safeguards are sufficient when issuing permits to every nuclear power station, nuclear decommissioning and waste management activity, and hospital releasing radioactivity. It **allows over 40 countries (C10) to comply with international recommendations and effectively implement and develop their national environmental radiological protection policies**. **C5** provides evidence of a wide range of examples where the ERICA Tool or Noble Gas Calculator have been used. Highlights include:

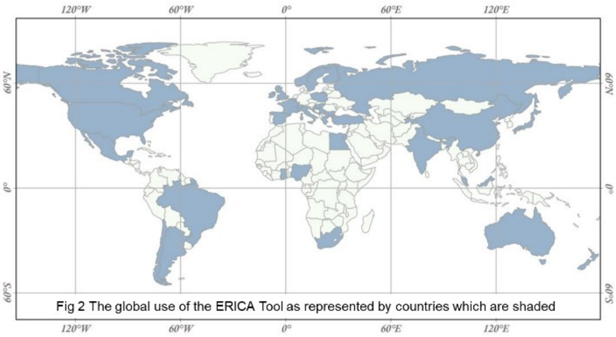

Fig 2 The global use of the ERICA Tool as represented by countries which are shaded

1) In the United Kingdom all UK environmental regulators (Environment Agency, Scottish Environment Protection Agency (SEPA), Natural Resources Wales, and Northern Ireland Environment Agency), the Health Protection Agency and the Food Standards Agency recommend use of ERICA and the noble gas calculator (e.g. **C1**, **C2**, **C4**). In **C4**, the UK environmental regulators confirm that they use ERICA (**R1**) for their *"assessments of radiological impacts of discharges upon non-human organisms*" (**C4**), and affirm their expectation that "*operators carry out an assessment and to draw conclusions about the effects of the site on the environment*" (**C4**).

To meet its "*legal duty*" (**C1**) under the EU Birds and Habitats Directives, the Environment Agency used "*the internationally recognised ERICA tool*" (**C1**) for its Habitats Assessments for Radioactive Substances (**C5**), to determine whether radioactive materials released under permit could impact on any Natura 2000 site in England. This involved conducting a detailed assessment of 603 permitted radioactive discharges on the 349 potentially at-risk Natura 2000 sites. They also state that demonstrating protection *"from the harmful effects of radiation is vital if nuclear energy is to make a contribution to sustainable development goals*" and that "*the ERICA tool is used routinely"* as *"an important part of our permitting process*" (**C1**). The use of nuclear energy moving forward was recently highlighted in the 'Green Industrial Revolution' announcement from UK Government.

2) All nuclear licensed sites in the UK require an environmental permit to operate (**C1**, **C2**). Without this permit, both routine and decommissioning activities are at risk. The latest estimate for nuclear clean-up (not including new power stations) is between GBP99,000,000,000 and GBP232,000,000,000 (UK Government Nuclear Provision) with the Sellafield nuclear licensed site, alone, estimated to be around GBP91,000,000. In 2019, Sellafield was re-permitted for its continued operation as it transitions fully into decommissioning, with the ERICA Tool used to assess impacts on wildlife as one of "*several high-profile permit determinations undertaken in recent years*" (**C1**). Others include the independent assessment of proposed discharges from new nuclear power stations planned for the UK, such as Hinkley Point C and Sizewell C (**C5**). Furthermore, Radioactive Waste Management Ltd, who lead on the UK's geological disposal of radioactive waste, commented that our research to develop the ERICA tool "*helps to ensure societal confidence in nuclear programmes*" having reduced uncertainty in assessments (**C6**).

3) Magnox Ltd is responsible for the safe and secure clean-up of 12 nuclear sites in the UK. To address the requirements for nuclear licensed sites to be released from Radioactive Substances Regulation (**C4**), Magnox Ltd have received bespoke training (see also **Impact 2**) on the use of

the ERICA tool specifically for the purpose of undertaking 'optioneering' studies to identify the best approach to decommissioning nuclear facilities while taking into account social, environmental and economic factors. Magnox Ltd have stated that the ERICA Tool and bespoke training have "*built capacity within the Central technical function's environment team*" and through the use of the ERICA tool demonstrated there is no environmental risk from leaving contaminated materials *in situ* with "*estimates of the cost savings to the business" …. "expected to be in the £millions*" (**C7**).

4) In 2017 the Canadian Nuclear Safety Commission deployed the ERICA environmental risk assessment tool, which it describes as "*internationally and nationally recognized*" (**C5**), to demonstrate that radionuclides from three Canadian sites (totalling 18 operating reactors) do not pose an environmental threat to the Great Lakes region. This allowed Canada to demonstrate it was meeting its commitments under the Canada-United States Great Lakes Water Quality Agreement and specifically not threatening Great Lakes fisheries, which are valued at USD7,000,000,000 and directly support 75,000 jobs in Canada and the United States (**C5**).

5) The Norwegian Radiation Protection Authority (NRPA) employed ERICA in 2017 to develop accident scenarios for the release of radionuclides from the wreck of Russian nuclear-powered submarine K-159 (sunk 2003), which now lies at 238m depth on the seafloor of the Barents Sea. Such assessments are deemed critical by the NRPA, as it considers K-159 to represent the "*single largest potential source of radioactive contamination to the Arctic marine environment*" and as such also a threat to Norway's fishing industry and public health (**C5**).

6) The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) consider that *"ERICA is the most effective and efficient tool available to achieve* [their] *goals and is essential for ensuring robust and reliable environmental assessments*" (**C3**). They provide examples where the ERICA tool and noble gas calculator have been used to undertake wildlife assessments for uranium mining, Nuclear Medicine facilities and former nuclear weapons testing sites (**C3, C5**).

7) In 2015 the ERICA tool was used by the UN IAEA to develop a radiological assessment procedure for determining the suitability of materials for disposal at sea under the London Convention 1972 and London Protocol 1996 (**C5**).

Impact 2: Building capacity and resilience in the use of the ERICA Tool

To ensure the appropriate and effective use of the ERICA Tool (**R1**) and Noble Gas Calculator (**R6**) and that the ICRP recommendations and the international regulations that build on them are understood, Copplestone and colleagues deployed their research and expertise to deliver regular capacity building courses including for the UN IAEA (e.g. Egypt and Malaysia, see **C9**), and for national organisations in the UK (e.g. Environment Agency, SEPA, Magnox) and Australia (e.g. ARPANSA, Energy Resources of Australia) (**C1**, **C2**, **C3, C6**, **C7**). These courses have been attended by more than 350 people, with, in some cases, bespoke materials tailored to the specific needs of the participants (e.g. in Australia focused on the uranium mining industry, see **C3**, and in the UK on the requirements of the nuclear industry, see **C7**). **C10** provides evidence, collated from course participants and an associated recent international survey, on the effectiveness of the training and knowledge exchange, and the subsequent impact of this training, on the application of radiological dose assessments of the environment using ERICA. Participants report the course to be of "*outstanding quality*" with delivery by "*the absolute experts in radiological risk assessment*" and that it has given them "*confidence to use the ERICA Tool in practice*" (**C3**, **C10**). Approximately 80% of survey respondents stated that this training has changed the way in which they conduct assessments and "*allowed improved decisions to be made*" (**C10**). 97% of the respondents stated that they use the ERICA Tool for wildlife assessments, while national documentation in 50% of countries represented within the survey recommends ERICA (**C10**).

Developing "*capability and capacity of the nuclear regulators*" is a key part of the UK Government's Clean Growth Strategy. Since 2014, more than 25 Environment Agency non-nuclear and nuclear regulators and "*nearly half of the SEPA radioactive substances team*" have attended the ERICA training. This has been recognised by the Environment Agency and SEPA, respectively, as having: "*increased our in-house capability*", *"increased resilience and reduced risk to our business*" (**C1**) and "*built our in-house resilience and capability"* for wildlife radiological assessment (**C2**).

Impact 3: Shaping recommendations and guidance

Our research on dosimetry (**R3**) and the use of DCRL (**R4**) has directly underpinned essential components of new ICRP guidance and recommendations on environmental protection (**C10**). The UN IAEA General Safety Guidance (**C9**) was also directly informed by these publications. The impact has been derived through Copplestone's leading role in both national and international (ICRP and IAEA) approaches to protecting the environment from ionising radiation. He has participated in ICRP Committees on: i) Protection of the Environment (2009-2017) and ii) Applications of the ICRP's recommendations (2017-present); three ICRP Task Groups (TG) (2010 to present); and UN IAEA activities (e.g. **R2** and also ongoing revision of the IAEA's modelling approaches for dose assessment to include wildlife (2005 to present) (**C9**)). For example, ICRP TG 105, chaired by Copplestone, has provided guidance on site-specific decision making for the public (human) and wildlife exposures to ionising radiation under planned, existing, and emergency exposure situations. This guidance underpins implementation of radiological protection of the environment in the overall international system of radiological protection.

Since 2013, our research has made a "*tremendous contribution*" (**C10**) in shaping the ICRP framework for environmental protection. For example, based on Stirling research, ICRP TG 99 (**C10**) has agreed a reduction in the DCRL (the dose rate band in which some deleterious effects of radiation exposure are expected to occur – see Figure 1) for the 'Reference Bee' (**R6**).

5. Sources to corroborate the impact

C1: Testimonial from the New and Operational Sites Manager of the Environmental Regulator for England (the Environment Agency) on the contribution of Stirling research to enable the independent evaluation of radiological assessments of the environment submitted to the EA, e.g. for 2019 Sellafield permit review, the habitats assessments (**Impact 1**) and the capacity building and business resilience aspects (**Impact 2**).

C2: Scottish Environment Protection Agency (SEPA) testimonial highlighting the use of ERICA in independent evaluation of dose assessments of the environment (**Impact 1**), and capacity building and business resilience aspects from the Radioactive Substances Unit Manager (**Impact 2**).

C3: Letter from Deputy CEO of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) on the significant contribution of Stirling research to the application of, and training on, the ERICA Tool in Australia (**Impacts 1 & 2**).

C4: SEPA, Environment Agency, Natural Resources Wales (2018) Management of radioactive waste from decommissioning of nuclear sites: guidance on requirements for release from Radioactive Substances Regulation. Version 1.0: July 2018 (**Impact 1**).

C5: Document listing sources by country which describe the use of the ERICA Tool and/or the Noble Gas Calculator in radiological dose assessments of the environment globally (**Impact 1**).

C6: Letter from the Head of Environmental Safety & Sustainability, Radioactive Waste Management on the impact of Stirling research and the use of the ERICA Tool and Noble Gas Calculator on their business to develop the UK's geological waste disposal facility (**Impact 1**).

C7: Testimonial from the Process and Environment Section Head, Magnox Ltd who are responsible for the safe clean-up of 12 nuclear power stations. They describe the use of the ERICA Tool to determine the most appropriate approach for long term waste management/disposal and bespoke capacity building (**Impacts 1 and 2**).

C8: Responses from an international survey and ERICA course participant feedback on the use of the ERICA tool for wildlife dose assessments globally (**Impact 1**) and the increase in confidence of using ERICA and communicating outputs following the training courses (**Impact 2**).

C9: Letter from the Director of Division of Radiation, Transport and Waste Safety, IAEA confirming the courses, and an evaluation of their effectiveness and use of the radiological protection approaches/ERICA tool in Eastern European countries (**Impact 2**).

C10: ICRP testimonial from the ICRP Scientific Secretary detailing the use of **R4** and how Stirling research has been shaping ICRP recommendations (**Impact 3**).