Institution: University of the West of England, Bristol		
Unit of Assessment: 6		
Title of case study: Managing the impact of nuclear power on food and the environment		
Period when the underpinning research was undertaken: 2013 – 2020		
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:**
Neil Willey Eleni Siasou	Professor Research Fellow	September 1992 – present February 2014 – February 2017
Period when the claimed impact occurred: 2014-2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Research by Professor Neil Willey at the University of the West of England (UWE) has been described by the Environment Agency (EA) as *'game changing'* for their predictions of the transfer and effects of radioisotopes in plants. At a time of increased focus on low-carbon energy generation, and therefore nuclear power, UWE research on radionuclides in the soil-plant system has contributed to the UK's preparations for geological disposal of nuclear waste, and increased confidence in the UK's regulation of its nuclear installations. The research has also improved international control of agricultural contamination arising from controlled and accidental releases of radioactivity from nuclear sites; this includes providing the evidence needed to shift perceptions around the Chernobyl Exclusion Zone to enable land reuse in Ukraine.

2. Underpinning research

UWE research into radionuclides in crops has focused on both transfer (from soil to plant) and effects. Compartmental models based on concentration ratios (CRs) are used by national and international regulators to predict the transfer and effects of radionuclides to plants during: the approval of new nuclear power stations; the operation of existing nuclear sites; environmental assessments for geological disposal facilities; and responses to releases of radionuclides into the environment. The International Atomic Energy Agency (IAEA) compiles CRs for the soil-to-plant transfer of a range of radionuclides. These have long been essential for nuclear new-build and waste disposal risk assessments around the world, but have a level of uncertainty that is often several orders of magnitude. Most crop-radionuclide combinations lack specific CR data. Prior to the research conducted at UWE, there had been no systematic methods to reduce uncertainty in CRs, nor to predict specific CR data for most crops. UWE research provided the first systematic method to reduce uncertainty in the few current CRs for wild plants and crops, and to use them to predict CRs for the thousands of plant species for which they were unknown.

Professor Neil Willey's research, in particular his contribution to the Natural Environment Research Council's RATE programme (2013-2018), has built the rationale for moving beyond current CRs (**R1**) and was the first research ever to develop taxonomic methods which, by disentangling evolutionary constraints from environment influences, reduce uncertainty in the prediction of CRs (**R2**). Between February 2014 and January 2017, a NERC-funded UWE Research Fellow (**G1**), Dr Eleni Siasou, developed this research for radionuclides of agronomic significance (**R3**) in order to inform the work of Radioactive Waste Management Ltd (RWM - a public organisation responsible for planning and

delivering geological disposal in the UK) and the Environment Agency (EA). For the first time, UWE researchers are now able to identify evolutionary constraints in plant uptake and use them to reduce uncertainty in CRs and to predict CRs of radionuclides of particular interest to national (RWM/EA) and international (IAEA) stakeholders. This work was done as part of the TREE consortium (one of three consortia working on the RATE programme) (2013-2018), and is currently being applied to work for the UK's statutory 'Radioactivity in Food & the Environment' (RIFE) report.

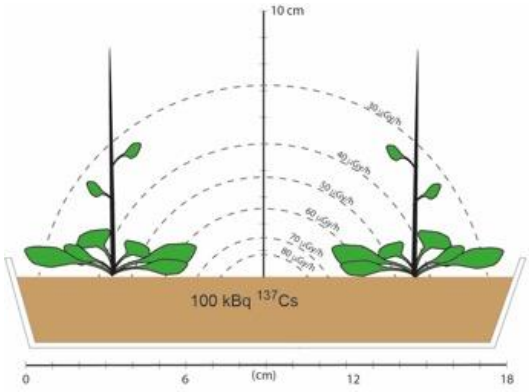

Fig 1. Growing plants with isotopes and dose rates simulating the Chernobyl exclusion zone.

UWE research on the RATE programme also focused on the effects of radionuclides on crops. Derived Consideration Reference Levels (DCRLs) for plants, are dose ranges that the International Commission on Radiological Protection recommends for radioprotection of the environment around the world. A variety of high-profile studies at Chernobyl have suggested that DCRLs are set too high for flora and fauna. UWE's world-leading research has shown for the first time that the numerous claims of oxidative stress to organisms at Chernobyl are mechanistically unfeasible, and that available data in DCRL ranges was dominated by genotypic (genetic makeup) information collected in a single generation in the field (**R4**). UWE researchers carried out, at DCRL and Chernobyl dose rates, the first multi-generational experiments under controlled conditions that focused on phenotypic (physical appearance) endpoints relevant to the populations and communities that legislation is designed to protect (**G1**). In contrast to some previous assertions, the results showed that environmentally relevant effects of ionising radiation (IR) on plants occur *at or above* DCRL dose rates (**R5**). UWE research on the effects of IR on plants has demonstrated to key regulators that the recommended DCRLs for plants are fit for purpose. This was a key contribution to the largest coordinated investigation ever carried out on the effects of radioactivity at Chernobyl and supports the work of national (EA) and international (IAEA) environmental regulators (**R6**).

3. References to the research

R1 Beresford, N.A., Willey, N. (2019) Moving radiation protection on from the limitations of empirical concentration ratios. *Journal of Environmental Radioactivity,* 208-209, 106-120. https://doi.org/10.1016/j.jenvrad.2019.106020

R2 Willey, N., Wilkins, J. (2005) Phylogeny and growth strategy as predictors of differences in cobalt concentrations between plant species. *Environmental Science & Technology* 42 (6), 2162-2167. https://doi.org/10.1021/es071531r

R3 Siasou, E. and Willey, N. (2015). Inter-Taxa differences in iodine uptake by plants: Implications for food quality and contamination. *Agronomy*, *5(4)*, 537-554. https://doi.org/10.3390/agronomy5040537

R4 Caplin, N., Willey, N. (2018) Ionizing radiation, higher plants, and radioprotection: From acute high doses to chronic low doses. *Frontiers In Plant Science*, 9:847. https://doi.org/10.3389/fpls.2018.00847

R5 Caplin, N., Halliday, A., Willey, N. (2020) Developmental, Morphological and Physiological Traits in Plants Exposed for Five Generations to Chronic Low-Level Ionising Radiation *Frontiers in Plant Science* 11:389, https://doi.org/10.3389/fpls.2020.00389
R6 Beresford, N.A., […] Willey, N. (2020) Towards solving a scientific controversy – The effects of ionising radiation on the environment. *Journal of Environmental Radioactivity*, vol 211. https://doi.org/10.1016/j.jenvrad.2019.106033

Evidence of the quality of the underpinning research
G1 Willey, N. *Transfer-Exposure-Effects: Integrating the science needed to underpin radioactivity assessments for humans and wildlife (TREE),* Natural Environment Research Council (NERC), 2013 – 2018, £304,861.

4. Details of the impact

Informing the work of environmental regulators in the UK and internationally
The RATE programme of research transformed the UK's capacity to protect the environment from the effects of ionising radiation (**S1**). UWE research into radionuclides in plants was a crucial strand in this programme. As part of the TREE consortium, UWE researchers had sole responsibility for research on crops and plants; particularly modelling radionuclide transfer and predicting long-term effects on plants (**S1**, p9-12).

The RATE programme responded to requirements specified by the EA and Nuclear Decommissioning Authority (NDA). These requirements related to improvements in the permitting, regulating and monitoring of new and existing nuclear power station sites, and to necessary conditions for a geological disposal facility for nuclear waste (**S2**, p1). In May 2018, RATE was recognized by the EA as having met these requirements (**S3**). Referring specifically to the TREE component of RATE, EA noted that '*TREE has helped to ensure that society can continue to gain maximum benefit from low carbon nuclear power generation and other important uses of radioactivity*' (**S3**, p2). In addition, UWE research helped the UK to meet the International Commission for Radiological Protection's 2007 recommendations on environmental protection (**S2**, p1).

A 2018 statement from the EA and RWM described the new approaches for modelling radionuclide transfer proposed, developed and implemented at UWE (**R1**, **R2**), as '*…game changing, removing much of the uncertainty associated with the current, simple, ratio approach'* (**S3**, p2). EA and RWM also noted that '*the resultant reduction in… uncertainty helps to ensure societal confidence in nuclear programmes* (**S3**, p2)'. In addition, UWE's research provided the most comprehensive dataset ever published for soil-plant transfer of two key radionuclides in nuclear waste, Se-79 and Tc-99. This data has supported '*regulation, safety case development and disposability advice for the UKs multi-billion pound nuclear programme*' (**S3**, p2). UWE's research on modelling transfer to plants is also recommended in the International Atomic Energy Agency's Technical Report 479 for the assessment of the transfer of radioactivity to wildlife and food crops by environmental regulators around the world (**S4**, p122-123, ref 97).

Research confirms that UK radiological risk assessments work, assuring the public and regulators alike
UWE's research on effects of radiation has established that authorised releases of radioactivity do not present a long-term risk to plants, which are grouped under 'wildlife' in radioprotection legislation (**R4**). This has now been recognized by EA and RWM (**S3**, p2). The UWE research looked at the International Commission on Radiological Protection (ICRP) benchmarks that are used across the world to protect the environment. The ICRP,

and therefore national organisations such as the EA and RWM Ltd, have been *'challenged, especially during public consultations*' (**S3**, p2) on the suitability of current radiological risk assessments. These challenges have been primarily based on claims of effects at low dose rates in the Chernobyl and Fukushima Exclusion Zones. UWE was the sole provider of the RATE scientific evidence relating to the effects of radiation on plants and UWE's experiments addressed the deficiencies in data underpinning claims from the Exclusion Zones. In particular, it supported the ICRP's Derived Consideration Reference Levels and their use of Reference Animals and Plants (**R5**). The EA and RWM are now able to demonstrate, when challenged, that their current radiological risk assessments are fit for purpose. The EA and RWM note that this has helped establish *'UK leadership in the field of environmental radiation protection and [made] significant contributions to the international framework via engagement with the International Commission (ICRP) on Radiological Protection and the United Nation's International Atomic Energy Agency (IAEA)* (**S3**, p2-3)*'.* UWE research provided the clearest evidence yet published that for plants, current systems of radiological protection are fit for purpose, enabling the ICRP to recommend its current dose rate criteria in the light of the best possible evidence (**S5**). In a letter of support, ICRP commented that '*the international environmental protection framework would not have been so advanced without the outcomes from the TREE project*' (**S5**).

Research changes perceptions, enabling land re-use in Ukraine

Through the TREE Consortium, UWE's research has also had an impact on the management of Chernobyl-contaminated land in the Ukraine. The Deputy Director of the government agency responsible for managing the >4000 km^2 of contaminated land commented '*research in TREE project on transfers of radioactivity to plants and animals…has greatly assisted my Agency and Ukrainian… authorities in planning the management of Chornobyl contaminated areas…* [and] *has changed perceptions of Chornobyl Exclusion Zone in Ukraine and internationally …* [and] *has put us in position to*

Fig 2. The 'cooling pond' at Chernobyl Nuclear Power Station. This has now been drained and vegetation is invading radioactivity contaminated dried sediment, necessitating predictions of transfer helped by UWE research.

bring major economic benefits to Ukraine by enabling the State, local populations and business to reuse lands [unused because of concerns about contamination]' (**S6**).

Increasing public awareness and confidence

UWE research into radioactivity and plants has changed attitudes and awareness among interested members of the public. The research has been presented through public science activities such as the Manchester Science Festival, a BBC Science Focus podcast, an article in the open access online magazine *ResearchFeatures*, a 'behind the science' video for *ResearchFeatures* magazine (**S7**) and the Bristol Festival of Nature. At the Festival of Nature, attended by 40,000 people, 90% of 126 participants in a survey said that engagement with the UWE research had increased their confidence in the way the UK manages the impact of radioactive material on plants and foods (**S8**, p6). In the UK, and especially in the South West of England, public confidence in the nuclear industry is vital. The EA and RWM commented that UWE research had helped make *'a significant contribution to changing public understanding of radioactivity and its impacts as a result of extensive public engagement activities and media coverage'* (**S3**, p2).

5. Sources to corroborate the impact

S1 RATE *Radioactivity and the environment programme impacts and legacy* January 2018

S2 Natural Environment Research Council, Nuclear Decommissioning Authority and Environment Agency *Environment Agency stakeholder interests*

S3 Radioactive Waste Management Ltd and Environment Agency joint letter on '*Impacts of the TREE project from the perspective of national regulatory and waste management organisations*' May 2018

S4 International Atomic Energy Agency *Technical Reports Series no.479: Handbook of parameter values for the prediction of radionuclide transfer to wildlife*

S5 International Commission on Radiological Protection *Letter of support for the TREE project consortium* April 2018

S6 Letter from the First Deputy Director of the State Agency of Ukraine for Exclusion Zone Management (SAUEZM)

S7 List of appearances of TREE research in the media 2014-2017

S8 Bristol Festival of Nature 2019 survey data