Chernobyl: the disaster zone becomes a laboratory

Zapping plants with radiation might not initially appear useful, but **Prof Neil Willey** from the University of the West of England monitors the responses of plants under conditions similar to those at the infamous Chernobyl site, and for good reasons. The nuclear waste generated from the 439 on-grid nuclear power stations worldwide has yet to find a permanent home. We must understand the effects of low levels of radioactivity entering the environment from a repository after thousands of years, as well as the other effects that this primordial biological stressor might have.

On 26th April 1986, reactor four of the Chernobyl Nuclear Power Plant exploded during a poorly executed safety test. The resulting radioactive fallout spread across Europe at varied intensities, affecting people, animals, plants and ecosystems. Since the dramatic decrease of human activity in the Chernobyl Exclusion Zone, wildlife there has flourished due to lack of interference, despite higher than normal levels of chronic ionising radiation (IR). As the area has become less dangerous, it has provided scientists with an opportunity to study the effects of radiation on organisms more closely, providing both answers and questions alike. But why is this research necessary?

We live in a world where nuclear energy provides around 10% of all our electricity. It's possible that nuclear weapons might be used and they are still occasionally tested. The final destination of nuclear waste has proven difficult to arrange, with Sweden being the closest to finishing the first waste repository. In addition, there is a certain level of background radiation which varies geographically, and can impact human health. Radioactivity can transfer through ecosystems, from the soil and into plants, which in turn, we eat. This is just the tip of the iceberg for Prof Neil Willey, who is exploring the multiple avenues of this complex, and highly informative topic.

IS RADIOLYSIS A THREAT?

Perhaps the most obvious area of study is monitoring the effects of IR on organisms. To date, this has mostly been testing tolerance of acute exposure to IR. Although potentially dramatic, this is perhaps only relevant to immediate 'post-blast' scenarios. What Prof Willey wishes to focus on, is the much longer-term chronic lower level of radiation left as a result of events such as Chernobyl or Fukushima.

One way in which IR can damage an organism is through radiolysis of water resulting in excessive harmful reactive oxygen species (ROS), which can damage cell health – this is known as oxidative stress. It has been hypothesised that this could be the reason for some of the negative effects on biota reported from radioactive sites. This is assumed because of, for example, the low levels of

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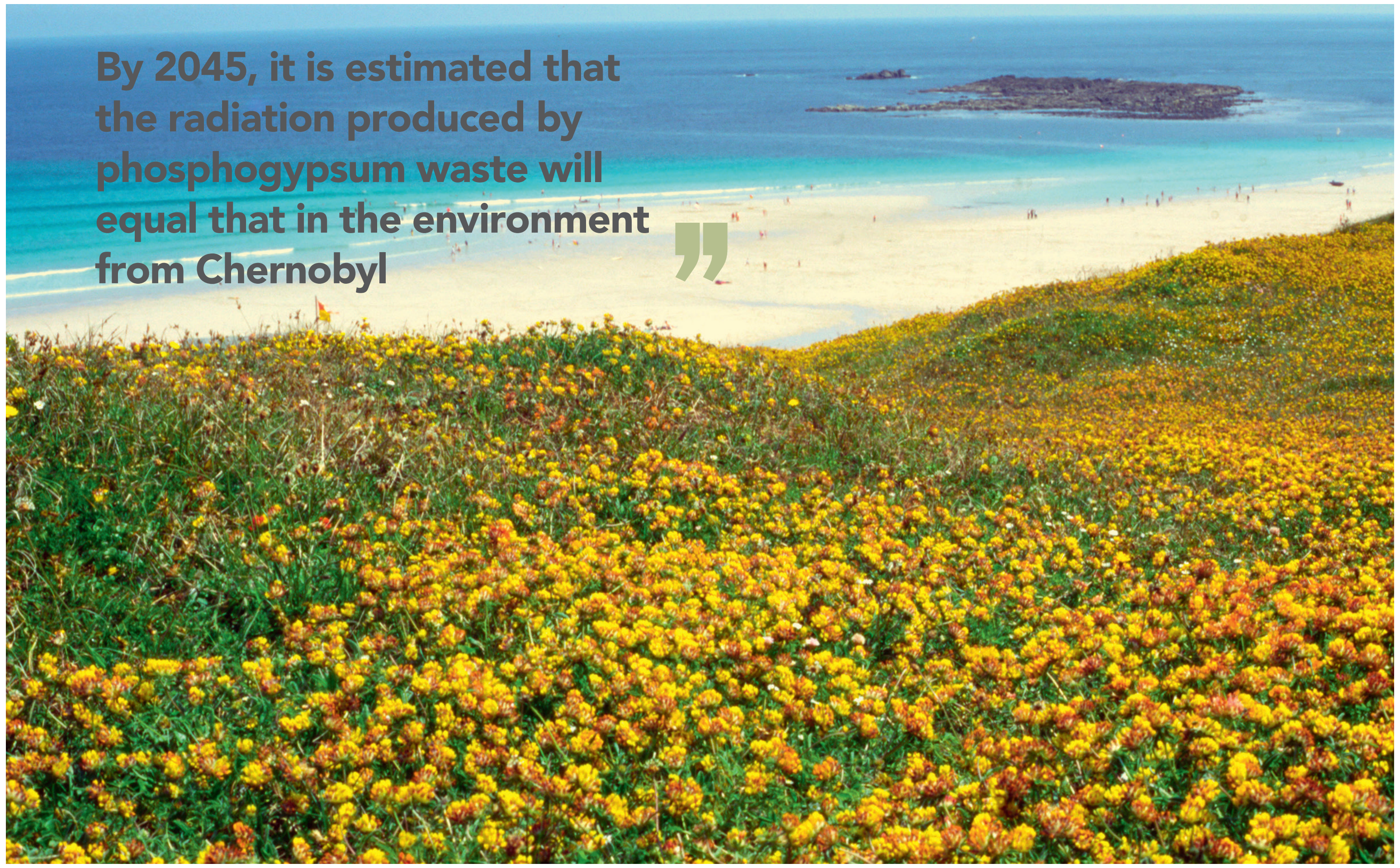

antioxidants measured in the bodies of birds at Chernobyl. Antioxidants could be 'used up' when combating high levels of oxidative stress in their cells. However, Prof Willey found little evidence to support this theory.

Simply by applying physical equations to pre-existing data, Prof Willey found that this low level of antioxidants could not be achieved solely due to radiation. Even with unrealistically low levels of antioxidant replenishment, 'normal' birds would not reach the low levels of antioxidants of birds at Chernobyl, when exposed to the same level of radiation over 1,200 days. Although not directly tested, it is likely that this is also applicable to other organisms, suggesting that these differences are more likely due to diet, habitat or ecosystem structure. The antioxidant capacity of cells is simply too great. Observed problems with biota, if attributable to IR, could perhaps be due to the direct damage it causes to DNA, such as strand breaks and deletion mutations.

AN ANCIENT STRESSOR

So why might organisms have the ability to negate some effects of chronic exposure to IR? The answers may lie in the deep past, at a time when background radiation was at an all-time high. When prokaryotes originated around 3.5 billion years ago, IR was ten times higher than the current level. Plants colonised land 420 million years ago, when IR was still significantly higher. Life has been exposed, and has had to adapt, to much higher levels of radiation than we see today. This may go some way to explaining current levels of radio-resistance. The incorporation of 'tough' prokaryotic structures such as mitochondria and chloroplasts into eukaryotes further supports this theory.

In fact, the efficiency of our cells to repair (or negate) types of DNA damage may have evolved in part due to primordial radioactivity. A double strand rather than a single strand, and a second chromosome rather than just one, may have evolved to provide 'recovery' templates in case of DNA damage. It is also likely that current high antioxidant levels are due to significant ultraviolet (UV) radiation which was an additional source of oxidative stress in the past.

A PHYLOGENETIC APPROACH

In order to understand the effects of radionuclides on the environment, Prof Willey and his team are looking at the uptake of radionuclides from the soil. It would be useful to either grow crops which did not take up radionuclides, or ones which did in order to 'biomonitor' availability. It will also be very important when presenting credible environmental safety cases for potential nuclear waste repositories.

Uptake of radioisotopes has rarely been measured in most plant species, and it would be an impossibly large task. There is also variation between species, subspecies and environments. To make the process of prediction more efficient, Prof Willey has taken a phylogenetic approach, and modelled the transfer of radionuclides based on plant evolutionary relationships. From this, activity concentrations in one plant can be reasonably predicted by the activity in another. Prof Willey so far has found that this is useful for predictions: within taxonomic groups there is consistency of the type, and amount, of radionuclide uptake.

Q&A

Is there any threat to you or your field assistants working at Chernobyl?

With appropriate precautions, the risks from short visits to the exclusion zone are insignificant. The precautions are routine monitoring in and out (just to check that no especially radioactive particles have been picked up somehow) and carrying dosimeters to check that the total dose received is not accumulating too much. There would be some risks if a long period of time was spent in the most contaminated parts of the zone but this can be avoided during research work.

Should we be worried about this delay in producing nuclear waste repositories? Where is the current waste held?

There is some potential for accidents involving nuclear waste. In the UK, most of it is at Sellafield. In other countries it is also stored at a few major sites, often with a view to reprocessing and so on. Often a proportion of it hasn't yet been converted into easily manageable forms.

Are there any dangers to crops produced from radioactive mutagenesis?

Not that anyone's found after the appropriate tests and a significant proportion of humanity eating them for half a century or more.

How could we target and use plants to warn us against high levels of radioactivity?

Some researchers have suggested that increased rates of DNA repair, which have been shown at places at Chernobyl for example, could be used for this purpose.

Are there examples of radionuclides transferring through animal feed and into animal products that some humans might consume? Should people be concerned about eating crops / produce with radioactive traces?

Yes. Radioactive iodine transferred very quickly from grass into cattle and then milk after Chernobyl. This was less significant after Fukushima because the cattle were mainly inside. Radioactive strontium contaminated milk via similar mechanisms during the period of weapons testing fallout. Several of the Pacific Islands where nuclear tests occurred were not reinhabited afterwards because radioactive caesium very rapidly entered food chains.

Could your phylogenetic work be applied to the phosphogypsum dilemma?

Yes. The phosphogypsum stacks are sometimes vegetated to stop them blowing around. Plants that tend not to take up the radioisotopes that occur in the stacks might be useful for this. Others that take up more of the radioisotopes might be useful for monitoring bioavailability.

Even now there are other dilemmas that Prof Willey's research into environmental radioactivity is addressing. Phosphate fertiliser underpins global food supplies, but its production leaves behind huge quantities of a mildly radioactive waste – 'phosphogypsum'. By 2045, it is estimated that the radiation produced by phosphogypsum waste will equal that in the environment from Chernobyl. However, if we run out of rock phosphate reserves, it will threaten our food supply. Prof Willey suggests that one way to aid this situation would be an increased efficiency of phosphate usage through recycling and recovery, or to use alternative methods of supplying phosphate.

This research is part of a wider consortium known as TREE (TRansfer Exposure Effects), which includes Prof Willey. TREE aims to provide a more scientifically supported and realistic estimate for the risk of radioactivity to humans and wildlife. Most of the fieldwork takes place at Chernobyl, with the study of radionuclide uptake by plants being a key goal. TREE is looking to resolve the often-inflated worries concerning the threat of IR to flora and fauna, whilst re-evaluating dangerous IR dose rates in order to provide guidance for future nuclear waste management. For more information about the TREE project please visit http://tree.ceh.ac.uk/

Detail

RESEARCH OBJECTIVES

Professor Willey's research focuses on plants and pollutants, specifically on the uptake and effects of environmentally relevant radionuclides and toxic metals. His research is used to predict soil-plant transfer of radionuclides in models of radionuclide movement in both natural and agricultural ecosystems. Prof Willey has also developed methods to select plants for phytoremediation. He is a member of the large, multi-institution TRansfer-Exposure-Effects (TREE) Consortium, which aims to integrate the science needed to underpin radioactivity assessments for humans and wildlife.

FUNDING

- Natural Environment Research Council (NERC)
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- Radioactive Waste Management Ltd (RWM)

BIO

Professor Willey earnt both his BSc (1987) and his PhD (1992) from Bristol University. He went on to work at the University of the West of England (UWE), where he became Professor in 2016. Professor Willey has authored many publications and books, and is currently UWE's Director of Graduate School.

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