RADIOECOLOGY

Ionising radiation arises from many natural sources, from the unstable atoms within our own bodies and in the materials around us, from the Sun, and even from beyond the Solar System. Additional sources include the legacy of testing nuclear weapons, nuclear waste, and nuclear accidents. All these sources have provided means of dating environmental materials and tracing the movements of substances through land, sea, and air. But ionising radiation also interacts with DNA, which has led to a remarkable range of studies to examine how and how quickly unstable atoms are accumulated by both humans and biota, and their various effects on both. Providing an overview of the sources, uses, and impacts of ionising radiation in the environment, and the frameworks developed to manage exposures to them, this is a valuable reference for graduate students and researchers interested in radioecology, environmental science, and radiological protection.

R. J. Pentreath is an emeritus professor at the University of Reading; an emeritus research fellow of the Centre for Environment, Fisheries and Aquaculture Science (CEFAS); and a research fellow at the Plymouth Marine Laboratory. He is both a Chartered Biologist and a Chartered Radiological Protection Professional and has been elected Fellow of the Institute of Biology and of the Society of Radiological Protection. He began his career as a marine radiobiologist at the Fisheries Radiobiological Laboratory at Hamilton Dock and went on to become the first chief scientist (and a director) of the UK's Environment Agency. He is one of only a handful of emeritus members of the Main Commission of the International Commission on Radiological Protection.

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RADIOECOLOGY

Sources and Consequences of Ionising Radiation in the Environment

R. J. PENTREATH
Plymouth Marine Laboratory

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Preface

I imagine that any preface is essentially an apologia – an upfront reason, or excuse, for writing what follows. So what's mine? Although I spent a large part of my career being what I regarded as some sort of radioecologist (actually a marine radiobiologist), and in spite of the widespread use of the word throughout that part of my career, it seems that there has never been any agreed upon definition of what the word *radioecology* actually means in the English language. And so, I would argue, there has never been an agreed list of subjects or topics that fall within its purview, let alone upon what basis they all relate to each other, if at all. Such subjects can be as varied as the origin and impact of cosmic radiation, the use of radionuclides in geological dating, or the many and varied pathways leading to human radiation exposure as a result of discharges from the nuclear industry. Unfortunately, the subject has also never been regarded as a basic component of the environmental sciences and has therefore never enjoyed any form of standing within the academic community (at least not in the UK, and not at all by many UK academic bodies). As an undergraduate in the early 1960s I had never come across the word 'radioecology'. I was later to discover that it was then, and indeed ever since then, largely regarded as being no more than some sort of specialised component of 'pollution control' relating to the radiological protection of humans rather than to the environment; although, ironically, it had also never been seen as part of the mainstream discipline of radiological protection (of humans) either. So it neatly fell between both stools. It is also a very multidisciplinary subject, but unlike, say, meteorology or oceanography, it has never really developed any core set of relationships between theory and observation that are unique unto itself.

Hence the purpose of writing this book was initially twofold, or possibly threefold. On the one hand, it tries to bring together a broad range of what I see as related but very different subject matters under a common heading, primarily, but not entirely that of unstable nuclides in an environmental context, the environment covering everything from Earth's core to outer space. On the other hand, it tries to draw out some of the basic scientific ideas that pervade what I regard as being the subject called 'radioecology', many of which are still deserving of better experimental enquiry than they seem to have done in the past. To this I could add a third aim, or perhaps just a vain aspiration: to explore the world of 'radioecology' in such a way that it may be seen as an interesting component of basic 'environmental science', understanding and explaining how the natural environment works. It is, of

course, also an important applied science, enabling nuclear industries to function in a responsible way and to ameliorate situations in which they don't.

Those who take an interest in radioecology generally have a background in a specific scientific discipline (physics, chemistry, biology, mathematics) and may thus not be fully *au fait* with the other facets of the subject. So the approach I have taken in writing this book is to meander through what I see as the basics of the subject across all of the relevant disciplines, with an historical introduction of its overall origins, followed by my very personal analysis of what I think we have learned so far. And I have done so in a very broad way rather than treat the subject as merely a spinoff from the development of nuclear power. Thus, as already intimated, my real ambition is to see radioecology treated as an integral component of the environmental sciences (taken in its very broadest sense), an understanding of which needs to be maintained within the academic community, not simply because we will need such knowledge in the future, but because it is sufficiently interesting in its own right. This is particularly important because interest in it, and hence funding for it, has varied so greatly over the years that there is now little to maintain a core of specialist radioecologists worldwide to advise on what to do when the next nuclear accident, or related crisis, occurs – as it surely one day will.

It is also fair to say that many of the 'classic' studies that constitute the backbone of radioecology were made in the days when the results were exchanged through symposia, annual laboratory reports, and by other means (often referred to as the 'grey' literature) rather than through the specialist journals that now exist. Such experiments were large, expensive, and unlikely ever to be repeated. Indeed, many of the laboratories that conducted them no longer exist. As a result, their findings are not always easy to uncover. Thus I have deliberately drawn upon examples from those pioneering days – which are as good, or even better than, experiments that have been made since – in order to illustrate some of the basic principles upon which the subject has been based. It is not, therefore, a summary of all that has been discovered, but an attempt to draw out and identify the basic cornerstones of the subject and, in so far as I can establish, how such information arose. It is also unapologetically based on material published in the English language. There is a vast Russian literature on the subject, much of which has never been translated, and even when it has been, the results are often difficult to evaluate because of the lack of clarity about when, how, and often where, the experiments (or observations) were made.

Acknowledgements

Sadly many, or even most, of the scientists who have played key roles in the development of radioecology are no longer with us, and the list of those who have played a part in my own education is impossibly long to include here, so I can only name those institutes and laboratories with which I have had connections in one form or another. I spent some 20 years at what was then the Fisheries Radiobiological Laboratory (FRL) at Hamilton Dock, Lowestoft, and will be forever grateful to all of my colleagues there for their friendship and their knowledge that they did their very best to pass on to me. At that time we collectively enjoyed close collaboration with colleagues all around the UK, particularly at what were then the Institute of Marine Environmental Research, Plymouth; the Marine Biological Association, Plymouth; the Atomic Energy Research Establishment, Harwell; the National Radiological Protection Board; the Institute for Terrestrial Ecology, Merlewood Research Station, Cumbria; Lancaster University; the Institute of Oceanographic Sciences, Taunton; and the Scottish Universities Research and Reactor Centre, Glasgow. Elsewhere in Europe there was the International Atomic Energy Agency's wonderful International Laboratory of Marine Radioactivity at Monaco; the Commissariat à l'Énergie Atomique Laboratoire de Radioécologie Marine, (Marine Radioecology Laboratory), Cap de la Hague; Trinity College Dublin; Lund University; the Swedish Environment Protection Board, Uppsala; the National Institute of Radiation Protection, Stockholm; the Institute of Radiation Protection, Helsinki; the University of Helsinki; the Risø National Laboratory, Roskilde; the Université Catholique de Louvain; the Biologische Anstalt, (Biological Institute), Helgoland; the Deutsches Hydrographisches Institut, (German Hydrographic Institute), Hamburg; the Bundesforschungsanstalt für Fisscaheri Isotopenlaboratorium, (Isotope Laboratory, Federal Research Institute for Fisheries), Hamburg; CEEN, Mol; the Netherlands Energy Research Foundation, Petten; the Institute Ruder Bošković, Rovinj; the Laboratorio Studio Contaminazione Radioattiva del Mare, (Laboratory for the Study of Radioactive Contamination of the Sea), La Spezia; the Joint Research Centre, Ispra; and the Departemento de Proteccao e Seguranca Radiologica, (Department for Radiological Protection and Security), Sacavem, Lisbon.

In North America there was the Oak Ridge National Laboratory, Oak Ridge, Tennessee; the Argonne National Laboratory, Lemont, Illinois; the Pacific Northwest Laboratories, Richland, Washington; the Lawrence Livermore Laboratory, Livermore, California; the Savannah River Ecology Laboratory, Aiken, South Carolina; the Laboratory of Radiation Ecology, University of Washington, Seattle, Washington; the Sandia Laboratories, Albuquerque, New Mexico; the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; the National Centre for Estuarine and Menhaden Studies, Beaufort, North Carolina; the Scripps Institute of Oceanography, La Jolla, California; the Colorado State University, Fort Collins, Colorado; the Oceanography Department, Oregon State University, Corvallis, Oregon; the Bedford Institute of Oceanography, Dartmouth, Nova Scotia; and the Chalk River Nuclear Laboratories, Deep River, Ontario. Further afield there was the Institute of Biology of the South Seas, Sevastopol; the Bhabha Atomic Research Centre, Trombay; the National Institute of Radiological Sciences, Chiba-shi; and the Atomic Energy Research Institute, Kinki University, Higashi-osaka.

To all of these must be added those centres of excellence that orchestrated so much of the manner in which international research was conducted and its results argued over and debated – as it quite correctly should have been, and still should be – for many years: above all, the International Atomic Energy Agency in Vienna, the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development in Paris, and the Commission of the European Communities in Brussels.

In writing this book I have contacted and then harried several colleagues from the past, and they have most helpfully supplied me with information, jogged my memory, or commented helpfully on various passages of text. I would like to express my particular gratitude to Dennis Woodhead, Carroll Baker, John Hunt, Paul Leonard, Peter Liss, Scott Fowler, Mike Bewers, Almadena Real, and Jolyon Hendry for doing so. But any mistakes are mine.

The idea for the book came from my great friend Eric Hamilton at the Plymouth Marine Laboratory (PML) now, sadly, one of those who is no longer with us, and from discussions with Robert Gurney at the University of Reading. The actual writing of it, however, would never have started were it not for the needling of Stephen de Mora, the then Chief Executive of PML, and it would never have been finished were it not for the excellent help and advice of Emma Kiddle and Sarah Lambert of Cambridge University Press, and to copyeditor Theresa Kornak for her patience and advise, and without whom it would be far more difficult to read. To all three, I am very grateful indeed.

Finally, I would like to dedicate, if that is the right word, this book to all of those whom I have encountered in the field of radioecology – for their friendship, their scholarship, and for their wonderful company over a great many years.