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Biological consequences of Chernobyl: 20 years on

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The disaster at the Chernobyl nuclear power plant in 1986 released 80 petabecquerel of radioactive caesium, strontium, plutonium and other radioactive isotopes into the atmosphere, polluting 200 000 km^2 of land in Europe. As we discuss here, several studies have since shown associations between high and low levels of radiation and the abundance, distribution, life history and mutation rates of plants and animals. However, this research is the consequence of investment by a few individuals rather than a concerted research effort by the international community, despite the fact that the effects of the disaster are continent-wide. A coordinated international research effort is therefore needed to further investigate the effects of the disaster, knowledge that could be beneficial if there are further nuclear accidents, including the threat of a 'dirty bomb'.

Introduction

One of the four nuclear reactors of the Chernobyl nuclear power plant exploded on 26 April 1986 as a consequence of human errors owing to a temporary shutdown of the cooling system. The explosion transported vast amounts of radioactive material into the atmosphere, much of which was subsequently deposited not only in the immediate vicinity of the power plant in Ukraine, Russia and Belarus, but also over large parts of Europe and other continents (Figure 1). On this, the 20th anniversary of the worst environmental nuclear disaster in history, there is still much disagreement among government agencies, health professionals and scientists over the long-term effects of low-level nuclear contaminants. The official UN position [1] suggests that the consequences to human health are much lower than expected, the park-like appearance of the 2044.4 km^2 Chernobyl exclusion zone, with large mammals appearing to be increasing in numbers, suggests an ecosystem on the rebound. However, the UN report, and interpretations of it in the popular and scientific press (e.g. [2,3]), has generated an optimism that might be unfounded.

Here, we discuss the information available concerning the effects of the Chernobyl disaster on wild plant and animal populations, and also humans. It is our hope that this information will serve as a foundation for future studies investigating the long-term ecological and evolutionary repercussions of chronic exposure to low-level radioactive contaminants (low-level radiation has been defined as the dose below which it is not possible to detect adverse health effects, typically 1–20 rads). Given that the effects of the disaster were felt on a continent-wide scale but that research has generally been the result of investment by a few individuals, we also call for a coordinated international research effort to further investigate the environmental outcomes of the disaster.

A brief history of the Chernobyl event

On 26 April 1986, during a test of the ability of the Chernobyl nuclear power plant to generate power while undergoing an unplanned shutdown, safety systems were turned off, leading to an explosion and nuclear fire that burned for ten days, releasing between 9.35×10^3 petabecquerel (PBq) and 1.25×10^4 PBq of radionuclides into the atmosphere (by contrast, the Three Mile accident in Pennsylvania, USA on 27 March 1979 released just 0.5 terabecquerel). Although many of these radionuclides either dissipated or decayed within days (e.g. ^{131}Iodine), ^{137}Caesium (^{137}Cs) still persists in the environment even hundreds of kilometres from Chernobyl. Likewise, ^{90}Strontium (^{90}Sr) and ^{239}Plutonium (^{239}Pu) isotopes are common within the exclusion zone. Given the 30, 29 and 24 000 yr half-lives of ^{137}Cs, ^{90}Sr and ^{239}Pu, respectively, these contaminants are likely to be of significance for many years to come.

Physiological and genetic effects of radiation

Immediately following the accident at Chernobyl, humans exposed to high-level radiation suffered from acute radiation sickness, including dizziness, vomiting and fatigue [1]. The long-term physiological effects of immediate and later exposure have also shown changes in levels of antioxidants, immunity and hormones. Most of the long-term consequences of the Chernobyl disaster stem from the inhalation and ingestion of radionuclides generated by the explosion and nuclear fire (Box 1), in contrast to the effects that result from direct exposure to radiation from a nuclear blast. The genetic consequences of radiation exposure will depend on the received dose, dose rate and other indirect effects (Box 1).

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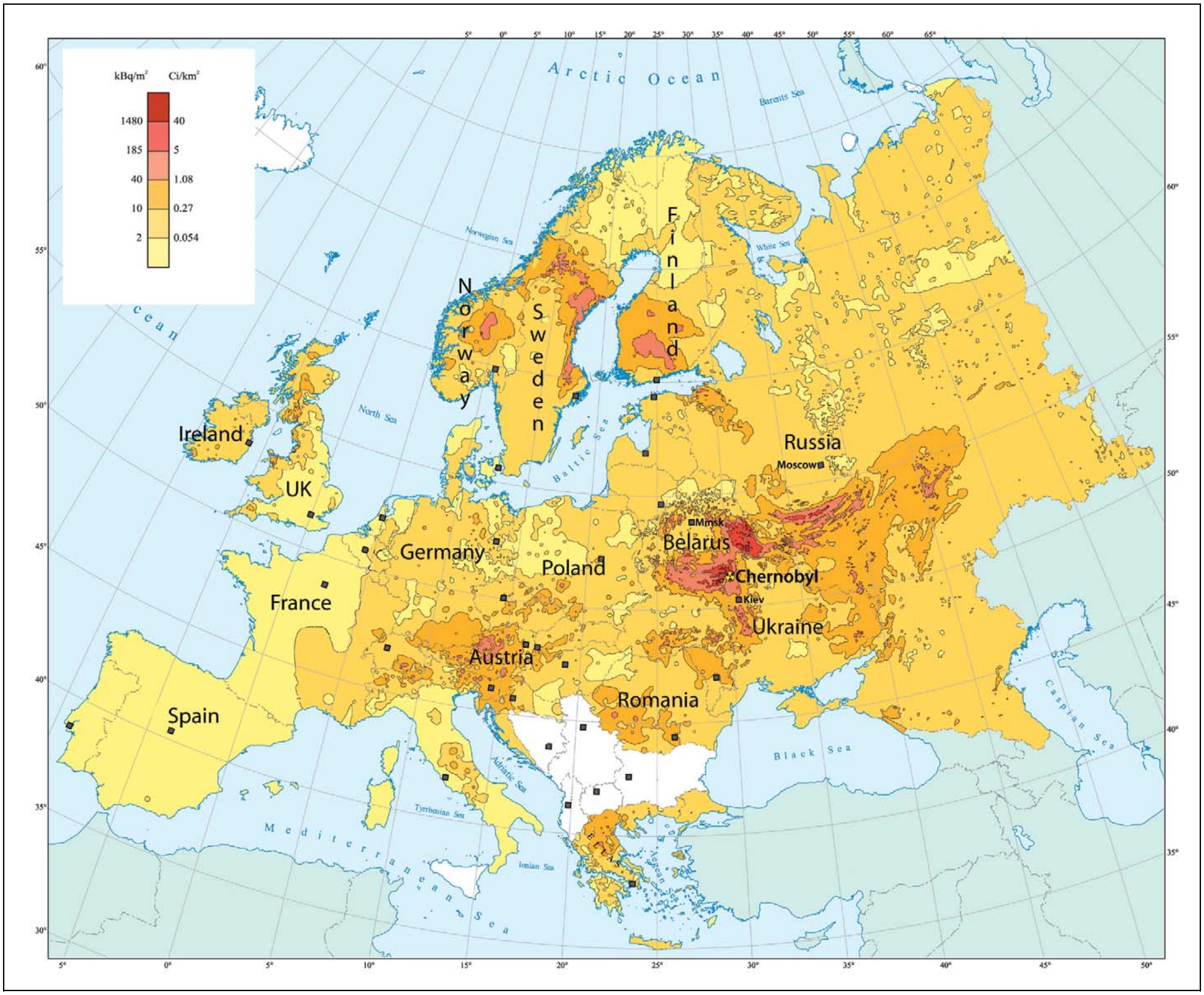

Figure 1. Distribution of radiation in Europe in May 1986 as a result of the Chernobyl disaster. Black squares indicate capital city locations. Adapted with permission from [31].

Antioxidant, immunity and hormone effects

Radiation can reduce levels of antioxidants, such as carotenoids and vitamins A and E, which are used for protecting DNA and other molecules from damage caused by free radicals [4–8]. Consistent with this prediction is the finding that barn swallows *Hirundo rustica* studied during 2000 from the most radiation-contaminated areas had significantly reduced amounts of carotenoids and vitamins A and E in blood and liver, compared with birds from control areas [9] (Box 2), although the level of radiation was low compared with previous studies of humans [4–8] (Box 3). These reductions were the best predictor of increased frequency of abnormal sperm from male barn swallows in such areas [9].

Antioxidants can have important consequences for immunity owing to their immunostimulating effects (reviewed in [10]). Studies of Chernobyl staff involved in cleaning-up immediately after the accident revealed impaired immune function compared with that of matched control individuals [11–13]. Likewise, barn swallows from Chernobyl had depressed levels of several types of leukocytes (e.g. heterophils and lymphocytes) and immunoglobulins, and reduced spleen mass compared with individuals from control areas [14], suggesting a reduced ability to raise an efficient immune response. The heterophil:lymphocyte ratio, which is an important physiological indicator of stress [15], was also elevated in barn swallows from Chernobyl compared with control individuals.

The elevated frequency of partial albinism in barn swallows, humans and other organisms from the Chernobyl region can also be linked to an antioxidant deficiency [16,17]. Normal plumage or skin colour is produced by the migration of melanocytes from the skin (so-called 'melanoblasts') to feathers; such migration can be disrupted or melanocytes can die prematurely owing to low concentrations of antioxidants in the skin, resulting in albinism. Mutations in genes encoding plumage colour can have a similar effect [17], as shown by the finding that feathers with melanin-based colour are paler in barn swallows from Chernobyl compared with those from individuals from control areas [14]. Surprisingly, to our knowledge,