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GUEST EDITORIAL

Health Risks from Radiation – Fission versus Fusion

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There is worldwide interest in developing fusion technology for energy generation. This is driven partly by the public's reluctant acceptance of nuclear fission technology, particularly around the waste generated during decommissioning, which, in some countries, has led to rejection of the technology [1]. One of the perceived benefits of fusion versus fission is that it does not produce long lived fission products and actinides [2]. However, the technology will produce tritium emissions, contaminated materials and wastes from neutron activation [3].

Relationship Between Radiation Dose and Health Effects

Health effects are driven by the dose of radiation delivered to the tissues of the human body. When the dose is low, the health effects are minimal, particularly when compared with the effects of lifestyle factors, such as drinking, smoking and obesity [4]. Human health is affected by a great number of different factors, and it is almost impossible to attribute an effect to a cause with 100% certainty. Instead, health effects are quantified by an increased probability related to a putative causal agent – this is true even in the case of the association of lung cancer with smoking habits [5].

In the case of radiation, high doses (in excess of 1 Sv whole body dose) can have immediate health effects due to direct effects on tissue integrity, whereas lower doses can increase the probability of a later effect, similar to exposure to chemical toxins, such as those implicated in lung cancer.

The dose to a given tissue is determined by a number of different factors:

(a) Physical factors include the energy and type of radiation released, and the physical half-life of the radioactive element.
(b) Chemical factors include whether a mechanism exists to bind particular structures within particular tissues, for example iodine on thyrogolublin within the follicles of the thyroid gland.
(c) Biological factors include how quickly an element transits the body (i.e. the time taken between ingestion/inhalation and excretion), which can be related to solubility of the radioactive element, and whether it is bound for a period of time within a specific tissue.
(d) In addition, the age of the person exposed can play a major role in risk, and this may depend on whether the tissue is undergoing protracted cell division at the time of exposure. A good example for this is the case with those exposed to radioactive isotope 131-I in childhood and early adolescence, at a time when the thyroid is undergoing a relatively rapid phase of growth. An elevated risk of developing thyroid cancer is only observed in those who are exposed at a young age and is reduced almost to zero if exposure occurs in adulthood, when the majority of thyroid cells are no longer undergoing cell division.

In terms of health risks, a useful rule of thumb is that if the energy of the radiation emitted is low, and the physical half-life of the radioisotope is much longer than its biological half-life (determined by (b) and (c) above) the dose to which a given tissue is exposed will be low, and the effect on health will be small. A dose can only be delivered if the tissue comes into contact with the radioactive isotope. The whole premise of handling radioactive waste is therefore to minimise exposure by introducing physical barriers to prevent exposure in the human environment.

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Health Risks from Nuclear Waste Fission Versus Fusion

There are a variety of radioactive waste produced from nuclear fission, but the ones of major public concern tend to be those with very long physical half-lives, such as U-235, Pu-239, other transuranics and fission products. These elements will remain radioactive for many thousands of years, although, as noted previously, it should be clear that their long physical half-lives may not make them a particular radiological risk in terms of the health of the individual. For example, despite the large amount of Cs-137 (half-life 30 years) that was released from the Chernobyl accident, radiation doses attributable to this element for individuals in the resident population were between 10 and 30 mSv over a 20 year period [6]. To put this into context, a whole body CT scan provides a radiation dose of around 10 mSv in a few minutes. Despite this, the generally accepted disposal route for long lived radioactive waste is a geological disposal facility (GDF). This provides security for the long term, and reduces the perceived threat from misuse of the waste [7]. However, this security comes at a considerable cost together with significant technological, geological and sociological challenges.

In contrast, although nuclear fusion will produce radioactive waste forms, they will be of a different nature which may warrant a policy change in the way these wastes are handled and regulated. One of the major radioactive wastes will undoubtedly be tritium (H-3), and tritiated products (materials that become contaminated with tritium). Tritium is a particularly mobile radionuclide due to its nature as a hydrogen isotope, and it readily substitutes with hydrogen in water, inorganic and organic compounds. Despite its mobility, there are a number of factors that lead to a low radiotoxicity from exposure to tritium. Its long physical half-life (12 years) relative to its short biological half-life of 10 days for tritiated water, or 40 days for organically bound tritium, coupled with low energy of its beta-radiation (-5.7 keV) means that penetration within the body is only a few microns. As health effects are dependent on dose of radiation to individual tissues, tritium would need to be ingested or inhaled in large quantities for a health effect to result. To put this into some context, drinking 2 L of water that has been contaminated at the highest level permissible by the WHO (10,000 Bq/litre) every day for a year would result in a dose of 0.1 mSv, roughly equivalent to two weeks of natural background radiation [8].

Other likely wastes come from activation of elements within high-performance steels that will comprise the structural materials and in-vessel components, most notably the first wall and breeder blanket regions in a fusion reactor. The exact nature of these wastes will depend on the engineering design of the reactor, and the materials used in its construction. Even with judicious selection of materials, opting for low activation materials, wastes will be likely to include some small concentrations of isotopes such as Ni, Nb and C, which give rise to Ni-63, Nb-94 and C-14 under neutron irradiation. As can be seen from the data in Table 1, all these radioisotopes have much longer physical half-lives relative to their biological half-lives, resulting in low doses to individual tissues. However, their long physical half-lives may mean that some of the waste contaminated by these isotopes may require long term storage, either on site or in a GDF. However, it is also possible that other radionuclides may be produced through the use of certain materials or impurities that are used in the reactor, and careful consideration will need to be given to this in the design process. Those that are of high energy and short half-lives that concentrate in particular tissues in the body (for example Hg-203 which concentrates in the kidney) would require appropriate handling to ensure risk of human contact is minimised, both during operation of the reactor and during the decommissioning process. The amount and type of radionuclides produced may well be dependent on the final design of the reactor, but careful consideration should be given to likely exposure scenarios (e.g. inhalation, ingestion), and to the amount of each isotope produced in order to take appropriate precautions when dealing with the waste stream.

Summary

In summary, nuclear fusion will result in radioactive waste production, albeit of a different nature to that produced by nuclear fission. However, as we have seen with nuclear fission, there will be a considerable challenge in communicating the small risk to human health from any possible human exposure to these wastes. It will be important that the regulation required to develop nuclear fusion takes into account these reduced risks, otherwise progress in implementation

Table 1 Radioactive wastes produced by fusion

Isotope	Physical t1/2	Biological t1/2	Type of radiation	Energy	Penetration	Reference
3-H	12 years	10–40 days	beta	5.7–19 keV	few microns	[8]
63-Ni	100 years	500 days	beta	17–67 keV	less than 0.07 mm	[9]
14-C	5700 years	10–40 days	beta	49–156 keV	0.03 cm	[10]
94-Nb	20,000 years	100 days	beta	156–500 keV	will penetrate skin	[11]
94-Nb	20,000 years	100 days	gamma	700 and 870 keV	will penetrate skin	[11]

will be slow. In recent months we have all seen how important self-sufficiency in energy – particularly from low carbon energy sources – is to our daily lives. Nuclear Fusion technology has the potential to play a major role in this, but social licence will be required to realise its full potential. As we have already seen with nuclear fission, it is an ongoing challenge to create a constructive dialogue with a general public that lives with a fear any mention of the word "radiation".

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