Assessment of the Impact of Radioactive Disposals and Discharges from the United Kingdom Low Level Waste Repository on the Ecosystem – 9051

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ABSTRACT

This paper describes an assessment of the impacts to ecosystems and wildlife species from radioactive discharges and disposals at the United Kingdom's low level waste disposal facility in West Cumbria. The assessment was undertaken in response to a requirement in the site's current authorisation and comprised a detailed desk based review along with an exercise to screen relevant monitoring data from the site against generic assessment criteria and undertake a numerical risk assessment.

Much of the site is vegetated, comprising a variety of habitats including grassland, relict dune heath and surface water bodies. Furthermore, the site is located adjacent to a coastal/estuarine area which is protected as it provides a habitat of high ecological value and species of animals and plants are present that are rare, endangered or vulnerable. However, the current impact of aerial and liquid radioactive discharges from the low level waste repository on ecosystems and wildlife species is considered to be low. Site monitoring data also indicate that there has been a reduction of radionuclide activities in ground and surface water and leachates over time, a result of measures initiated to minimise rainwater infiltration and improve leachate management associated with the disposal area.

A quantitative assessment was undertaken to assess future impacts to relevant terrestrial, fresh water and marine ecosystems. This showed that modelled peak radionuclide concentrations in the first 4,000 years after site closure were not sufficiently high to cause potential impact to any of these ecosystems or associated wildlife. This cut-off date was chosen as it is considered probable that, due to the effects of future climate and landscape change and, unless actions are taken to defend the coastline, the site is likely to be disrupted by coastal erosion in the next 4,000 years.

INTRODUCTION

The Low Level Waste Repository (LLWR) located near the village of Drigg, West Cumbria in north-west England is the United Kingdom's (UK) principal facility for the disposal of Low Level (radioactive) Waste (LLW). The site is owned by the Nuclear Decommissioning Authority, the Government body with responsibility for the management of the UK's nuclear legacy sites, and is operated by the LLWR Site Licence Company, LLW Repository Ltd.

Disposals to the LLWR are carried out under the terms of an authorisation granted by the Environment Agency of England and Wales under an Act of Parliament called the Radioactive Substances Act 1993. This authorisation is periodically reviewed by the Environment Agency. The most recent authorisation came into effect on 1st May 2006 [1].

One of the key requirements under this authorisation was for the operator to carry out a comprehensive study of the impact of radioactive discharges and disposals on ecosystems and wildlife species by 1 May 2007, using the most up to date assessment framework, together with the results of relevant environmental monitoring. In order to satisfy this requirement, a detailed desk-based review was undertaken along with an exercise to screen relevant monitoring data from the site against generic assessment criteria and undertake a numerical risk assessment.

This paper describes the technical approach, methodology and key results. The full results from this study were submitted to the Environment Agency in order to satisfy the requirements of the authorisation, thus allowing continued disposals of LLW at this strategically important site [2]. The site understanding included within the model described in this paper is based on work undertaken to support the most recent environmental safety case for the LLWR [3]. The LLWR is developing its understanding of the site and repository system and will be undertaking further assessments of the impact of radionuclide discharges on ecosystems prior to preparing a new Environmental Safety Case in 2011.

BACKGROUND

The LLWR is the UK's principal facility for the disposal of solid LLW and receives waste from a wide range of nuclear licensed sites, such as operational power plants, and non-nuclear licensed sites, such as research establishments and hospitals. The site is situated on a coastal plain in west Cumbria adjacent to the Irish Sea coast of north-west England, located about 0.5 km inland and about 0.5 km from the village of Drigg.

Disposal operations at the LLWR commenced in 1959. For the first three decades of operations, disposals were made under the required regulatory authorisations in place at the time by tumble tipping essentially loose wastes into excavated trenches. A total of seven trenches (Trenches 1 to 7) were excavated and filled between 1959 and 1995. A major upgrade in disposal operations at the LLWR was initiated in 1987 to phase out trench disposal in favour of vault disposal. In addition, measures were initiated to minimise rainwater infiltration and improve leachate management associated with the disposal area.

Vault disposal involves the orderly emplacement of containerised, conditioned wastes in engineered concrete vaults. The chosen waste form is based on high force compaction of the waste, emplacement in standard half-height International Standards Organization (ISO) containers and grouting the voidage with cementitious material within the ISO container to form a solid, monolithic product. Larger items of waste are grouted directly into the vault. The first disposal vault (Vault 8) commenced operations in 1988 and is close to being full. Planning permission has been granted for the construction of a further vault, Vault 9, initially as a storage facility, and there is further scope for additional vaults within the available area.

An aerial photograph of the site and its immediate setting is shown in Fig. 1, showing Vault 8 and, in the centre of the photograph, the grass-covered interim cap that has been constructed over the trenches. The future site management strategy is yet to be finalised. For the purposes of this assessment, it is assumed that disposals cease in 2050 when the site enters a post-operational management phase. During this period, site closure engineering will be emplaced. At some point thereafter it is assumed that controls over the site will be relinquished.

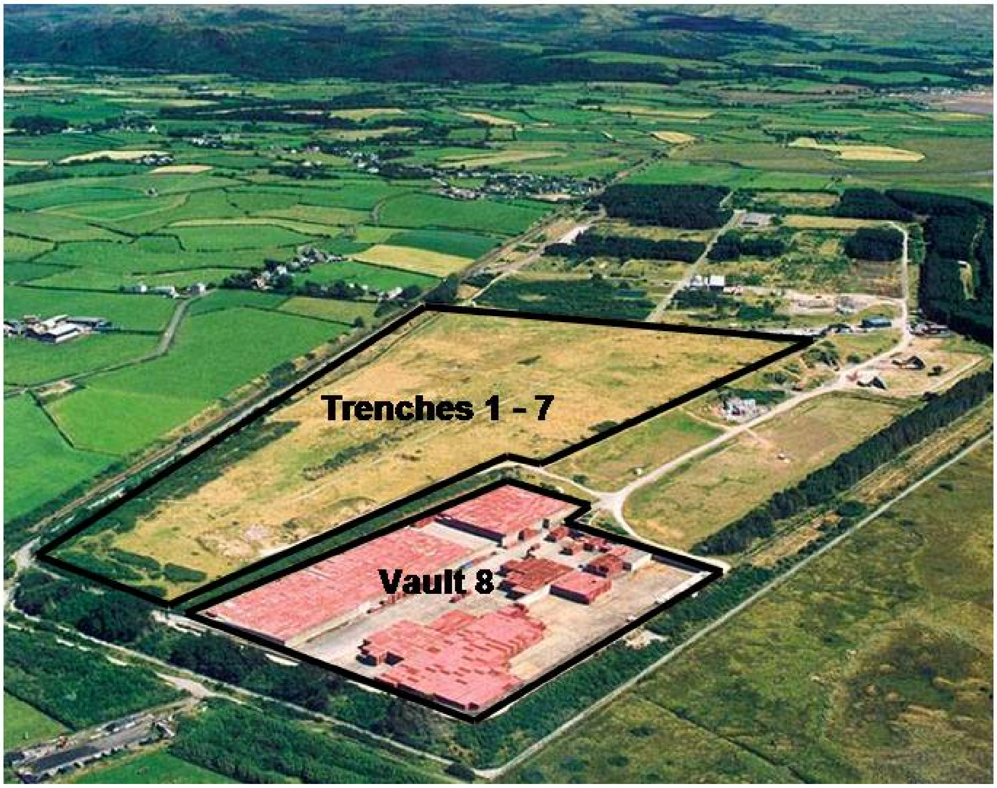

Fig. 1. Aerial Photograph of the LLWR c. 2000 (viewed from north-west to south-east)

ECOLOGICAL SETTING

Slightly under half of the LLWR site is used for radioactive waste disposal. Other areas of the site include the historic waste retrieval facilities and operational buildings associated with the disposal of LLW (e.g. the LLWR Grouting Facility and rail sidings). There are also areas of open grassland, scrub and woodland. The site is surrounded by farmland, which is mainly used for grazing.

A watercourse, the Drigg Stream, flows through the site roughly parallel with the western site boundary. Towards the centre of the site, the Drigg Stream is joined by the East-west Stream which originates off site to the north east, draining farmland and also taking surface water from the railway line which runs adjacent to the north-eastern site boundary. The Drigg Stream leaves the site to the south and discharges into a larger river, the River Irt, close to its estuary with the coast. The Irt estuary is approximately 1.5 km south of the site. To the west of the site the topography gently undulates towards a small cliff line marking the edge of the Drigg beach, which is approximately 0.5 km from the site at its closest point. The surface of the interim cap that covers the trench area is around 25 m above Ordnance Datum.

The LLWR site has a variety of habitat types including:

- Open dry grassland, extensive areas of unimproved acid and neutral grassland. The acid grasslands are associated with heathy vegetation or are remnant dune communities.
- Relict dune heath.
- Two areas of marshy grassland and swamp adjacent to the fire pond which support a diverse ecology. There are several, less diverse areas of swampy grassland scattered over the site.
- Water bodies: there are several semi-natural and man-made seasonal and permanent ponds within

the site. The banks of the Drigg stream are steep (about 50° - 60°) and up to 2 m high. The stream is 2 – 3 m wide and 20 – 30 cm deep. For much of its length it is choked by weeds. In contrast, the east-west stream supports fairly tall diverse vegetation. In addition, there are several small lengths of ditch (most of which are shady and support little vegetation).

- Plantations, woodlands and scrub (trees are predominantly aspen, willow, pines and white poplar).

Three ecologically significant sites have been identified in the vicinity of the LLWR. The Drigg Coast area is identified as a Special Area of Conservation (SAC) Natura 2000 site under the terms of the 1992 European Union Habitats Directive as an area which supports support rare, endangered or vulnerable natural habitats and species of plants or animals. The Drigg Coast is also designated as a Site of Special Scientific Interest (SSSI) as an area of land which, in the opinion of Natural England (the Government body with responsibility for conserving and enhancing the natural environment of England), is of special interest at a national level due to its flora, fauna or geological or physiographical features. It covers 1400 hectares of the coastal area adjacent to the LLWR.

Habitat types identified in the Drigg Coast SSSI/SAC are summarised in Table I. Protected species identified as inhabiting the area include: mammals (e.g. otter, red squirrel and water vole), amphibians (e.g. great crested newt and natterjack toad), reptiles (e.g. slow worm, viviparous lizard and adder), insects (e.g. large heath butterfly) and flora (e.g. bluebell and meadow clary).

Table I. Summary of Habitat Types for the Drigg Coast SSSI / SAC

Habitat Type	Percentage Cover
Tidal rivers, estuaries, mud flats, sand flats, lagoons (including saltwork basins)	44.5
Salt marshes, salt pastures, salt steppes	12
Coastal sand dunes, sand beaches, machair [a]	41
Shingle, sea cliffs, Islets	2
Bogs, marshes, water fringed vegetation, fens	0.5

[a] Machair is a distinctive type of coastal grassland found in the north and west of Scotland, and in western Ireland. It is associated with calcareous sand, blown inland by very strong prevailing winds from beaches and mobile dunes.

Two further SSSIs are located in the vicinity of the LLWR. These are Hallsenna Moor SSSI, which is situated approximately 2 km from the LLWR and consists of 30 hectares of lowland dwarf shrub heath and lowland broadleaved, mixed and yew woodland, and Drigg Holme SSSI, which is approximately 2.5 km from the LLWR and consists of 9 hectares of lowland neutral grassland (Fig. 2). It is not considered that either of these sites can be impacted by the LLWR; aerial discharges from the site are minimal [4] and there are no watercourses which run inland from the site. The direction of regional groundwater flow is to the south-west, towards the coast.

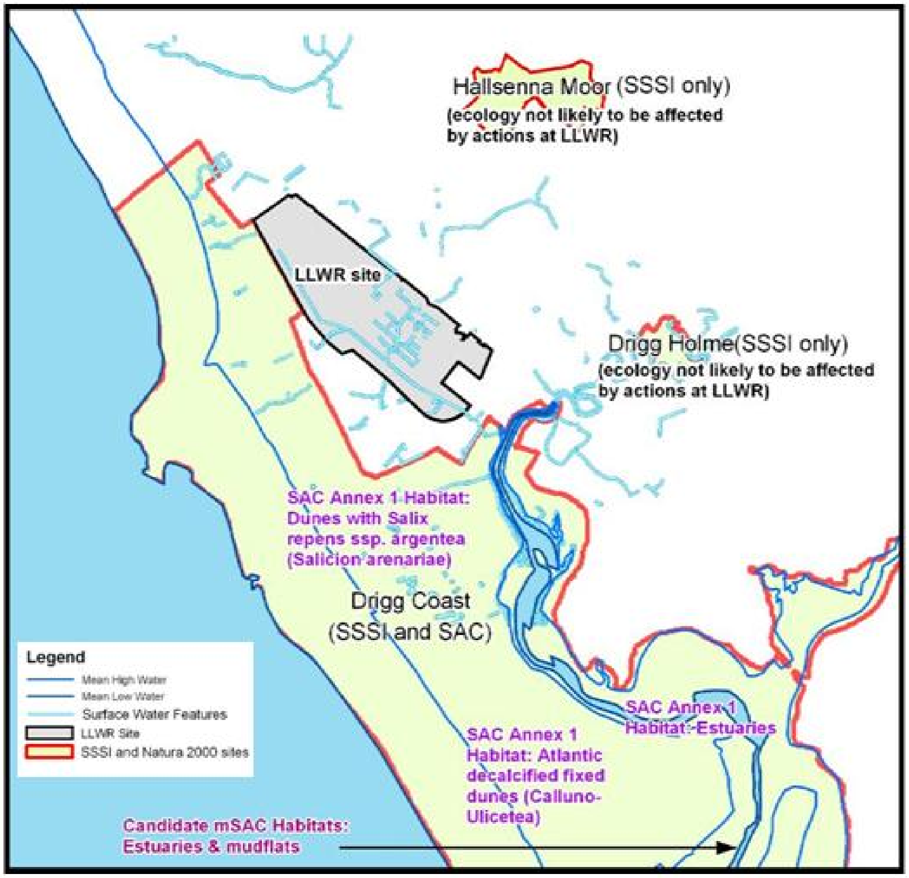

Fig. 2. Location of SSSIs and Natura 2000 sites in the vicinity of the LLWR

PRESENT DAY IMPACTS

The assessment focussed on impacts associated with radionuclides leached from the disposal facility and transported by ground and surface waters. As noted above, there are few aerial discharges, and statutory environmental monitoring shows that environmental levels of total alpha and beta activity sourced from the LLWR are insignificant compared with those from Sellafield, a nuclear licensed site including reprocessing and chemical separation facilities and a former nuclear power station which is located 5 km to the north of the LLWR [4].

Present day risks associated with leachates from Trenches 1 to 7 and Vault 8 are managed by sampling and monitoring. Interceptor drains and a holding tank ensure that the discharges can be contained and analysed prior to discharge to the sea. Routine discharges are well within discharge limits; for example, in 2004 the total alpha, total beta and tritium levels discharged were <0.07%, 0.3% and 0.18% respectively of the authorised limits [4]. This discharge is therefore likely to have a low impact on the marine environment.

Surface water drains into the intertidal region of the River Irt via the Drigg stream. Analysis of the stream shows that activity levels are much less than the authorised limits; in 2004 the total alpha, total beta and tritium levels discharged were <0.06%, 0.04% and 0.004% respectively of the authorised limits [4]. This discharge is therefore also likely to have a low impact on the marine environment. However, it has to be considered that there is the potential for concentrations of key radionuclides in the groundwater to increase in the future after the site is no longer actively managed and closure engineering starts to degrade, which could potentially harm nearby ecosystems.

In order to further assess the potential for impacts to nearby ecosystems and wildlife, an analysis of all available statutory and non-statutory groundwater, surface water and leachate drain monitoring data was undertaken. A total of 1,871 samples for the period January 2000 to October 2006 were available for assessment. This period was selected as it post-dates emplacement of an interim trench cap and cut-off wall around the north and east sides of the trenches, which significantly reduced the flux of radionuclides from the facility. In addition, historical monitoring data were analysed, comprising a total of 53,057 samples dating back to 1971.

The monitoring data were compared against two sets of criteria. Firstly, monitoring data were screened against screening levels derived by the Environment Agency to assess the impact of radioactivity on water bodies [5]. If the activity concentration of a radionuclide in a water body is below its screening level then there is an insignificant effect on wildlife within the watercourse; if the radionuclide activity concentration exceeds its screening level, then further assessment is required to determine whether there are significant risks of harm. Secondly, monitoring data were screened against screening levels derived by the US Department of Energy (US DOE) [6]. This screening exercise was considered to reflect impacts to ecosystems during the operational phase of the LLWR up to 2050 (at which time disposals to the LLWR are assumed to cease).

Both the Environment Agency and US DOE approaches are based on the assessment of doses to ‘reference’ organisms. Doses from exposure to radionuclides in water, air or soil are assessed from calculations of the energy absorbed by different shapes which represent the reference organism arising. The radiation may be absorbed from radionuclides outside the body of the organism (external radiation) or from radionuclides which have been taken up by the organism (internal radiation). The uptake of radionuclides by the reference organisms is assessed through the use of concentration factors which are the ratio of concentrations of radionuclides in organisms to concentrations in water and soil. Both sets of screening levels are derived by considering the maximum amount of a particular radionuclide in a given environmental compartment that could give rise to a dose rate of 400 $\mu Gy\ h^{-1}$ being received by the critical aquatic wildlife group in a particular water body. The 400 $\mu Gy\ h^{-1}$ dose rate is based on available data on the biological effects of ionising radiation and has been proposed by a number of international organisations (e.g. International Atomic Energy Agency and the United Nations Scientific Committee of the Effects of Atomic Radiation) because at this level it is not expected to see any effects that would be manifest at the level of population.

The Environment Agency and US DOE screening levels can vary by about two orders of magnitude in each direction for different radionuclides. Much of this variability is due to different concentration factors assumed for the aquatic organisms. The Environment Agency draft screening levels are based on the most restrictive freshwater reference organism whilst the US DOE screening levels are provided for a general aquatic system and general data available for that system. Consideration of different organisms and use of different data sources for concentration factors will inevitably lead to these observed differences. In general, the Environment Agency habitats approach has more restrictive screening levels for the alpha radiation emitting radionuclides (e.g. U, Pu and Am isotopes) whilst the US DOE approach is more restrictive for the gamma emitting radionuclides (e.g. ^{131}I, ^{137}Cs). This is partly as a result of the selection of default cautious concentration factors for ^{239}Pu and ^{241}Am in the Environment Agency approach and for ^{137}Cs in the US DOE approach. For the purposes of comparing water concentrations to these screening levels for the assessment described here, the Environment Agency and US DOE approach were used separately rather than using the most conservative screening levels from each approach.

In general, there were proportionally fewer radionuclides exceeding the screening levels for total alpha and total beta in the samples taken during 2000 to 2006 compared with the earlier samples, indicating the reduction of environmental concentrations of radionuclides with time. The results for total alpha measurements between 2000 and 2006 showed that 63% of the samples exceeded the Environment Agency screening levels and 2% exceeded the US DOE screening levels. Using data dating back to 1971, these percentages were 96% and 36% respectively. The results for total beta measurements between 2000 and 2006 showed that 3% of the samples exceeded the Environment Agency screening levels and 30% exceeded the US DOE screening levels. Using data dating back to 1971, these percentages were 34% and 73% respectively.

Only ^{137}Cs, Pu-alpha, ^{90}Sr, total alpha and total beta and ^{234}U exceeded the screening levels in the samples taken during 2000 to 2006. Of these radionuclides, only total alpha, total beta and ^{234}U exceeded both the Environment Agency and US DOE screening levels. Screening level exceedances were recorded in trench leachate, groundwater and the Drigg and east-west streams. The historical data showed screening level exceedances for a greater range of radionuclides; concentrations of ^{241}Am, ^{134}Cs, ^{40}K, ^{226}Ra, ^{232}Th, ^{234}U and total gamma also exceeded either the Environment Agency or the US DOE screening levels in the period 1971 to 2000.

As screening levels for radionuclides in water have been exceeded, a further assessment was carried out using the European Union ERICA (Ecological Risk from Ionising Contaminants: Assessment and Management) integrated approach to ecological assessment and software tool [7] (see below).

FUTURE IMPACTS

In order to determine potential future impacts, an assessment model was set up using the GoldSim software [8] to calculate concentrations of radionuclides in the relevant ecosystems (i.e. the biosphere) at times in the future.

Give the coastal location of the LLWR, the site must be considered potentially vulnerable to the effects of future climate and environmental change. This is an issue which has been the subject of many recent studies both within the UK and internationally. Scenarios for climate and environmental change for the LLWR have been developed based on the output from the international BIOCLIM programme [9]. The most likely scenarios for the west Cumbrian region comprise a period of enhanced warming combined with significant sea level rise, of the order of 7.3 m to 23.8 m at 3,000 years after present (y AP). Consideration of the effects of such significant sea level rise combined with studies of the rates of coastal change in the environs of the LLWR have indicated that the coastline will recede as far as the LLWR site within a few thousand years. Unless actions are taken to defend the coastline, the disposal facility is likely to be disrupted by coastal erosion between 750 and 2,500 y AP, with the period of disruption lasting up to 2,000 years [10].

The assessment model was therefore set up to calculate environmental concentrations in the period 0 to 4,000 y AP, taking into account a period of mild global warming.

Within the GoldSim model, releases from different subregions of the repository were represented as well mixed equilibrium source terms for which the key controls on the flux of radionuclides from the near field were:

- the volume of water which infiltrates the cap and leaches radionuclides from the wastes (dependent on cap performance and climate state);

- contaminant solubility limits within the leachate (dependent on the specific contaminant and the prevailing biogeochemical conditions); and
- contaminant mobility limitation through sorption onto the wastes (dependent on the specific contaminant and the prevailing biogeochemical conditions).

It was assumed that all the radionuclides were available for leaching from the wastes from the start of the assessment, regardless of the waste-form. This was a conservative assumption since only the surface would be exposed to water for some forms of waste, e.g. aluminium ingots. The assessment started at 2050 which is when disposals to the LLWR are assumed to cease.

The geosphere was modelled as a series of one-dimensional legs through the unsaturated and saturated zones, taking account of advection, longitudinal dispersion and contaminant retardation. The principal groundwater pathways that have been identified for radionuclide migration and were represented in the model comprised migration from the vaults and trenches towards the coast in a south-westerly direction, following the direction of the regional groundwater, and migration from the southern trenches and future vaults in an upper groundwater system in a southerly direction towards the Drigg Stream.

The activity was assumed to enter the biosphere (i.e. the accessible environment) either at the lower foreshore (regional groundwater pathways) or the Drigg Stream (upper groundwater pathway). The geographical extent of the biosphere was discretised into compartments which allow the transfer of mass or contaminants between them with instantaneous uniform mixing within the compartment.

The local biosphere comprised 12 compartments: Drigg Stream; Drigg overbank soils; Drigg stream banks and bottom sediments; Irt estuary waters; Irt estuary tide-washed pasture; Irt estuary sediments; Local coastal waters; Local coastal sediments; Drigg coastal land; Drigg beach; Upper foreshore; and Lower foreshore. The marine environment comprised six compartments: Irish sea east waters; Irish sea east sediments; UK coastal waters; UK coastal sediments; World's ocean waters; and World's ocean sediments. Radionuclide transfer processes considered within the biosphere model were:

- leaching interactions associated with the transport of radionuclides due to leaching between a soil site compartment and a soil or aquatic compartment;
- sedimentation from overlying waters to bottom sediments;
- erosion interactions representing the rate of erosion of surface material occurring principally by weathering. They may take place between a soil compartment and an adjacent soil or aqueous compartment;
- resuspension interactions which are converse to sedimentation and represent bed sediment being disturbed and transported into the aqueous media;
- hydrosphere exchange interactions from an aqueous compartment to either another aqueous or a soil/sediment compartment; and
- horizontal sediment exchange interactions representing the transfer of sediment between compartments, as brought about by tidal action and the action of biota.

The relationship between the compartments of the biosphere model is represented in Fig. 3.

Peak radionuclide concentrations in each of the biosphere compartments were compared in order to select the biosphere compartments with the highest peak radionuclide concentrations, which were used for the analysis of doses to wildlife using the ERICA integrated approach. The following biosphere compartments from the model were selected to represent freshwater, marine and terrestrial ecosystems on and in the vicinity of the LLWR site:

- Freshwater ecosystem: Drigg stream compartment and stream overbank soils compartment (freshwater sediment in direct contact with Drigg stream).
- Marine ecosystem: Local coastal waters compartment and lower foreshore sediment compartment (marine sediment directly interacting with the local coastal waters and containing the highest (i.e. most conservative) radionuclide concentrations of marine sediment compartments).
- Terrestrial ecosystem: Drigg stream overbank soils compartment (freshwater sediment, containing the highest (i.e. most conservative) radionuclide concentrations of terrestrial compartments) and the Drigg beach marine sediment (providing an assessment of the potential impacts on the Drigg Coast SSSI/SAC).

ERICA INTEGRATED APPROACH

The ERICA Integrated Approach [7] is supported by the ERICA tool, which is a software programme that guides the user through the assessment process, keeps records and performs the necessary calculations to estimate dose rates to selected biota. The tool interacts with a number of databases and other functions that help the assessor to estimate environmental media activity concentrations, activity concentrations in biota, and dose rates to biota. The tool also interfaces with the FREDERICA database, a web-based radiation effects database [11].

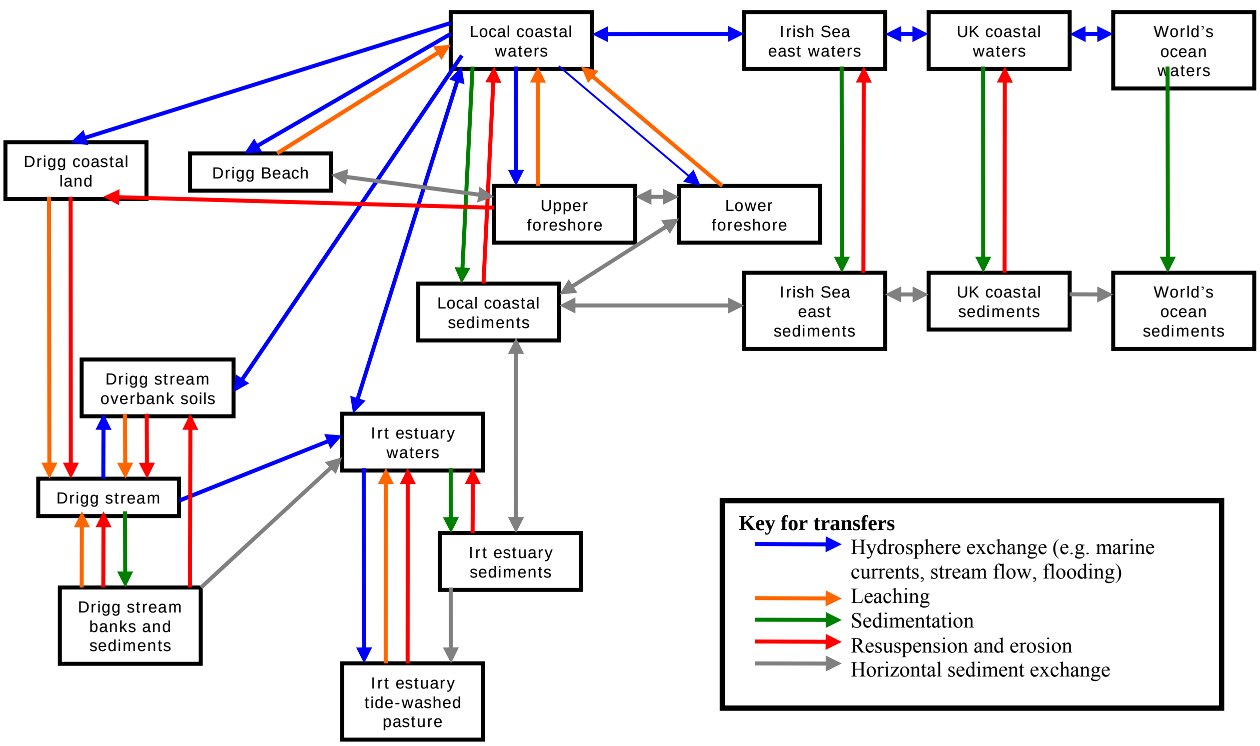

Fig. 3. Biosphere compartmental model and radionuclide transfers

The databases of the ERICA tool have been built around a number of reference organisms which are listed in Table II. It was considered that the variety of reference organisms provided a suitable analogy for the terrestrial, freshwater and marine ecosystems identified in the vicinity of the LLWR. Each reference organism has its own specified geometry (and default transfer data) and is representative of either the terrestrial, freshwater or marine ecosystems. The following radioelements are included within the ERICA integrated approach: Ag, Am, C, Cd, Ce, Cl, Cm, Co, Cs, Eu, H, I, Mn, Nb, Ni, Np, P, Pb, Po, Pu, Ra, Ru, S, Sb, Se, Sr, Tc, Te, Th, U and Zr.

Table II. Reference Organisms for Each Ecosystem in the ERICA Tool

Freshwater	Marine	Terrestrial
Amphibian	(Wading) bird	Amphibian
Benthic fish	Benthic fish	Bird
Bird	Bivalve mollusc	Bird egg
Bivalve mollusc	Crustacean	Detritivorous invertebrate
Crustacean	Macroalgae	Flying insects
Gastropod	Mammal	Gastropod
Insect larvae	Pelagic fish	Grasses & Herbs
Mammal	Phytoplankton	Lichen & bryophytes
Pelagic fish	Polychaete worm	Mammal
Phytoplankton	Reptile	Reptile
Vascular plant	Sea anemones/true corals	Shrub
Zooplankton	Vascular plant	Soil Invertebrate
	Zooplankton	Tree

The assessment element of the ERICA integrated approach is organised in three separate tiers, where satisfying certain criteria in Tiers 1 and 2 allows the user to exit the assessment process while being confident that the effects on biota are low or negligible, and that the situation requires no further action. Where the effects are not shown to be negligible, the assessment should continue to a higher tier.

Tier 1 Assessment

The Tier 1 assessment is a screening level which is intended to evaluate risk using a conservative approach. Radionuclides can be selected for assessment of impacts to generic freshwater, marine or terrestrial ecosystems.

Maximum environmental activity concentrations derived from measured or modelled concentrations in various environmental media are used, taking no account of spatial or temporal variation, and compared against the lowest environmental media limiting activity concentration back-calculated from predicted no-effect dose rates. The tool derives a risk quotient (RQ) by dividing the input media concentrations by the most restrictive environmental media concentration limit for each radionuclide. The radionuclide specific risk quotients are then summed to determine a total RQ. If the RQ is less than one, then the tool suggests that the user should exit the assessment process. If the RQ is greater than one, the user is advised to continue with the assessment.

The default screening criterion is an incremental dose rate of 10 $\mu Gy\ h^{-1}$, to be used for all ecosystems and organisms. This value was derived from a species sensitivity distribution analysis performed on chronic exposure data in the FREDERICA database and is more conservative than the 400 $\mu Gy\ h^{-1}$ dose rate used by the Environment Agency and US DOE when deriving screening levels for radionuclides in surface water [5,6].

Tier 2 Assessment

At Tier 2, impacts to specific organisms are considered as opposed to generic ecosystems. There is also the potential to review the tool's default distribution coefficients, concentration ratios, occupancy factors and radiation weighting factors (the default values are 10 for alpha radiation, 1 for beta/gamma radiation and 3 for low energy beta radiation). An expected value of the RQ is calculated using expected (or best estimate) values for the input data and the parameters. The 95th or 99th percentile of the RQ is estimated by multiplying the expected value of the RQ by an uncertainty factor (UF) of 3 or 5 respectively (reported as the conservative RQ in the ERICA tool). The UF is defined as the ratio between the 95th or 99th percentile and the expected value of the probability distribution of the dose rate (and RQ). The 95th percentile has been used in this study.

A 'traffic light' system is used to indicate whether the situation can be considered to be: I) Green: high degree of confidence that there is negligible concern (conservative RQs below one for all organisms); II) Amber: of potential concern, where more qualified judgements may need to be made and/or a refined assessment at Tier 2 or an in-depth assessment in Tier 3 performed (conservative RQ above one for any one organism, probability of exceeding the screening value at Tier 2 is above that selected as defined by the UF); III) Red: of concern, where the user is recommended to continue the assessment either at Tier 2 if refined input data can be obtained or at Tier 3 (expected RQ and therefore conservative RQ above one for any organism, assessment has exceed the screening value at Tier 2).

Tier 3 Assessment

It is considered that situations which give rise to a Tier 3 assessment are likely to be complex and unique, therefore specific guidance on how the Tier 3 assessment should be conducted is not given. Each Tier 3 assessment should be constructed on a site-specific basis, using as much site data as possible, taking into account the most recent scientific literature and using sensitivity/probabilistic analysis. This allows the user to estimate the probability (or incidence) and magnitude (or severity) of the environmental effects likely to occur and, by discussion and agreement with stakeholders, to determine the acceptability of the risk to non-human species.

ERICA ASSESSMENT

A full version of the ERICA tool was not available when the study was undertaken and therefore it was agreed with the Environment Agency that a prototype version of the tool was suitable for use. If RQs calculated at Tier 1 exceeded one then the assessment proceeded to Tier 2. Otherwise it was concluded that impacts on the ecosystem were low or negligible and that no further assessment was required.

Present Day Impacts

For an estimation of present day impacts to the freshwater ecosystem, monitoring data from the Drigg stream and stream sediments were input to the ERICA tool. The Tier 1 ERICA assessment of the Drigg stream and sediments gave a sum total of risk quotients of 2.37E+01. The doses from ^{238}U and ^{241}Am exceeded the screening dose rate of 10 μGy h^{-1}, therefore a Tier 2 assessment was performed. At Tier 2, the total dose rates to organisms were all below the expected screening level of 10 μGy h^{-1} and for all reference organisms the expected risk quotient was below 1. However, for phytoplankton, the probability of exceeding the selected screening dose rate was greater than 5% (amber grading).

No monitoring data were available to assess impacts to the terrestrial and marine environments, however, an assessment on the current dose rates to non-human biota in the Drigg Coast SSSI/SAC using the ERICA assessment tool was undertaken as a case study during the ERICA project [12]. The assessment concluded that the impact of anthropogenic radionuclides on the sand dune ecosystem of the Drigg Coast

SSSI/SAC was well below the level where effects are likely to be seen in biota. In addition, measured radionuclide activities were considered to be influenced by marine discharges from the Sellafield site.

Future Impacts

For assessment of future impacts, peak radionuclide concentrations in the terrestrial, marine and fresh water environments were used for the analysis of doses to wildlife using the ERICA tool. Peak concentrations were selected for the period 0 to 4,000 years after 2050 (i.e. site closure). For terrestrial ecosystems, soil concentration data were input from terrestrial compartments (Bq kg^{-1}). For assessment of aqueous ecosystems, data were input for both water concentrations (i.e. from freshwater and marine compartments: Bq m^{-3}) and corresponding sediment concentrations (Bq kg^{-1}); the ERICA tool calculates doses from both data to assess organisms that live in both the water column and surrounding sediments.

Peak radionuclide concentrations in the first 4,000 years after site closure gave the following results in the Tier 1 assessment:

- Freshwater ecosystem (represented by the Drigg stream and stream overbank soils freshwater sediment) – the sum of the radionuclide risk quotients was 2.14E-07, meaning that the doses to wildlife from the radionuclides assessed were lower than the 10 μGy h^{-1} screening level.
- Marine ecosystem (represented by the local coastal waters and the lower foreshore marine sediment) - the sum of the radionuclide risk quotients was 1.05E+00 and the dose from one radionuclide (^{99}Tc) exceeded the screening dose rate of 10 μGy h^{-1}. Therefore a Tier 2 assessment was required.
- Terrestrial ecosystems (represented by the stream overbank soils freshwater sediment and the Drigg beach marine sediment) - the sum of the radionuclide risk quotients was 4.67E-08 and 2.64E-04 respectively, meaning that the doses to wildlife from the radionuclides assessed were lower than the 10 μGy h^{-1} screening level.

A Tier 2 assessment was performed for the marine ecosystem. Total dose rates were all below the screening level of 10 μGy h^{-1} and, for all reference organisms, the probability of exceeding the selected screening dose rate was below 5%. Thus peak radionuclide concentrations were not sufficiently high as to cause significant impacts to the marine ecosystem.

From these results, it was concluded that peak doses to identified wildlife and ecosystems in the first 4,000 years after site closure would be below the screening level of 10 μGy h^{-1}. For all reference organisms, the probability of exceeding the selected screening dose rate was below 5%.

It should also be noted that doses to non-human biota were calculated on the basis of the maximum concentrations in the environment, therefore, the total exposure to each organism was calculated by treating the maximum dose from each radionuclide as being additive, irrespective of the time at which the peak concentrations occurred. This assumed additivity of all doses which assumes the organisms experience the maximum concentrations of each radionuclide, is clearly conservative. In addition, the calculations assumed that the reference organisms occupy media with the highest level of radioactive contamination 100% of the time.

SUMMARY

The LLWR site comprises a variety of potentially important habitats, including dry grassland, relict dune heath, marshy grassland and surface water bodies. It is located adjacent to the Drigg Coast SSSI/SAC, which is protected as providing a habitat of high value and the presence of species of animals and plants which are rare, endangered or vulnerable.

This study confirmed that the current impact of aerial and liquid radioactive discharges from the LLWR on ecosystems and wildlife species is low. Analysis of groundwater, surface water and leachate drain monitoring data confirmed that proportionally fewer radionuclides exceeding published screening levels for total alpha and total beta are found in samples taken between the years 2000 to 2006 compared with earlier samples. This is likely to be a result of measures initiated to minimise rainwater infiltration and improve leachate management associated with the disposal area.

An ERICA assessment to assess future impacts to relevant terrestrial, fresh water and marine ecosystems has shown that modelled peak radionuclide concentrations in the first 4,000 years after site closure were not sufficiently high as to cause potential impact to any of these ecosystems or associated wildlife. This cut-off date was chosen as it is considered probable that, due to the effects of future climate and landscape change and, unless actions are taken to defend the coastline, the site is likely to be disrupted by coastal erosion in the next 4,000 years.

Although a prototype version of the ERICA tool was used in this assessment, the tool was found to be user friendly and well suited to the assessment context, having access to an up-to-date database of current reference data and covering all the radionuclides and ecosystems of concern.

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