Assessing doses to the public from discharges of radionuclides from non-nuclear establishments in the UK

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Introduction

Organisations disposing of radioactive wastes, including those making direct discharges to the environment, are regulated in the UK by the various environment agencies who enforce the provisions of the Radioactive Substances Act 1993 (RSA93). Where an authorisation (licence) to dispose of radioactive wastes is granted it will have a condition that the authorised undertaking (the "user") is required to use best practicable means ("BPM") to dispose of wastes in a form and manner that minimises the radiological effects on the environment and members of the public. The BPM requirement means that consideration always has to be given to avoiding or at least reducing discharges, but this is not judged practicable in many cases and discharges take place which will give rise to radiation doses to the public and some disposal workers.

Typical direct discharges that occur in the non-nuclear sector in the UK include

1. Discharges into public sewage systems of medical radionuclides such as iodine-131 and technetium-99m
2. Discharges to public sewers of radionuclides used in laboratory research, typically tritium, carbon-14, phosphorus-32, sulphur-35 and iodine-125.
3. Discharges to air from incinerators used to treat radioactive wastes.
4. Discharge of gaseous radionuclides from cyclotrons (carbon-11 and fluorine-18).
5. Occasional discharges to air and water air from industrial processes handling naturally occurring radioactive material (NORM) where activity concentrations exceed the thresholds for regulatory exclusion.

Discharges into public sewage systems are important as they will cause exposure of sewage workers, but also because all but the very short half-life radionuclides will pass through the sewage works and then into rivers and, in some cases, directly into the marine environment.

The decision on what BPM means in any situation involves an element of radiological optimisation where, at least in principle, direct and indirect costs of reducing or eliminating a discharge are balanced against the detriment associated with the radiation doses received as a result of the discharge. However, it is clear that other broader factors such as public acceptability may influence decision making. However, if radiation dose is to be a factor in decision making then it is important to assess such doses in a reliable manner. If doses are likely to be very low then the accuracy of the dose estimates is not particularly important and some overestimating of doses is tolerable, but this is not the case where the assessment suggests that critical groups (those most exposed as a result of the discharges) may receive doses close to or even above the agreed dose limit or dose constraint.

As part of the process of applying for an authorisation where direct discharges are involved the user is required to provide to the regulator their own radiological assessment. This assessment is then subject to scrutiny by the regulator before a decision is reached. This requirement for the user to demonstrate that doses from discharges are acceptable, rather than the regulator assume primary responsibility for this task, is an important element of UK practice in this respect.

The description so far would apply to both discharges from the nuclear sector and the non-nuclear sector. However, in the former case the discharge assessment is invariably undertaken by radiological specialists with access to the "best" models and with significant resources available. This tends not to be the case in the non-nuclear sector where the task of undertaking the assessment will fall to the

Radiation Protection Adviser or similar persons at a hospital, university, or a research laboratory, although some users will use radiological consultants to prepare these reports. Another important feature of non-nuclear assessments compared to nuclear sector ones is that normally there is no expectation that environmental monitoring will be done, and so these non-nuclear dose assessments rely on calculations alone.

Where solid radioactive wastes are disposed to a specified landfill site then the user is also required to provide a radiological assessment. This type of assessment, although likely to predict very low doses for non-nuclear wastes, is technically quite challenging because of the need to consider hydrogeology features which affect groundwater movement and probabilistic events such as waste fires. However, there are currently very few authorisations that permit this disposal route in the UK and so such assessments are rarely required. (Solid wastes containing very low levels of activity can be authorised for disposal in normal refuse without specification of the exact disposal site. Users are not required to assess this on the grounds that dose will always be low and it is judged best to demonstrate this at the national level.)

Published manuals for undertaking assessments

There is a range of publications available to those who need to undertake these assessments and here only two are described. Both documents are similar in scope and are designed to contain within one publication all the generic input data, formulae and results that a user would need to undertake an assessment. These input data and formulae are derived from the more elaborate publications produced by IAEA and other experts in this field. The reports do not themselves incorporate any substantial new scientific research.

The EA initial radiological assessment methodology

This report [1] was produced by the Environment Agency (EA), which enforces RSA93 in England and Wales. It presents an extensive set of results for doses per unit release (DPUR) for various exposure pathways and a wide range of radionuclides, including those encountered in both nuclear and non-nuclear sector discharges and NORM. These DPUR values can simply be scaled (multiplied) for the actual discharge level for the source being assessed. The DPUR results are based on a pre-determined set of dispersion parameters, with fixed values for parameters like stack height (for airborne discharges) and flow rates in sewage works and rivers (for liquid discharges). The report includes the various formulae used to calculate doses and explains how it is possible to adjust the standard results in the report to allow for different parameter values for the site concerned. This methodology is used by the regulators themselves as one of their tools for assessing applications under RSA93 but has also been made available to users in this publication.

NRPB-W63

This report [2] was produced at NRPB (now the Radiation Protection Division of the UK Health Protection Agency). It includes the same types of input data sets that are found in the EA report (e.g. values of dose per unit intake and habit data for critical groups). However, rather than calculate doses for a notional unit source and pre-set parameters W63 simply presents the necessary mathematical formulae need to calculate the doses and then provides some worked examples based on sources that are typical of real ones encountered in the UK. This approach makes it slightly easier to produce an assessment using the precise parameters relevant to a specific site (stack height, flow rate, etc). NRPB-W63 does not cover as many radionuclides as the EA report, the range being confined to typical medical and laboratory research applications. Radionuclides encountered in the nuclear industry and NORM scenarios are not included.

Typical non-nuclear assessments

The following is a description of what pathways and critical groups are frequently considered in these assessments and typical results of dose calculations. Levels of dose can be considered in the context of the annual dose limit for the public of one milliSievert and also the constraint of 300 microSieverts per year that is applied for all new sources in the UK. It should be noted that for these discharge sewer workers are treated as if they are members of the public, i.e. the higher dose limits for those routinely working with ionising radiations are not judged to be appropriate.

Liquid discharges

Most discharges will take place via engineered drainage systems serving buildings and will pass via municipal sewage systems into public sewage treatment works. Pathways and critical groups that may be assessed are as follows:

1. A sewer maintenance worker located close to the discharge point with occasional exposure to high concentrations of radionuclides in effluent (external radiation from gamma emitters such as iodine-131 and technetium-99m, and internal radiation from inadvertent intakes).
2. A worker at the sewage treatment works, where concentrations are much lower but occupancy is much higher (external from gamma emitters such as ^{131}I and internal from inadvertent intakes.
3. A family living on a farm which receives sewage sludge as a soil conditioner (internal from e.g. carbon-14 in milk and milk products produced on the farm, and external from some longer lived gamma emitters).
4. Those obtaining drinking water from the river (internal exposure, e.g. iodine-131)
5. Persons spending extended periods near the sewage works discharge point (external from gamma emitters absorbed onto sediment).
6. Those consuming fish caught in the river into which the sewage works discharges (internal doses from e.g. carbon-14 and phosphorus-32)
7. Those consuming marine foods from a local marine compartment receiving discharges (internal from e.g. carbon-14).

For both groups of sewer workers by far the most important source of exposure is the external radiation from iodine-131 discharges from those hospitals in the UK that use this radionuclide extensively for radiation therapy. For the largest source terms assessed doses in the range 100-300 microSieverts per year are possible for the maximum authorised annual discharge levels. (Actual discharges are usually rather lower that authorised, and discharges are, by custom and practice, taken to include the discharges from out-patients that take place away from the hospital, although a proportion of these may indeed enter the same public sewage works). These levels of assessed dose have been a subject of some discussion between users and regulators over the past few years in the UK and there continues to be interest in the possibility of abatement of iodine-131 discharges using delay tanks.

Relatively high doses can be assessed for the farming family/sewage sludge scenario for some larger authorised discharges of carbon-14. This and other radionuclides will transfer to milk and milk products, which may be consumed on the farm without the dilution that normally occurs at the dairy or in other food manufacturing processes. It is also possible to generate relatively high assessed external doses for longer lived gamma emitters, but not iodine-131 because of the effect of radioactive decay. This is an area of modelling that is relatively uncertain and on the basis of assessed doses a few users have determined to restrict some discharges including those of carbon-14 and some gamma emitters.

Assessed doses for the public drinking water pathway are always low, even for supplies taken down-river of the hospitals using large amounts of iodine-131. This is important given that there is no doubt that this pathway operates and, unlike the other pathways, large numbers of persons are exposed. (Note that users are not expected to calculate *collective* doses for their discharges, although that has been done by experts as part of various research studies).

With the freshwater fish pathway the highest assessed doses are for radionuclides which have high assumed fish concentration factors. Of these phosphorus-32 is the most important and with some larger authorised sources the assessed dose to frequent consumers (assumed consumption rate 20 kg y^{-1}) can be a few tens of microSieverts per year. Often it is not clear whether this pathway operates and some interesting features have emerged recently such as observations that immigrant communities (e.g. in East Anglia) may consume fish species that were not normally part of the UK diet. Also important to possible conclusions are the implications of considering fetal effective doses consequent on maternal intakes [3]. The ratio of fetal to maternal dose per unit intake for phosphorus isotopes can be quite high (up to ten for phosphorus-32) and that brings the implication that for some sources fetal doses could possibly approach the 300 microSievert constraint. This is a subject of continuing research which includes attempts to refine the effective concentration factor for phosphorus (the range of published values for this varies by well over an order of magnitude.)

Discharges to air

These are encountered with waste incinerators and for those users of relatively large amounts of volatile radionuclides in laboratory research (e.g. carbon-14 and tritium). There are authorised discharges in the medical sector (xenon-133 is still used in lung imaging) and there are a growing number of cyclotrons producing isotopes for positron emission tomography. These cyclotrons have authorisations to discharge gaseous carbon-11 (e.g. monoxide and dioxide) and there can also be discharges of some fluorine-18 compounds.

Most discharges to air are via purpose made ventilation systems leading to vertical stacks above or near to buildings. Although incinerator stacks are likely to be designed to allow efficient dispersion of emitted material the situation may not be so good for other types of discharge systems, for example short stacks on top of buildings that are themselves in the aerodynamic zone of influence of surrounding structures, as often happens in a typical urban environment. This clearly presents a considerable technical challenge to modelling airborne dispersion. So far most users' assessments have tended to approximate the situation by using a simplified standard Gaussian plume model or a variant of this, perhaps adjusting the effective height of the release to allow for building effects. This represents the limit of what most users are able to undertake themselves and any more precise modelling requires the use of expert consultants. When substantial new laboratory facilities are being constructed it is increasingly common for a general environmental impact report to cover aerial releases of from stacks, and this is often done using commercially available computerised fluid dynamic modelling software. The results of CFD modelling can with some care be used to add confidence to the radiological discharge assessment (one recent assessment of a new cyclotron facility even had access to wind tunnel modelling).

The critical groups for these discharges are always persons located close to the discharging site, or indeed those working on it. Pathways that are usually modelled are:

1. Direct inhalation of emitted material.
2. External exposure to photon emitters in the plume.
3. Consumption of locally grown foods.

In a typical assessment for a research laboratory the highest doses will be predicted where there is a substantial carbon-14 discharge and it is the food pathway that will dominate. There might be a dairy farm nearby and so transfer to milk could need to be assessed. A more likely scenario is consumption of locally grown vegetables, perhaps grown in a large family garden within a kilometre of the site. (In these assessments it is common to consider a hypothetical critical group like this without attempting to find out if such a high level of consumption of locally grown food actually occurs, and even if there is no such critical group at the time of authorising the discharges it is common to assume that the situation might change in future.) The assessed dose for a large carbon-14 discharge could be a few tens microSieverts per year. (These simple assessments of carbon-14 discharges to air use the specific activity model which may significantly overestimate dose.)

For non-nuclear assessments the direct inhalation pathway is associated with very low doses. The external plume dose depends on the radionuclides discharged, and will be the dominant pathway for discharges from cyclotrons where there is exposure to the 511 keV annihilation photons produced by positron emitters. This last pathway presents some additional modelling challenges since most simple dispersion calculations will deliver point concentration values around the discharge point. These are suitable for calculating inhalation or deposition at that point, but external photon exposure comes from the whole volume of material in the plume. There are some simple ways in which this can be calculated, for example the discharge of each pulse of emitted material can be modelled as a point photon source moving from the discharge point over the point of interest.

Discussion

Users in the UK now have considerable experience of being required to provide discharge assessments in support of licence applications, and there are publications that enable them to do the appropriate dose calculations. In most cases assessed doses are very low and these calculations are considered sufficiently reliable on their own to verify that radiological criteria for public dose are being met. A few assessments for larger sources do suggest doses that are significant in the context of public dose criteria, and these are subject to more attention and may be modelled more carefully. However, direct measurement of radionuclides in the environment is rarely used to support calculations, and it is very unusual to undertake any detailed site-specific investigation into the habits of the assumed critical group. In a few cases the level of assessed individual dose is used in deciding whether a particular discharge should be abated (for example by decaying a short lived isotope before discharge) but this is normally only when the calculated critical group dose appears close to or above the agreed radiological criteria. There is no significant use of the more formal optimisation tools that have been tried with discharges in the nuclear industry, and notably collective dose is not calculated, although subjective consideration of how many persons might be exposed might occasionally influence decisions on abatement of discharges.

References

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