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Reviewing non nuclear licensed site radiation dose assessments taking into account uncertainty

Sub Group on Uncertainty and Variability

The views presented in this paper are those of the authors in consultation with members of NDAWG. They represent the views of the majority of members of NDAWG but do not necessarily reflect the views of the organisations from which the members are drawn.

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1 Introduction

Principle 12 of the Principles for Assessment of the Prospective Public Doses[1] states **"Where the assessed mean critical group dose exceeds 0.02 mSv/y, the uncertainty and variability in the key assumptions for the dose assessment should be reviewed."** This document has been prepared by the Uncertainty and Variability Sub Group of the National Dose Assessment Working Group to provide practical guidance to those who need to comply with this principle.

The guidance is intended for those carrying out assessments for sites that are authorised to discharge radioactive material in accordance with the Radioactive Substances Act 1993, but do not have the resources and infrastructure associated with a nuclear licensed site. Discharges to the atmosphere and the sewage system and/or small watercourses are considered. Discharges to the sea or estuaries are not considered as such discharges are unusual for non-licensed sites.

Suggestions are given to approaches that could be used in place of an analysis of the uncertainty in the assessed dose. Alternatively, an iterative approach is suggested that could be used to reduce the uncertainty in the assessed dose. Finally, some brief advice is given on the employment of external experts to perform a full uncertainty analysis, if this is required. In addition to the guidance, examples of application of the guidance are given in the Annexes.

In common with the first report produced by this sub group of NDAWG[2] the term 'uncertainty' is used in a very loose sense.

2 Alternatives to uncertainty analysis

Undertaking a comprehensive uncertainty analysis on an assessment of the radiation exposure of members of the public resulting from authorised discharges of radioactivity is not straightforward. The first report of this subgroup of NDAWG[2] identified a number of areas that have to be carefully considered and gave descriptions of the experience others in the radiation protection field have had in carrying out such assessments. There are, however, a number of less rigorous approaches that can be used either to give some confidence in the robustness of the assessment or to demonstrate safety through appropriate bounding assumptions.

2.1 Upper bound assessments

Often the fundamental purpose of an assessment is not to calculate the exposure that the most exposed group of individuals may receive. Instead, the purpose of the assessment is to demonstrate that the most exposed individual will not receive a dose greater than a regulatory limit or criterion. If this is the case, it is not necessary to calculate the range of doses that an individual could receive. Instead, a realistic upper bound of the dose that could be received may be estimated. Rather than using distributions of the values of parameters in the models, including the quantification of habits such as occupancy and consumption rates, realistic values are used that tend to increase assessed doses relative to those that would be estimated from the use of typical values. If such calculations give a result that is lower than the relevant regulatory criterion, then it has been demonstrated that whatever the level of uncertainty in the assessed dose the dose would not be unacceptable.

However, there are drawbacks in this approach. Although each of the values chosen for the parameters and to describe the habits may be towards the upper end of the range of possible values and with a reasonable possibility of occurring, the combination of these may not be realistic. Thus, use of a number of individually possible parameter values and behaviours may result in a compounded pessimism which has sufficiently low probability to be impossible in practical terms. This can result in the calculation of an unrealistic upper bound dose which is greatly in excess of any likely dose. If the result of this calculation is still within the regulatory criterion this is not necessarily a great problem. However, if it is above the regulatory criterion then a more refined or alternative analysis will be required. Problems may also occur if the calculated dose is within the regulatory criterion, but is interpreted as 'real' and is used in calculations of collective dose and detriment or is used as part of a comparison with other sites carrying out similar activities.

2.2 Use of environmental monitoring

Any modelling carried out is a representation of 'real' environmental processes and systems. For sites where an assessment is being carried out on the impact of a practice that has already commenced (ie, the assessment is being carried out as part of an authorisation review), there may already be empirical evidence of the effects of the discharges on the local environment and food-chain, dependent on the timescales necessary to observe these effects.

Measurements of the radionuclide concentrations in food and environmental media from known historic discharges can allow extrapolation to planned future discharges to be made and exposures of members of the public to be estimated. Care should be taken when using empirical relationships based on monitoring data that the environmental conditions have not changed since the measurements were made.

In many cases, at least some of the monitoring data will be Limit of Detection (LoD) values. These LoD values can be used to produce more realistic upper bound estimates of the doses than those obtained from generic modelling, however for some combinations of foods and nuclides most if not all measurements will be below or well below the LoD. Use of these values to calculate doses will result in a significant overestimation relative to the doses actually received (eg, Ruthenium-106 and Pu-239 in milk).

2.3 Admit that there is uncertainty

The purpose of many assessments of the exposure resulting from discharges of radioactivity into the environment is to demonstrate to members of the public and other interested parties that the risks and doses are controlled and managed within authorised limits. The public does not always accept the assurances of scientists, particularly policy scientists. For example Wynne[3] cites the knowledge of farmers in the Lake District that variation and uncertainty are present in nature as part of their reason for distrusting official advice following the Chernobyl accident. For this reason even if no uncertainty estimates are included in the presentation of assessed doses the presence of uncertainty and variability should be explicitly acknowledged. It should also be stated that although the doses presented are 'best estimates' they are indicative only.

Often it is necessary to present results of a dose assessment to a number of significant figures. This can imply false precision and care should be taken to ensure that it is made explicit that this is not the case.

2.4 Perform a partial uncertainty analysis

For many sites where the radioactivity discharged is a mix of different radionuclides, it is often the case that the assessed exposure of members of the public is dominated by a single nuclide. Alternatively it may be the case that doses are dominated by one pathway and the contribution from other pathways is a very small proportion of the total. In these cases, carrying out a full uncertainty analysis on the complete assessment which included those nuclides or pathways would be an unnecessary use of resources. Much time and effort would be expended investigating parameter and habit uncertainties that had little influence on the total uncertainty. Rather, a partial uncertainty analysis can be undertaken relating to the key radionuclide(s) and pathway(s) identified from an initial deterministic analysis.

2.5 Identify the uncertain factors that are significant and can be resolved

If a standardised screening approach is used for the initial assessment of the doses received as a result of the discharges, many of the parameters used within the assessment will be generic parameters. For example the CARE model developed for the FSA[4] assumes a default stack height of 5 m and a distance to the site of agricultural production of 100 m. As well as not being directly appropriate to the site under consideration, the parameters are likely to be representative of the most extreme values that could reasonably be expected to occur in UK conditions. This will lead in turn to an overestimation of exposures. Generic values of some of the parameters used to create the exposure scenario can be replaced by site-specific values easily. For example estimates of food chain doses as a result of releases to atmosphere depend on the values used for the effective height of release and distance to locations at which food is produced. Conservative values used in screening approaches can be replaced by site-specific values without great effort. This approach requires that the screening model has been constructed in a manner that allows the easy manipulation of parameters and that staff using the model have the necessary expertise to manipulate it. Users who simply treat their model as a black box are liable to have problems in both understanding what is required to adapt it to site-specific applications and in performing such adaptations.

2.6 Perform scenario studies

In some cases, a significant proportion of the uncertainty in dose estimates is a result of uncertainty in the behaviour of members of the critical group. It is, therefore, possible to identify a range of scenarios each of which encompass different combinations of behaviour and report separate dose estimates for each of these. For example the Environment Agency, in their assessment of proposed discharges from the Springfields site, identified 8 candidate critical groups[5] covering a range of possible behaviours and calculated and reported doses for each of those groups.

2.7 Use of alternative models and model intercomparison

There are various models and codes available to represent the assessment problem. Use of alternative models or hand calculations (using different simplifying assumptions, default parameter values and boundary conditions) can help address model uncertainty or model structural error. A practical illustration of this approach is given in Annex A.

3 An iterative approach to dose assessment taking into account uncertainty

As implied by the above, an iterative approach is recommended for dose assessment[1,6], as illustrated by the flowchart in figure 1. This approach might start with a simple generic assessment based on estimated doses per unit discharge. In many cases this will be sufficient, as the estimated doses will be low and it will not be necessary to explicitly consider the uncertainty associated with the assessment, except to recognise that it exists. A more detailed assessment incorporating readily available site-specific information may be carried out if the estimated effective dose exceeds 0.02 mSv/y. If the estimated dose still exceeds 0.02 mSv/y, then it is necessary to review the uncertainty and variability in the key assumptions made in the assessment. The aim is to consider how much caution has been applied at each stage of the assessment to evaluate the extent to which doses have been over estimated. As discussed, a qualitative approach may be sufficient, perhaps based on a sensitivity analysis and a full statistical analysis of uncertainties will rarely be necessary[2]. A first step will be to identify the most important radionuclides and exposure pathways. Attention can first be given to considering the assumptions and data for those radionuclides and exposure pathways. However, the possibility that some of the other radionuclides and pathways may become comparatively significant following revision of the effective dose estimates for the key radionuclides and pathways also needs to be considered. In carrying out the review of uncertainties the following factors could be taken into account:

3.1 Source terms

Prospective dose assessments for authorisation purposes are based on the proposed authorised limit, which is greater than the expected level of discharges to allow for operational headroom. The degree of headroom expected gives an idea of the possible overestimate in the estimated dose compared with the dose that would actually be received. Generally, action is taken if actual discharges approach the authorisation, but the actual headroom may be less than expected. Retrospective dose assessments are based on the actual discharges, but these will have an associated uncertainty. Account should be taken of the extent to which they are based on measurements that are below limits of detection and whether there could be unmonitored sources.

3.2 Radionuclides

Authorised and actual discharges are often expressed in terms of the type of radiation, eg, 'total alpha' rather than particular radionuclides. In carrying out a dose assessment, specific radionuclides have to be specified and this can introduce additional uncertainty into the assessment. The most realistic option is to use a radionuclide breakdown estimate based on the operations at the facility. However, often a cautious approach is adopted where it is assumed that all of the discharge comprises the radionuclide in the relevant category that gives the highest estimated dose (eg, plutonium-239 for total alpha or phosphorus-32 for total beta/gamma from a research laboratory). The extent to which this might lead to an overestimate of doses can be determined by carrying out the assessment for other radionuclides that are likely to be discharged. Studies, for example of the River Thames[7], have shown that this is an important source of uncertainty in dose assessments and can lead to significant overestimation of doses.

3.3 Transfer of radionuclides through the environment

Both prospective and retrospective dose assessments rely on models to predict the transfer of radionuclides through the environment to estimate activity concentrations in air, water, etc. Although measurements may be available for retrospective dose assessments, they are rarely complete and need to be supplemented with model results. The results obtained from such models are uncertain[2] due to the limitations of the models themselves and uncertainties in the most appropriate parameter values to be used. As part of a staged approach to reviewing uncertainty, the first stage might be to consult the literature on the model being used to determine its pedigree and intended applications. Also how it had compared with the results of environmental measurements in validation studies and whether any estimates of uncertainty are given. It is likely that such models will be more uncertain for some situations than for others, depending on the extent to which they have been validated and the quality of the data available. For example, the environmental transfer of some elements (such as caesium, plutonium and strontium) has been much more thoroughly studied than other elements (such as iridium). Ideally the model estimates could be compared with measurements carried out at the location of interest to obtain a semi-quantitative estimate of the uncertainty associated with this stage of the assessment. Key parameters could be identified and the degree of uncertainty associated with them could be further investigated. For example, the transfer to fish could be important for a particular radionuclide discharged to a river and the transfer factor to fish could be considered to see if it could have been over or under estimated. There is also the possibility that the model may not fully represent the important transfer processes. A final stage would be to carry out a full numerical uncertainty analysis taking into account the likely distribution in the input parameters. However, this is unlikely to be required in the majority of cases.

3.4 Exposure locations

This is an important area when considering the degree of caution involved in any dose assessment, as the assumptions made have a significant effect on the resulting doses. Changing the location relative to the source can change the estimated doses by more than an order of magnitude. Retrospective dose assessments are normally based on where people actually live and so effective dose estimates for direct exposure pathways (inhalation and external irradiation) are not particularly cautious. Nevertheless, it is often assumed that people are at the location for 100% of the time, which is cautious, and it may be assumed that they are outside for a significant fraction of the day, which increases their estimated dose from external exposure. For prospective dose assessments, further caution may be introduced through assuming that people may live at other locations with higher estimated doses. The principles document[1] gives guidance on such assumptions and this document needs to be considered in any review.

3.5 Source of food production

As for location this is an important area affecting the degree of caution associated with a dose assessment, whether prospective or retrospective. The critical group is often assumed to get all of its food from small areas of land close to a discharge point, which might be theoretically possible but is unlikely in practice. Habits surveys may identify consumption of locally produced food, but this can come from a wide area and not all be produced at a single, small location. If the location is a farm this will cover a wide area and it is cautious to assume that the food is produced at a single location within the farm. However, it is also possible for some food to be produced in small areas of land, such as allotments. The habit data sub-group of NDAWG has considered the intake of locally produced food and other factors which need to be considered when reviewing the degree of caution implied in a dose assessment.

3.6 Selection of habits

The assumptions regarding the habits of the critical group will also form an important consideration in any review of uncertainty. The amounts of different foods that people eat and where they spend their time are both important. The habits data sub-group of NDAWG have considered this and their findings should be taken into account in any review of the degree of caution associated with a dose assessment. An important factor is the extent to which national generic data have been used rather than data specific to the location of interest.

3.7 Age groups considered

Three age groups are normally considered in dose assessments 1 y and 10 y old children and adults. In future it will also be necessary to consider the fetus for relevant radionuclides where intake by the mother can lead to a higher dose to the fetus than to the mother[8]. In reviewing the dose assessment, it might be important to consider if any other age group could be more exposed than those considered due to the particular circumstances. The review could also consider the likelihood of a particular group being present including a pregnant female or children of particular ages.

3.8 Dosimetric data used

In assessing radiation doses use is made of compilations of dosimetric data such as dose coefficients for intakes by inhalation and ingestion and for external irradiation. Such data are based on models and are therefore uncertain. However, in defining dose limits and constraints for members of the public, the uncertainties associated with such data were taken into account and so it is not be necessary to consider them explicitly in any review of an assessment undertaken for compliance purposes.

In summary as part of an iterative approach the first stage would be to consider the factors outlined above in a qualitative way to ask the question: 'could I have significantly underestimated the dose?' If the estimated dose is below the relevant criterion and the answer is that a significant underestimation is unlikely then further investigation is not required. If the dose is close to the criterion and underestimation is possible then the uncertainties associated with the different parts of the dose assessment may need to be investigated more thoroughly. The review could initially focus on source term issues, the assumptions regarding the exposure location and source of food production, and the associated habits, as these are often where caution is explicitly built into an assessment. A full quantitative uncertainty analysis should only be carried out if the assessed doses are sufficiently high and uncertain that it is considered possible that the dose limit for members of the public could be exceeded. Some examples of a qualitative approach to uncertainty evaluation are given in the Annexes to this document.

4 Use of external experts

If, after the approaches outlined above have been used or considered, there is still a need to review the uncertainty in assessed doses consideration may be given to the use of external experts. The use of external experts is recommended where the dose assessment is complex, eg, where significant contributions to effective dose arise from multiple pathways and radionuclides, where unusual pathways or radionuclides have to be addressed, or where there is the potential for significant environmental change to affect the results of the assessment. In all these cases, there may be either conceptual limitations to standard modelling approaches or deficiencies in the underlying data that are used. External experts specialising in the environmental transport of radionuclides may be particularly useful in identifying such deficiencies or may provide reassurance that, notwithstanding the complexities of the situation under investigation, standard approaches to assessment can be used. The use of external experts may also be appropriate where projects requiring major investments of resources are involved, as the commercial risks associated with such projects can be reduced by ensuring that the associated assessments are robust against any challenges that may be raised by regulators or other interested parties. If it is decided to employ external experts care should be taken to ensure that:

- The appropriate expert or experts have been selected. Examination of previous assessments carried out by the expert and discussions with past customers may be useful in ensuring that appropriate experts have been selected. In some cases, commissioning of the work by one expert and peer review by a second may give added assurance of the adequacy of the work.
- The extent of the study has been carefully specified to ensure that only the work that is required to meet the needs of Principle 12 is carried out.
- The tools proposed for use by the expert (computer models, databases, etc) are suitable for use and appropriate to the context.
- The work will be documented in a form that is readily scrutinised by third parties.

5 Conclusions

The requirement of Principle 12 of the Principles for the Assessment of Prospective Public Doses can be met in a variety of ways. A number of alternatives to an analysis of the uncertainty in the assessed dose are available. If it is decided to carry out an assessment of the uncertainty then an iterative approach is recommended.

6 References

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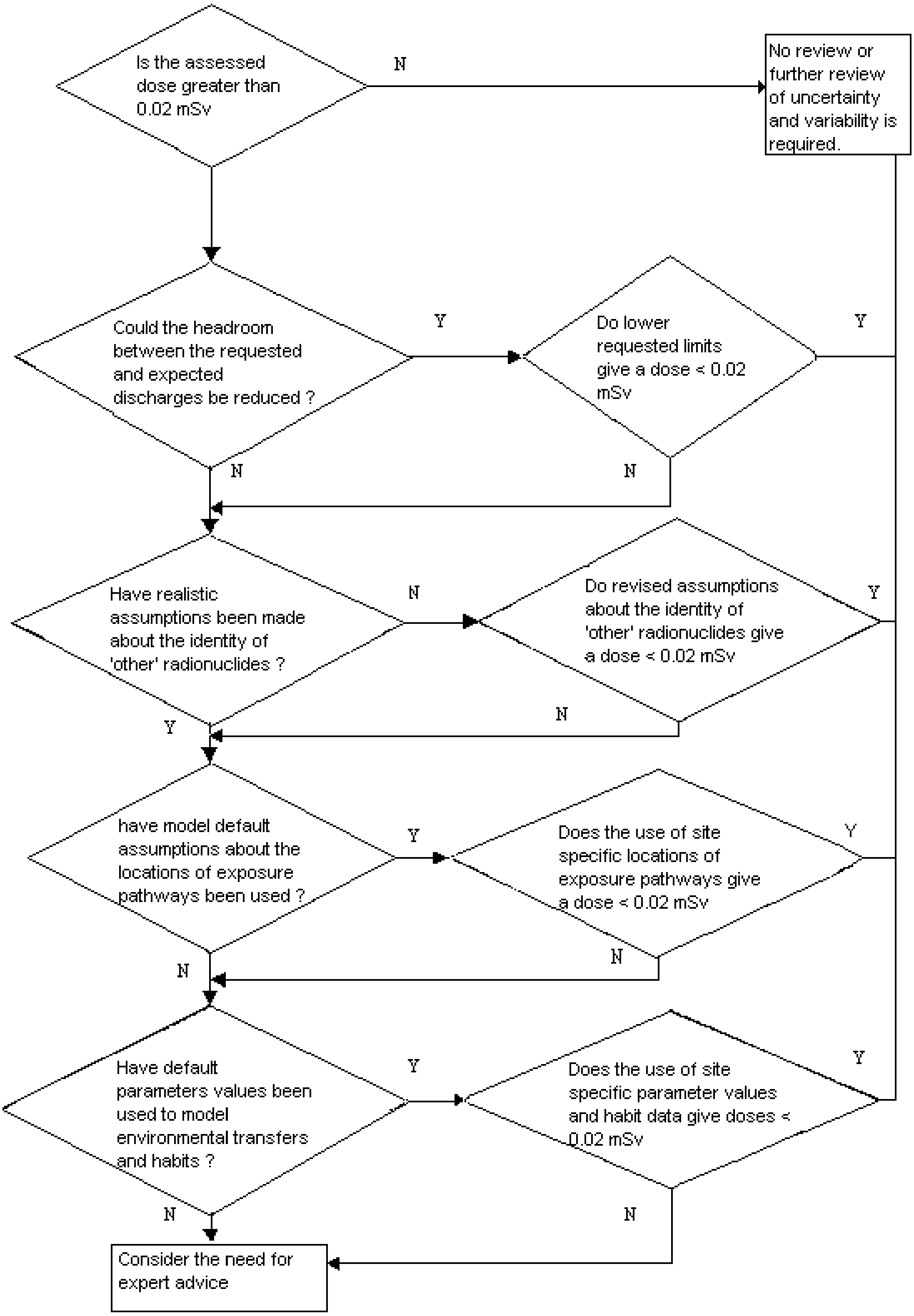
Figure 1. Stages in an Iterative Approach to a Review of Uncertainty



Annex A: Some examples of a qualitative approach to uncertainty: Combined impact of discharges reaching rivers

A recent study for the Environment Agency (EA) considered methods for modelling the combined impact of radionuclide discharges reaching rivers[1]. The aim of the study was to develop and test modelling tools that could be used to make assessments of the impact of multiple radioactive discharges into river systems and to trial them on the upper Thames river system. Three different tools were used in the study: a generic modelling tool developed previously for the EA, an enhanced version of the generic model and a more detailed model based on the PC-CREAM[2] assessment system. The three tools were used to estimate doses for authorised discharges from all sources into the upper Thames catchment. Potential effective doses estimated using PC-CREAM for the river Thames upstream of Teddington Lock ranged from 0.019 μSv y^{-1} to 13 μSv y^{-1} for groups of people living at different locations on the River Thames itself. The highest estimated effective dose was 170 μSv y^{-1} in the River Colne, a tributary of the Thames. The study considered the major areas of uncertainty and so provides some insights into using the qualitative, iterative approach outlined above. The following points are relevant.

- The potential critical group doses estimated using the original generic model were always higher, by a factor of 2 to 4, than estimates made using PC-CREAM.
- There were bigger differences between the 2 approaches for particular radionuclides and exposure pathways. For the generic model, irrigation of crops was the most important pathway, whereas using PC-CREAM the important exposure pathways were ingestion of fish in many cases, plus ingestion of river water and external irradiation from radionuclides on the riverbank in others. This was because the generic model was developed for the Anglian region, which has greater amounts of irrigation but less freshwater fish consumption than the Thames region.
- One of the most important sources of uncertainty was the discharge data. Using actual discharges rather than the authorised discharges decrease the estimated potential doses by factors of up to about 30. This is partly because actual discharges are lower than those authorised and partly because specific information about the radionuclide composition of the discharges was available.
- The grouping of radionuclides in authorisations causes additional variability in dose estimates, as there may be large differences in the radiological impact of the radionuclides contained in the same group. For example, tritium and carbon-14 were found to be authorised jointly in several cases, but the dose from a unit discharge of carbon-14 is greater than that from a unit discharge of tritium. The effect of generic authorisations, eg, ‘all beta emitters’ was also seen where the radionuclide giving the highest dose was used to estimate doses from the total discharge, leading to possible significant overestimation if the actual discharges were of other radionuclides. The study also showed that the choice of the representative radionuclide is not always straightforward and can have a significant impact on the estimated doses.
- The ingestion of freshwater fish was found to be an important exposure pathway, so the concentration factors for freshwater to fish were reviewed for the most important radionuclides for this pathway. For phosphorus the original generic concentration factor was $5\ 10^4\ m^{-3}\ t^{-1}$ whereas the review found that a value of $5\ 10^3\ m^{-3}\ t^{-1}$ was more appropriate for the Thames river system due to the high existing stable phosphorus concentrations in the area.
- Another key parameter was the ingestion rate for freshwater fish. The default generic ingestion rate recommended by NRPB[3] is 20 kg y^{-1}, but evidence from local habits surveys was that a lower rate, assumed to be 2 kg y^{-1}, was appropriate for much of the Thames river system. However, the higher rate was applied to the River Kennet, as there were fish farms on this part of the system, and to the River Colne, as there is evidence that there is higher consumption of river-caught fish there. Obviously, a factor of 10 difference in the fish ingestion rate has an impact on resultant estimated doses.
- As part of the study, it was possible to do a limited comparison of environmental measurement data and activity concentrations predicted by the models. Many of the measurements were less than limits of detection, which limited their usefulness for

comparison with the model. Also, some measurement data were not given for individual radionuclides but for ‘total alpha’ or ‘total beta’, which again caused difficulties. The models were run for the authorised discharges, which differ from actual, historic discharges so again limiting the comparison. The measurements also included other sources of radionuclides, such as fallout from nuclear weapons testing and naturally occurring radionuclides. Nevertheless, it was possible to draw some conclusions from the comparisons. It was found that there are uncertainties associated with the way complex processes are included in the models and the simplifying assumptions necessarily used to represent a complex river system as a series of compartments. Of particular concern was the transfer to sediments and the resulting external doses, where it appeared the model may give an underestimate. However, there was generally good agreement between the model results and measurements of activity levels in fish. This increased confidence in the results of the dose assessment, where ingestion of fish was the dominant exposure pathway.

- The overall conclusion was that, considering the areas of uncertainty the overall assessment was likely to be cautious, mainly as a result of using authorised discharge limits as a source term. However, the degree of caution is probably only between a factor of 1 and 10 due to the partially cancelling effect of uncertainty in the doses from external exposure from bed sediment.

References

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Annex B: Application of the approach to a small user

Many small users who have previously completed an assessment of the radiological impact of their discharges to the environment have utilised a fairly simplistic generic calculation methodology, such as that contained in the guidance document published in 1990 by the Association of University Radiation Protection Officers (AURPO)[1]. Alternatively, small users may have used the generic method of assuming raw effluent from the sewer on site is drunk during a maintenance operation and stream water is drunk downstream of the effluent discharge, as detailed in the EA Field Officers Handbook[2]. Historically such calculations yielded a value of less than 0.02 mSv y^{-1} to the most exposed individual (typically a sewer worker on site) using fairly pessimistic assumptions, hence there was no necessity for small users to get to grips with more complex modelling scenarios. Some small users may already have experience of using the methodology contained in the 1996 NRPB publication that is specifically aimed at small users (NRPB-M744)[3], which has recently been superseded by NRPB-W63 (2004)[4]. It is experience of use of W63 as opposed to M744 that now requires further consideration. With the many changes in workload and work patterns that are occurring on small user premises, there is now a need to look more closely at the assumptions being used in assessments and the benefits to be gained from obtaining site specific data to refine the output of assessments, even though this may prove an onerous task.

The best way to illustrate the benefits of using site-specific data is in a worked example. This example relates to a radiotherapy hospital with one radioiodine therapy in-patient treatment room and a single gamma camera, performing principally $Tc-99^{m}$ diagnostic imaging. Sm-153, Y- 90 and Sr-89 are also administered for in vivo therapy. Government targets for the NHS and changing work practices, such as introduction of an extended working day and proposed use of a private sector mobile PET facility on site a couple of days a week, prompted an application to increase the existing discharge authorisation by 25-50% for most radionuclides and to include the PET scanning radionuclide F-18 for the first time.

If it is assumed that uniform radionuclide discharge over the month is evenly diluted by the total water volume discharged from site will substantially under-estimate the potential doses to the on-site maintenance worker dealing with the blocked drain during a period of peak discharge of radionuclide activity.

At the hospital under consideration, the radioiodine suite is typically occupied for a few days each month and there is a dedicated drainage system from the suite to the main sewer pipeline out under the road at the point where the discharge leaves the hospital site. Here it joins the Water Authority main sewer which consists of a 225 mm diameter pipe, which carries not only discharges from the hospital site, but also from a large wing of an adjacent hospital and a large number of houses, all providing a substantial further dilution factor. The flow from the ablation suite is 970 litres per day. This is a worst-case estimate that assumes the patient does not shower or take a bath. The only other connection to this dedicated drainage system is from a unit occupied during normal working hours by approximately 95 staff and patients, with an estimated discharge of 5035 litres per day. The total discharge therefore from this section of the hospital drainage system is 182.7 m^3 per month, and this is realistically the total dilution of radioactive aqueous discharges made from the site. Whereas radioiodine discharges will be limited to a few days per month, the discharge of all other radionuclides will occur throughout this period. Discharges do not occur at a steady flow rate over a 24 hour period over 7 days, therefore it is more realistic to consider them occurring during the working day, thus during 200 working hours per month. For radionuclides other than I-131, even distribution of discharges during this 200 hour period represents a realistic scenario. Since I-131 discharges occur mainly during the first 24 hours following radionuclide administration, it has been assumed that three patients are treated with 8 GBq in close succession during a month and 100% is discharged during the first 24 hours following treatment, ie, a total of 72 hours of the working month. Realistically between 0.5-5% will be retained by the patient and there will be some radionuclide decay prior to excretion, but this level of caution in the calculation was deemed acceptable.

The two exposure scenarios considered:

1) Exposure of a worker at the sewage treatment works
2) Exposure of a sewage maintenance worker at the hospital discharge point to the main sewer.

For other exposure pathways, comparison is made with model assessments by McDonnell[4].

NRPB-W63 has advantages in that calculations can be made in the absence of site specific flow data for the drainage system, and utilises a point source method to calculate the dose to the on-site sewer worker. NRPB-M744 uses a line source method, which probably better fits the actual circumstances on this hospital site. W63 calculations utilise a generic 1 m^3/hour flow assumption which is probably overly pessimistic for a large hospital site but optimistic for the radioiodine treatment facility described above. Furthermore, W63 assumes that 5% of the monthly iodine discharge is involved in a blockage on site. This assumption is probably quite realistic for a radioiodine in-patient treatment facility, but would be a considerable over-estimate where the bulk of the radioiodine administrations on a site are to thyrotoxicosis therapy outpatients, where 30% of the administered dose is recorded as excretion on site, but in fact is discharged down the toilet of the patient's home.

In calculating the possible dose to the on-site sewer worker, it was established for our radiotherapy hospital that a 2 m^3 blockage of undiluted activity was extremely unlikely, so the M744 method of assuming that all of the radioiodine activity was discharged over three days for three patients each month provided a more realistic scenario. Using the same radionuclide activity discharge data, calculation of the dose to the on site sewer maintenance worker using W63 methodology resulted in a total dose of 0.119 mSv, but this reduced to 0.004 mSv using M744 line flow calculation methodology and actual measured water volumes for that part of the drainage system, hence illustrating the importance of consideration of site specific data.

Effect of different estimates of flow rates at each of the Exposure Scenario Locations

To the on site sewer worker - The calculation was refined by using site specific data of a total monthly discharge of 182.7 m^3 per month over 200 hours rather than assuming a 2 m^3 blockage on site.

At the sewage works:
A flow rate through the sewage treatment works of 43,200 m^3 per day is considered by McDonnell[4] to be representative of a medium sized facility. The local Sewage Treatment Works is a large facility with greater diluting volumes and consequently lower doses will occur. The International Journal of Water, Vol 2 No 1 (2002) quotes a value of 136000 $m^3\,d^{-1}$ or 1.6 ms^{-1} for dry weather flow at a large works such as that under consideration. Verification that this is a realistic value with the treatment works would be beneficial to further refine the data utilised for the assessment.

The ratio of volume of sludge produced to incoming sewage volume is assumed to be a constant of 0.005, which is again considered by McDonnell to be an appropriate ratio for a typical treatment works. To refine the assessment, data for the Sewage Treatment Works should be obtained and used if at all possible.

It may be beneficial to obtain actual data from sampling where water flows are reduced and there is concern that ingestion doses may be unacceptably high due to drinking water abstraction or alternatively in the case of a fisherman exposed at the riverbank and from fish ingestion. Although water and fish sampling often involve a financial arrangement for the sampling and measurement to be carried out by an external body, the benefits from refining the estimation of dose to the critical group by inclusion of actual data should not be under-estimated.

Conclusions

This site-specific environmental impact assessment considered discharges which are likely to be the maximum that might occur. The most significant doses at the sewage treatment works and hospital discharge arise from exposure to gamma radiation from radionuclides in blocked sewage or accumulated sludge. The relevant calculations in this assessment are likely to overestimate the doses that will actually be received. For external exposure at the hospital discharge, use of the McDonnell[4] assessment method results in an estimated dose to an individual of 0.119 mSv y^{-1}. This method assumes the accumulation of radioactivity normally discharged in 2 hours within a 2 m^3 volume of effluent. Such an accumulation is unlikely to occur at the Hospital Discharge point to the main sewer as there will be significant dilution from the adjacent hospital wing. This is therefore an unrealistic exposure scenario. A more realistic assessment assumes that the activity and diluting effluent normally discharged in 2 hours is accumulated in the blocked drain line. To account for the initial rapid excretion of I-131 from thyroid ablation patients it is assumed in this assessment that all administered activity is excreted in the first 24 hours. This results in a total dose to an exposed sewer maintenance worker of 0.004 mSv y^{-1}. It should be noted that this total includes doses due to the $Tc\text{-}99^m$ and F-18 which in reality are more likely to be disposed of to a different drain as these are likely to be out patients who excrete the activity at home. In addition, no account is taken of attenuation provided by the mass of effluent and by the sewer itself.

The assessment for the sewage treatment works estimates a maximum dose to an individual of 0.028 mSv/year. A parameter contributing to a likely overestimation of the true dose is the assumption that a worker will spend 1000 hours per year near unprocessed radioactive sewage and processed radioactive sewage sludge. In addition, the actual dry weather flow through the sewage treatment works is likely to be about three times the generic factor used in this assessment with proportional reductions in the estimated doses. Use of more realistic assessment parameters will reduce the assessed dose well below the 'Threshold of Optimisation' of 0.02 mSv y^{-1} specified by the Environment Agency[5].

It is likely that standard precautions specified by employees of exposed persons for the purposes of minimising other risks associated with the sewage, will make the ingestion of sewage at the rates used in the assessment an unlikely occurrence. Within the hospital, drains that carry radioactive liquid waste are appropriately labelled. Work on these drains is carried out by hospital staff within the Estates Department. Relevant employees receive radiation protection training and carry out the work to a written radiation safety protocol making it unlikely that an exposure significantly above background will be received.

References

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