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Existing Exposure Situations: Intervention in Practice

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Introduction

This paper describes some recent HPA experiences in dealing with radioactive contamination issues where the levels of existing exposure have ranged from quite significant to levels that are low but nevertheless of some concern to those exposed. One of the examples relates to the common situation of remediation of a contaminated site where the emphasis may be largely on optimising future exposures rather than the true existing ones, but there are common themes, notably the perception of contamination of premises, and the consequences of the way in which regulations define "radioactive" material.

Case 1: Intervention to reduce radon and other exposure pathways

In this situation there was very definitely existing exposure arising from past practices and the levels of exposures meant that intervention was judged appropriate.

The location concerned is utilised for small scale commercial and industrial activities with multiple employers involved. Some of the site buildings are more than one hundred years old. The site is not in a designated "radon affected area" within the UK and it was only by chance that tests were done that identified elevated radon gas levels. The maximum (time averaged) concentration measured in one room in a particular building was about 40,000 Bq m-3. In the regularly occupied areas radon levels were between a few hundred and several thousand Bq m-3.

Initial detection of radon was by PADC dosemeters and follow up work included more investigations elsewhere on the site and attempts to try to establish the possible causes of the high levels. A gamma radiation survey quickly identified that there was significant contamination by radium-226 residues caused by historic work involving radium luminised aircraft components. That work pre-dated modern UK controls on radioactive substances and the existence of the contamination appeared to be unknown to the current site users. In common with similar locations there was evidence of burial of wastes in external areas, substantial contamination underneath some internal floors, and superficial but largely fixed contamination within rooms (the building had undergone modifications and re-decoration since the original contaminating practices). It was suspected that one of the sub-floor radium deposits was the cause of the significantly raised radon levels within the building, since there was some correlation between gamma radiation readings and radon levels.

The initial radiation protection advice provided was aimed at dealing with the highest radon levels encountered. The room at 40,000 Bq m-3 was not an immediate problem due to low occupancy but there were a few rooms with high occupancy and radon levels around 2500 Bq m-3, which was related to an annual dose rate of about 15 mSv y-1. There were only a small number of workers exposed and the decision was taken to move them promptly as this could be done easily. There were a larger group of workers in a zone with levels around 800 Bq m-3 (corresponding to about 5 mSv y-1) and the building owner was recommended to reduce radon levels in this area within six months.

Another initial step taken was to suspend access to an external area that contained a substantial amount of buried radium. This area was being used for recreational purposes by site workers, e.g. during lunch breaks. Whole body gamma dose rates were in places up to ten microSieverts per hour. Occupancy was relatively low with annual external gamma doses unlikely to exceed 1 mSv y-1 but the conditions would nevertheless demand designation as a controlled area under the UK worker protection regulations, which would have proved problematic. This external area also had several fruit trees and samples of the fruit tested showed raised levels of polonium-210.

It was clear that normal approaches to the treatment of high radon levels (i.e. sub-floor sumps providing a positive pressure differential between the air above ground and the soil gas) might not solve the radon problem alone. Some but not necessarily all of the elevated radon was definitely attributable to the man-made radium contamination and the fact that this was distributed non-uniformly, with its location and full extent not known prior to excavation, meant that the best location for sumps could not be determined. The building was unusually shaped and the pattern of radon gas movement in above ground areas was not understood. There was even some concern that if disadvantageously placed sumps might modify the movement of soil gas in a way that could *increase* radon levels in some areas unexpectedly. Accordingly, the building owner embarked on a program of removal of radium contamination beginning with the identifiable deposit that was associated with the rooms with very high radon levels. After removal of as much contamination as was practicable and fitting of a sump the radon levels in this part of the building have been successfully reduced right down to around 100 Bq m-3. Further testing in the building has continued and there are still areas with radon levels of several hundred Bq m-3 with the likelihood of at least one further radium deposit that may require removal.

This was a relatively unusual recent case of radium contamination as the site appeared to have had no remediation of the original radium contamination at all. Many situations that HPA lately has been involved in have already had at least one campaign of remediation, including some of those described later. It is fairly unusual now to find quite so high radon levels associated with radium contamination in a building in the UK. In the case of this site this must reflect a substantial radium inventory and the peculiarities of the emanation rates and soil gas transport aspects, since other sites with substantial levels of radium-226 buried under solid floors have not shown high indoor radon levels. It is also relatively unusual to consider intervening against the direct gamma dose rate pathway on these sites and to see the potential operation of a (minor) food pathway arising from radium residues.

Optimisation in the broad sense is clearly a significant operational factor for a site like this, indeed worker dose limitation is an issue with the higher high radon levels. Formal cost benefit analysis (CBA) approaches are not applied, partly because it is not possible while removing the

radium contamination to judge exact how much must be removed to secure a given reduction to the radon level. The cost of the specialist radium decontamination work including radioactive waste disposal is a significant factor here and decision making although aimed primarily at reducing radon exposures is in some ways similar to the approach taken to the change of use of contaminated buildings (Case 3).

Case 2: Concerns caused by even low levels of residual contamination

This example refers to a series of locations investigated by HPA over the period 2008-2010. It was not known initially if the premises were currently contaminated or if so at what levels. but if they were then their current occupancy would have implied they were definitely "existing exposure" situations.

The initial prompt for this work was concerns raised about possible historic radium contamination in two historic laboratory buildings at Manchester University. These centred on (but were not exclusively related to) the work of Ernest Rutherford who was at Manchester from 1907-1919. In respect of this location HPA undertook a retrospective dose assessment for the more recent occupants of the buildings. The HPA report has been published by the University on its own web site along with other related investigation reports. The radiological assessment did not find evidence of significant exposure of building occupants but it nevertheless represented a considerable effort in seeking to allay concerns of those who had been (and still are) in the relevant buildings.

The investigations at Manchester prompted questions about where else Rutherford and other earlier researchers had worked with radium and other radioactive materials and this led to a request to HPA to survey parts of the Old Cavendish Laboratory building at Cambridge University, where Rutherford worked between 1919 and his death in 1937. There were also concerns raised about where the powerful radium sources that Rutherford secured for his work came from and where they actually ended up, as records of this were very limited so long after the events. This led to requests to HPA to investigate a number of sites in London where radium was known to have been sold in the earlier years of the twentieth century.

The university buildings at Manchester and Cambridge had already been subject to decontamination (sometimes in several stages) although the records were relatively limited meaning that there were few records of historic contamination levels, and this made the retrospective dose assessment for Manchester a difficult task. Where HPA actually undertook monitoring (at Cambridge) only trivial contamination was identified, typically small spots or patches with only kBq levels of radium-226. An interesting feature when planning this survey was the need to consider the possibility of contamination by separated lead-210 (formally referred to as "Radium D"), thorium-230 (formally "ionium") and actinium-227. All these had been purified by those undertaking early nuclear chemical research. One of the survey methods was collection of dust samples from inside buildings and radiochemical assay of polonium-210, this serving as a "marker" for lead-210.

The venues investigated in London comprised a varied assortment of commercial and office locations. Some showed no radium contamination, but several showed detectable but still low level traces on or under floors. In no case was intervention anywhere near warranted on the basis

of the contamination found. (It is not possible to state that these residues are completely outside the scope of the current UK legislation for radioactive substances, which is an interesting issue from the point of view of long term management: Details of these recent HPA surveys may prove hard to find in another hundred years time!) Many of these buildings in London had undergone substantial internal modification and refurbishment over the years and it likely possible that greater contamination had been present at some stage but it was inadvertently removed over time.

In all these cases where contamination was detected there was an existing exposure situation albeit the levels were so low as not to warrant intervention. What is significant is the power of even reports of contamination or suspicion of contamination to cause concern to building occupants: here the "intervention" was of the form of monitoring to provide public reassurance that the premises were safe, so effectively to rule out existing exposure to residues. As will be described later the very existence of "contamination" whatever the risk level exercises a powerful influence on perceptions and is a significant influence on decision making. Another feature of these scenarios is the difficulty of maintaining usable records of past practices including previous contamination levels. This is not new but is a continuing theme in this part of radiation protection.

Case 3: Remediation of a thorium contaminated site

This third example is the common one of "full" remediation of a contaminated site where we are moving from a largely disused premises, where occupancy is by now low (and so "existing" exposures limited) to complete re-development. Unlike Case 1, the main driver here is not reduction of existing exposures but the desire to redevelop the site for commercial reasons. This and the likely high cost of radioactive decontamination point to high value end-use for the site, such as domestic dwellings or commercial/office use, or a mixture of these. These applications will typically be characterised by high occupancy so the exposure to any residual contamination (after remediation) will be higher than were the site to be used for lower value applications such as simple storage space or, say, car parking.

The optimisation we are seeking is of the future exposure of future site occupants. As we cannot measure such exposure in advance we must predict future exposure based on measurable levels of residual contamination and so determine what "end point" is appropriate when planning the decontamination work, and against which we will demonstrate success by measurement before new buildings are erected. This requirement is well known to those who work in this area.

The site was in London and had been used for manufacture of gas mantles containing thorium oxide. There was easily detectable but relatively minor contamination of the above ground building structures which were to be completely removed (an interesting feature was the desire for extensive salvage and re-cycling of some of the building materials). This contamination required the usual worker radiation protection measures including "controlled area" working and the use of respiratory protective equipment. As is often the case there were much more significant radioactive deposits below ground arising from past disposal practices, again undertaken prior to modern UK regulations. These were the primary source of radioactive wastes requiring disposal from the site.

Key questions were, what would be the decontamination end point, how would that be verified,

and what if any area averaging of results would be acceptable when demonstrating that the end point was met? In fact the chosen end point for this site had already been agreed between the owner and the environmental regulator as 0.1 Bq g-1 to be applied above a "local background" level (which was nominally taken as 0.03 Bq g-1 in this case). The 0.1 Bq g-1 figure applied to thorium-232 in equilibrium with all its decay products and had been originally derived from consideration of a predicted fatal cancer risk rate to future site occupants of 10-6 per year. (Some assessments suggest the excess risk rate for an incremental level of 0.1 Bq g-1 of thorium-232 in soil may be several times higher that this.) It was clearly going to be a challenging end point to achieve and verifying it required not only use of gamma radiation surveys but also a detailed grid of soil samples that were assayed by gamma spectrometry. There was no need to employ area averaging arguments in this particular case, although clearly gamma surveys inevitably provide for some area averaging in the monitoring process, unlike discrete sampling.

The project has been a success in that the desired end point was achieved and verified, but this does not mean that it was necessarily the radiologically optimised solution. What is now considered here is what alternative end point might have been possible. Intuitively, the question might be how much higher could the end point have been set? An incremental level much below 0.1 Bq g-1 would stray into the normal variability of the natural level of thorium in soils and attempting to pursue an ultra-low end-point could lead to an exponential increase in waste volumes and costs and, in addition, a much more difficult and expensive final survey.

HPA advice on determination of end points for change of use of a contaminated site like this one is that where there may be future public exposure a constraint on predicted future doses of 300 microSieverts per year should be applied. This sets a minimum standard of remediation which can be regarded as acceptable. Below this constraint the remediation should be optimised so that predicted future exposures will be as low as reasonably achievable. A separate reference level of 20 microSieverts per year (which relates to an excess risk rate of the order of 10-6 y-1) is described. Below this the requirement for optimisation can be considerably relaxed but this is *not* intended as the automatic level that all remediation strategies should aim for and it is definitely *not* the boundary between "acceptable" and "unacceptable" risk.

The methodology and results in report NRPB-W36 can be used to determine that the following thorium-232 chain concentrations would correspond to the 300 and 20 microSieverts per year levels for a range of physical distributions of the residual contamination. In all these cases it is the residential housing scenario that is being considered, as this tends to be the most sensitive, and it was relevant in this particular situation.

Distribution of contamination	Uniform (no cover)	Uniform (covered)	Uniform (covered, disturbed))	Patchy (covered)	Patchy (covered)	Patchy (covered, disturbed)
Bq/g for 300 microSv/y	0.25	1.11	0.62	1.22	2.00	1,79
Bg/g for 20 microSv/y	0.017	0.074	0.041	0.081	0.133	0.120

On this basis it would have been possible to consider an end point for thorium-232 in soil rather

higher than the chosen 0.1 Bq g-1, perhaps allowing area averaging against one lower value with a second higher threshold of maybe 1 Bq g-1 for "peak" concentration as determined by discrete samples. Secondary thresholds applicable to small areas could be useful in some situations of non-uniform contamination, and they can be radiologically justified.

For the widespread contamination scenario the thorium-232 concentration corresponding to the 20 microSieverts per year level is very low (a few tens of Bq kg-1). This is definitely within the variability of normal levels of thorium in many soils and building materials. This shows how for natural radionuclides (but especially thorium and radium) attempts to "achieve" very low residual risk targets are likely to be impracticable on grounds of inability to detect the additional man-made contamination above the normal background, while they are certainly unlikely to represent optimisation of protection.

Discussion

Cases 1 and 3 above present different examples of intervention to deal with radioactive contamination. In Case 1 the intervention was in a true existing exposure situation caused by historic residues whereas in Case 3 it is mainly future exposure to residues that is important. However, the two scenarios share a common theme that once a decision is taken to intervene, i.e. carry out decontamination actions, the question of how far should these actions be pursued becomes most important. In Case 1 it could be argued that only limited decontamination would be required to suppress the radon levels but judging this would present problems because of the difficulty of predicting radon levels after remediation. In addition given the disruption involved the marginal cost of removing more contamination could be relatively small so there was in that case a strong incentive to treat the situation as a "full" decontamination exercise. That would, for example, facilitate future changes to use of the affected premises: by not leaving significant contamination behind there would be no concern about the need to re-visit and undertake further remediation in future.

Thus the setting of end-points for site decontamination is important both to intervention in existing exposures to historic residues and to changes of use of contaminated sites. The ALARA method would suggest that end points would have upper bounds (related to dose constraints or even limits) but otherwise consider the balance between implied future doses (minus the reduction in any existing does) against the costs expended to reduce those. That alone is a difficult judgement partly because of the difficulty of predicting future doses and or predicting the costs of remediation before it begins. However, in practice further factors are significant in the selection of the remediation end point and one of the most significant of these is the definition of "radioactive substance" for the purpose of regulatory control.

Current UK regulations for radioactive substances activities including waste disposal set a concentration threshold for application of the regulations to practices involving solid radioactive materials. The thresholds for each radionuclide or decay chain are derived from RP-122. The UK regulations do not seek to require permitting for in-situ contamination above this level but they would, unless an exemption applied, require permitting for disposal of radioactive wastes arisings. Thus, while contamination remains undisturbed these regulations do not require action, but any deliberate radioactive decontamination or just wastes produced from building modification work can come into the scope of the regulations. Disposal of such wastes may fall

within exemption provisions but these are not unconditional, all that is avoided is the requirement for a formal permit. This means that when planning decontamination there is often a strong desire for decision makers to achieve a result which implies no future regulatory burden, and that makes the regulatory reference level a strong candidate to become the chosen decontamination end-point.

In the case of the thorium-232 decay chain the preceding W36 results show that the UK threshold value of 0.5 Bq g-1 if applied as an end-point for uniform widespread contamination implies future doses to site occupants above 300 microSieverts per year for some scenarios. That would not be compatible with the HPA advice and so supports the decision to use a lower end point in the Case 3 scenario. The corresponding threshold for cobalt-60 in the UK regulations is 0.1 Bq g-1 and for the uniformly contaminated uncovered ground/housing scenario in NRPB-W36 implies a dose rate of about 90 microSieverts per year. This seems comfortably below the HPA recommended constraint for a change of use of contaminated land whilst not being excessively low. More extreme cases are the regulatory thresholds for radionuclides such as tritium and carbon-14 which are in the UK respectively 100 and 10 Bq g-1. These if applied as end points are likely to imply much lower dose rates and their use could distort optimisation, especially if the even lower value for carbon-14 of 1 Bq g-1 in the IAEA publication RS-G-1.7 is applied. But at least these tritium and carbon-14 values are more sensible than the previous threshold of 0.4 Bq g-1 that would have been considered for these radionuclides prior to the UK's adoption in its regulations of a new exemption and exclusion regime.

Conclusions

There is clearly a role for optimisation of radiation protection in relation to decontamination whether this is to reduce existing doses or to restrict (predicted) future doses. The significant direct financial costs of remediation and waste disposal surely support this assertion.

When considering extensive remediation work other non-radiological risks are not often considered but perhaps ought to be, for example movement of large volumes of contaminated soils to landfill sites imply transport risks.

However, as usual in ALARA situations there are other factors that impinge on decision making:

The psychological perception of contamination (including where residues may be forgotten and then re-discovered long after the original contaminating practices) can be a significant factor and may prompt expensive attempts to remove "all" contamination, or to remove it down to very low levels, which will clearly lead to verification issues with NORM and may be simply impractical for widespread contamination by radionuclides such as cobalt-60 which can be detected at extremely low levels.

The regulatory thresholds for "radioactive material" are attractive as end-points for very practical and logical reasons. However, since they tend to be derived from concepts of exclusion and clearance based on very low nominal risk rates they can "drag" the decision making process to what should be the lower end of the range of doses relevant to optimisation of protection. Related to this is the need to recognise that low risk rate criteria such as 10 or 20 microSieverts per year are not automatically suitable for deriving end-points as targets for decontamination. They may be practical for some scenarios but the cost of applying them in others could be that remediation

is not undertaken because it is just too expensive or disruptive. In some cases complete regulatory clearance may not be practicable and managing radioactive residues in-situ should be considered.

However, even if the concept of optimisation is fully embraced in remediation work there are considerable problems in its application including considering how to apply quantitative techniques such as cost benefit analysis. As well as the question of how to cost radiation detriments (which for residual contamination may be delivered over long times) there are significant uncertainties peculiar to these scenarios. One is that despite the best preliminary surveys the extent of remediation required or even practicable cannot always be determined before physical processes such as excavation are begun. Another is the difficulty of predicting future exposures to residual contamination. With gamma emitters this may appear relatively easy but for radon arising from radium residues this is certainly more difficult.

References

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