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Radiological Impact Assessment of the Proposed Construction of a
Residential Development on land at Stanbury House, Spencers Wood,
Shinfield, Wokingham, Berkshire

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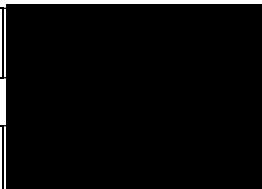
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Executive Summary

- E.1 This report supports a planning application for the development of up to 63 new homes on land at Stanbury House, Spencers Wood, Shinfield, Wokingham, Berkshire., in respect of the application site's location within the boundary of the Detailed Emergency Planning Zone – DEPZ for AWE Burghfield.
- E.2 It is demonstrated that the effective dose of radiation that might be received by a resident as a result of the accident described in the AWE Burghfield consequences report is about 1.3 mSv (which is only slightly more than the limit on annual effective dose to a member of the public from planned exposures and less than the 2.7 mSv annual effective dose received from natural background radiation), or 8.1 mSv under adverse weather conditions. Effective doses of this magnitude are described in the REPPIR guidance as 'Minor' and would not justify disruptive mitigation activities either in the short or the longer term. Sheltering alone, if implemented rapidly enough, should be sufficient to decrease the effective dose received to less than about 1 mSv in daytime meteorological conditions. The proposed development would also be so far from AWE Burghfield that neither urgent nor subsequent evacuation would be required, even for extreme accidents; and longer-term relocation is extremely unlikely to be necessary.
- E.3 Given the distance from the site and its location on the road network there should be no adverse impact on the access of emergency services to AWE Burghfield.
- E.4 An important supplementary consideration is whether the proposed development would place an additional burden on first responders and carers in respect of dealing with medical emergencies and addressing the needs of vulnerable individuals. However, in most accident scenarios, sheltering would either not be required at the location of the proposed development (although it would be initially advised for everyone within the DEPZ) or would only be required for between a few hours and, at most, two days. Therefore, even if visits were discouraged during the sheltering phase, this would be only a short hiatus.
- E.5 Furthermore, the assessed effective dose rates are so low that visiting (including multiple visits) during the period of sheltering should be acceptable if considered necessary for the well-being of a resident. In this context, it would be important to emphasise to carers and other responders that entry into areas with low levels of radioactive contamination would not pose a threat to their health. This is a general aspect of their training and does not have any specific implications for the acceptability of the proposed development.
- E.6 If residents of the proposed development decided to relocate following an accident at AWE Burghfield, it would be their choice and would primarily be to dispel their own anxiety and not to avert effective dose.
- E.7 Overall, whilst the location of the proposed development within the DEPZ of AWE Burghfield is a material planning consideration, the low probability of exposure and the low consequences of any reasonably foreseeable exposure suggest that this

is a consideration that should be given little weight when determining the overall planning balance in respect of the proposed development.

- E.8 Furthermore, the application proposal has no material impact on the resources required in the event of implementation of the off-site emergency plan for AWE Burghfield; and can therefore be safely accommodated under that plan having regard to the needs of “Blue Light” services and other parties involved in implementing or responding to that plan. This means that the application proposal complies with MDD Policy TB04. Furthermore, it means that implementation of the proposed development would not have any potential to render the off-site emergency plan inadequate. In turn, this implies that implementation of the proposed development has no potential to adversely impact operations at AWE Aldermaston. This is important, because continued operation of AWE Burghfield is an essential input to maintaining the UK Continuous at Sea Deterrent (CASD).

Contents

Executive Summary.....	3
1. Introduction.....	6
2. Activities at AWE Burghfield and Radiological Accidents that Could Occur.....	8
3. Radiological Impacts on Residents of the Proposed Development.....	12
3.1 Effective Dose from an Accident.....	12
3.2 Frequencies of Accidents Impacting the Proposed Development.....	14
3.3 Radiological Risks to Residents of the Proposed Development.....	17
4. Setting the Size of the Detailed Emergency Planning Zone.....	18
5. Implications of the Proposed Development being Located within the DEPZ.....	20
5.1 Warning, Informing and Sheltering.....	20
5.2 Discouraging Self-evacuation.....	22
5.3 Longer-term Protective Actions, including Evacuation.....	23
5.4 Off-site Traffic Movements.....	24
5.5 Monitoring and Decontamination.....	24
5.6 Long-term Remediation.....	24
6. Acceptability of the Proposed Development.....	26
6.1 Introduction.....	26
6.2 Warning and Informing.....	26
6.3 Sheltering.....	27
6.4 Evacuation.....	28
6.5 Vulnerable Individuals.....	28
6.6 Access to AWE Burghfield.....	29
6.7 Monitoring and Relocation.....	29
7. Conclusions.....	31
References.....	34
Appendix A: Atmospheric Dispersion Calculations.....	36
A.1 Background.....	36
A.2 Mathematical Form of the Gaussian Plume Model.....	37
A.3 More Complex Dispersion Models.....	39
A.4 Deposition.....	40
A.5 Resuspension.....	42
A.6 Model Application in This Assessment.....	43
A.7 References.....	45

1. Introduction

- 1.1 This report examines a planning application for the development of 63 new homes on land at Stanbury House, Spencers Wood, Shinfield, Wokingham, Berkshire, in respect of the location of the proposed development within the boundary of the Detailed Emergency Planning Zone – DEPZ for AWE Burghfield (see Figure 1).



Figure 1: Location of the Proposed Development. The Phase 1 development is currently being built out. ‘Site’ is the location of the proposed Phase 2 development and ‘Kingfisher Grove’ identifies the location of another site that has received planning permission for residential development.

- 1.2 The background to this proposal is that, in 2018, planning permission was granted for constructing 57 new homes in Phase 1 of the development and in 2019 a planning application was submitted to construct a total of 120 new homes on Phases 1 and 2 of the development. The Case Officer advised that he was recommending approval for this application and work in preparing the S106 had commenced when, as a result of the change from REPPiR [2001] to REPPiR [2019], the Detailed Emergency Planning Zone (DEPZ) for AWE Burghfield was expanded such that the site of the proposed development lay within, but near the outer boundary of, the expanded zone. In consequence, the application was refused for one substantive reason only, i.e. that there would be an unacceptable impact on the offsite emergency plan. Currently, the Phase 1 development is being built out and an outline application for up to 63 new homes in Phase 2 of the development is being submitted. It is this Phase 2 submission that is the subject of this report.
- 1.3 The reason that it is timely to submit such a submission for Phase 2 of the development is that, since 2019, planning inquiries relating to other proposed developments within the DEPZ have demonstrated that those developments can be accommodated under the offsite emergency plan for AWE Aldermaston and AWE Burghfield (e.g. at Kingfisher Grove, see Figure 1).

- 1.4 In this report, Section 2 describes the activities undertaken at AWE Burghfield and the types of accident that might result in significant off-site releases of radioactive materials. Section 3 then uses this information to assess the radiological impacts of such releases on individuals located on the proposed Phase 2 development, assuming it to be downwind of AWE Burghfield at the time of an accident. Section 4 addresses the basis on which the size of the current DEPZ was set; and Section 5 sets out the implications of the proposed Phase 2 development being located within the DEPZ. Section 6 then demonstrates that there should be no difficulty in accommodating the proposed Phase 2 development under the off-site emergency plan and, therefore, that its location within the DEPZ, while relevant to the overall planning balance, should be given little weight when evaluating that balance. Conclusions from the analysis are provided in Section 7.

2. Activities at AWE Burghfield and Radiological Accidents that Could Occur

- 2.1 AWE Plc is a Non-Departmental Public Body, wholly owned by the Ministry of Defence, and is the company that provides and maintains nuclear warheads for Trident, the UK's continuous at sea deterrent. AWE Aldermaston and AWE Burghfield are the company's two main sites. Burghfield operated as an ordnance factory until it entered the Atomic Weapons' Programme in 1954. Today, on-site operations include the entire cycle of warheads from concept and design, manufacturing, assembly, servicing, decommissioning and disposal [ONR, 2018; MOD, 2023].
- 2.2 Until 2019, requirements relating to off-site emergency planning were defined under the Radiation (Emergency Preparedness and Public Information) Regulations 2001 [REPPiR, 2001]. However, these have now been replaced by REPPiR [2019]. Whereas under REPPiR [2001] the extent of the DEPZ was determined by the Office for Nuclear Regulation (ONR) based on dialogue with the operator, under REPPiR [2019] it is determined by the lead Local Authority, which, in this case is West Berkshire District Council (WBDC), based on advice from the operator. The other main change of relevance here is that the accident conditions to be addressed in defining the DEPZ have been redefined. Previously, the DEPZ would have been determined based on the maximum size of any radiation emergency which could be reasonably foreseen and a dose contour of 5 mSv. Under REPPiR [2019] the term 'reasonably foreseeable accident'¹ is no longer used. Instead, the operator is expected to determine a representative range of source terms and consider a range of weather conditions providing more understanding of the potential variability of accident severity. REPPiR [2019] advice is that a probability of 1 in 20,000 in a five-year period is the lowest likelihood for which detailed emergency planning should be required. In fact, this is very close to the understanding of reasonably foreseeable in REPPiR [2001].
- 2.3 The 5 mSv contour, required in REPPiR [2001], has been replaced with a requirement to estimate the downwind distance to which a lower Emergency Reference Level of dose² for the relevant protective action could be averted by the application of that protective action. This applies separately to shelter, evacuation and stable iodine prophylaxis, this last relevant only to releases of radioactive isotopes of iodine and their short-lived precursors and does not apply to AWE Burghfield.
- 2.4 The remit of AWE Burghfield under REPPiR [2019] is to identify and assess all hazards that have the potential to result in a radiation emergency. This is achieved through the Hazard Evaluation and Consequence Assessment (HECA). The principal output from the HECA is the determination of the minimum distances to which urgent protective actions may need to be taken, marking against each

¹ According to REPPiR [2001] guidance "A reasonably foreseeable event would be one which is less than likely but realistically possible".

² 3 mSv for shelter, 30 mSv for evacuation and 30 mSv for iodine dose to the thyroid. This corresponds to unprotected doses of 7.5 mSv, 75 mSv and 75 mSv (thyroid) respectively.

- distance the timescale for implementation of the relevant action. The area thus defined is known as the Urgent Planning Area (UPA). This information is published in the site's Consequences Report. The UPA distance defines the minimum size of the DEPZ around AWE Burghfield.
- 2.5 In defining the location of the 7.5 mSv contour that bounds the UPA (for sheltering), the Consequences Report [AWE, 2019] provides details of the environmental pathways of exposure that require consideration and the atmospheric stability conditions that they adopted in calculating the dispersal of radioactive materials beyond the site boundary. The information provided is summarised below.
- 2.6 The exposure pathways that require consideration include:
- First-pass inhalation of air in the plume of contamination,
 - Short-term external irradiation during the passage of the plume (cloud-shine),
 - Long-term inhalation after resuspension from ground contaminated by the plume,
 - Long-term external irradiation from ground contaminated by the plume (ground-shine), and
 - Ingestion of food crops contaminated by the initial plume.
- 2.7 The most likely predicted accidents would spread material by explosive distribution, where the dominant material would be plutonium (or potentially highly enriched uranium) in an inhalable particulate form³. However, for potentially more energetic events a range of fission products would be produced. Details of these more energetic events are not provided, but the reference to fission-product releases suggests that criticality accidents could be the postulated accident type.
- 2.8 For most fault sequences, the material released would be in the form of fine particulates of plutonium and the predominant pathway would be exposure by inhalation. Therefore, overall, the primary concern for early response decision making in emergencies involving possible accidents at AWE Burghfield only merits consideration of the first-pass inhalation dose and this means that sheltering is the recommended urgent protective action.
- 2.9 The term “explosive distribution” suggests a violent event in which a significant fraction of the total release is released within minutes of initiation after which it tails off rapidly (though there may be a slower tailing off of release of a small fraction of the activity. This has been assessed as less than 5% of the total release, and this assessment has not been contradicted by AWE when introduced in evidence at planning inquiries. Combined with the understanding that the majority of the dose is from first pass inhalation this means that the dose uptake by members of the public occurs mainly during the time that the plume passes by them after which there is very little additional dose and very little to be gained by continuing

³ The radiological impacts of highly enriched uranium are very similar to those arising from plutonium. In this report, material related to plutonium can be taken to apply also to highly enriched uranium unless an explicit distinction is made.

protective actions such as remaining in shelter. Thus, a focus of off-site emergency planning must be the obtaining relevant data on areas that may have become contaminated by the initial plume and on relaxing advice on sheltering as quickly as possible to minimize the adverse physical and mental stresses associated with prolonged sheltering..

- 2.10 In respect of atmospheric dispersion, the REPPiR [2001] determination was based on a 5 mSv contour using 55% stability Category D conditions, i.e. the weather was taken to correspond to average conditions applicable in the UK (see also Appendix A). In contrast, the new REPPiR [2019] determination is based on a 7.5 mSv contour but on a weather category that is less likely, but which could provide significantly greater doses. Consideration of less likely weather categories that occur for around 12% of the time in the local geographical area, increases the 7.5 mSv dose contour, defining the UPA to 3160 m from the centre of the Burghfield site [AWE, 2019].
- 2.11 Because there have been few changes in operations at the Burghfield site over the last few years, a further insight on the types of accident of interest can be obtained from ONR [2018]. This is based on the reference accident concept and states that AWE Plc identifies the reference accident at AWE Burghfield as a detonation within a cell (meaning a ‘hot cell’ for the manipulation of radioactive materials). In practice, such an explosion would most likely occur in one of the Gravel Gerties that are used for assembly of the weapons.⁴ Furthermore, ONR [2018] reports that the AWE Plc Report of Assessment (RoA) concludes from the reference accident that the area in which a member of the public might potentially receive a radiation dose of more than 5 mSv is bounded by a circle of radius 1.252 km (1252 m) from the centre of the nuclear licensed site.
- 2.12 ONR [2018] further comments that all accidents that could lead to a reasonably foreseeable radiation emergency result in the release of uranium and/or plutonium compounds. These materials emit alpha and weak gamma radiations. The AWE dose assessment includes internal contributions from plume inhalation over the year following the release. External irradiation from the passing plume or from deposited uranium/plutonium material was assessed as negligible due to the nature of these materials. The dose associated with the inhalation of re-suspended radioactive material was also assessed as being less than 1% of the dose uptake.
- 2.13 The exclusion of ingestion dose as adopted by AWE in its assessment was not initially accepted by ONR, as the definition of a radiation emergency according to REPPiR [2001] required that the dose averted by urgent early health protection protective actions initiated during the first 24 hours (such as food bans) should be

⁴ The Gravel Gertie has thick reinforced concrete walls and roof, but a large vent in the top to prevent the shell from rupturing in an explosion. Below the roof is approximately 7 metres of loosely compressed porous gravel suspended from steel cables above a false ceiling over the work area. In the event of an explosion, the mass of gravel is designed to compress and move upward with the initial blast, sealing the hole in the roof while allowing some of the gas pressure to escape by passing through the gravel. This filters the escaping gases and prevents the building from rupturing. The mass of gravel then falls down into the room when the gases cool, trapping large amounts of radioactive particles under and within the gravel, further minimizing leakage.

- disregarded when projecting the dose that members of the public are likely to receive. However, an assessment undertaken by the ONR found that the contribution to public dose from ingestion was negligible (i.e. approximately 1% of the total dose) compared with inhalation. This is because ingested uranium and/or plutonium compounds, particularly oxides, pass through the body quickly and are absorbed from the gastrointestinal tract to a negligible degree, in contrast to inhaled material which remains in the lungs and is subsequently transferred to a significant degree to the systemic circulation. Therefore, ONR concluded that ingestion dose would not be significant.
- 2.14 The ONR [2018] further noted that high consequence, low frequency external events such as aircraft impacts were considered in the AWE safety case and no faults were identified that give rise to a significant off-site release of radiation. Also, the inadvertent detonation of a warhead was judged to be well beyond a reasonably foreseeable occurrence. A security review was also undertaken by AWE Plc and was assessed separately by the Defence Nuclear Safety Regulator, and ONR [2018] judged that it is not reasonably foreseeable for any security related event to lead to public dose consequences beyond the reference accident.
- 2.15 In summary, a large accident with potentially significant off-site radiological consequences that could arise at AWE Burghfield would be due to detonation of conventional explosives with the release of plutonium (or enriched uranium) to the atmosphere. This release is likely to persist for a timescale of minutes to hours, with an early peak followed by a low release rate tail due to material initially delayed in the building structure. Under average weather conditions, such an accident could result in an individual effective dose of about 5 mSv at 1252 m downwind of the centre of the AWE Burghfield site, but under adverse weather conditions that occur for about 12% of the time, the individual effective dose could be as large as 7.5 mSv at 3160 m downwind of the centre of the site. In either case, the dose would be almost entirely due to inhalation of radioactive material from the plume by the individual while they were immersed in the plume. Furthermore, the dose would be largest on the centreline of the narrow plume and would fall off rapidly with increasing distance from the centreline.
- 2.16 Recently, AWE Burghfield has clarified some issues related to the characteristics of the accidents used in establishing the size of the UPA [AWE, 2023]. The weather conditions used in setting the 7.5 mSv contour were Pasquill Category F (see Clarke [1979] and Appendix A for a discussion of atmospheric dispersion in different stability conditions). These conditions occur only at night and typically on cold winter nights. Therefore, if an accidental release occurred during daylight hours, its radiological impact would be less than that assessed and would be similar to that assessed for REPPiR [2001]. However, AWE [2023] clarifies that, at the present time, AWE Burghfield operations involve working shift patterns including nighttime working, meaning that Category F conditions may overlap with AWE operations. Also, AWE [2023] confirms that the initial phase of the accident considered will be an energetic release, and notes that this may be followed by a longer passive release phase (see above). The implications of this for the recommended emergency response of sheltering is discussed further in Section 6.

3. Radiological Impacts on Residents of the Proposed Development⁵

3.1 Effective Dose from an Accident

- 3.1 Using Google Earth Pro, the distance from the centre of the proposed development to the declared centre of the DEPZ for AWE Burghfield was estimated by the authors as 3000 m. Thus, the proposed development is located just inside the 3160 m contour that defines the UPA (Figure 2). Various studies have shown that the effective dose varies approximately as x^{-n} , where x (m) is the distance downwind from the release location and n is a numerical coefficient that typically takes a value of 1.5 [see Highton and Senior, 2008]. Thus, an effective dose of 5 mSv at 1252 m downwind would correspond to an effective dose of $5 \times (1252/3000)^{1.5} = 1.3$ mSv at 3000 m downwind. In contrast, 7.5 mSv at 3160 m corresponds to $7.5 \times (3160/3000) = 8.1$ mSv at 3000 m downwind. Assuming the characteristics of the accidents considered under REPPiR [2001] and REPPiR [2019] are similar, the adoption of less likely weather conditions under REPPiR [2019] has resulted in an increase in the assessed effective dose by a factor of approximately six. This is reasonable given the degree to which atmospheric dispersion varies between different atmospheric stability categories (see Appendix A).

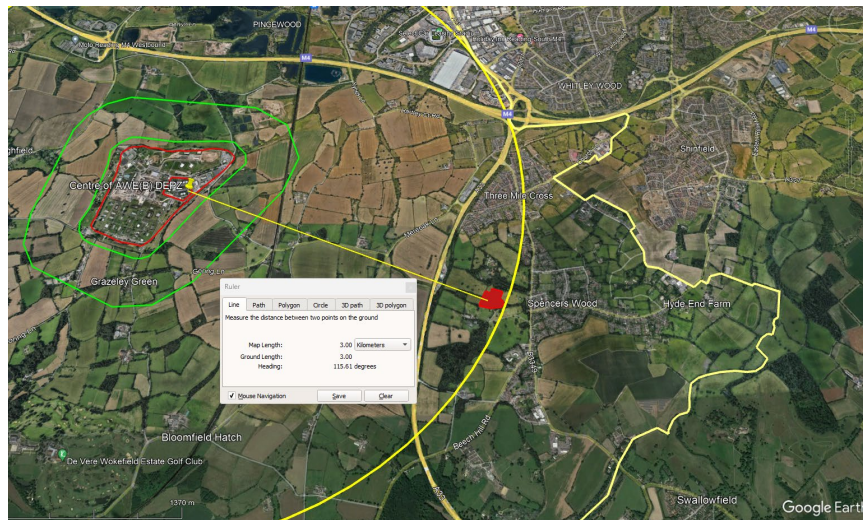


Figure 2: Google Earth plot showing the AWE site (red left hand side) and the 150 m prompt evacuation zone and 600 m subsequent evacuation zone (as detailed in the Off-site Emergency Plan) (green). The plot also shows part of the new operator-determined 3160 m UPA (yellow circle) and council determined DEPZ (yellow). The proposed development is highlighted in red near the centre. (Note for illustration only, not definitive plots). The distance (3 km) from the centre of the DEPZ to a point on the proposed development close to AWE Burghfield is illustrated as a yellow line and information box.

⁵ All numerical values used in this section have been presented at planning inquiries at which AWE gave evidence. Throughout, the AWE witness confirmed that the values used in the calculations were reasonable.

- 3.2 Based on the above analysis, residents of the proposed development would incur an effective dose of about 1.3 mSv if an accident occurred under average weather conditions and about 8.1 mSv if it took place under weather conditions that occur for only 12% of the time and only at night. Furthermore, these effective doses are conditional on the wind blowing toward the proposed development at the time of the accident and take no account of sheltering, which is an effective measure in mitigating first-pass inhalation dose (the effectiveness assumed in emergency planning is that 40% of the dose is averted by sheltering). At night, most individuals, particularly most children, might be expected to be indoors prior to any warning of an accident being issued.
- 3.3 Thus, overall, in the event of the reference accident under typical weather conditions, an unprotected resident of the proposed development could incur an effective dose of about 1.3 mSv. This effective dose is ‘Minor’ (see paragraph 3.6) i.e. it is only slightly more than the annual limit on effective dose for a member of the public of 1.0 mSv [ICRP, 2007] and is within the range that the linear dose response with no threshold (LNT) model is generally applied in radiological protection [ICRP, 2007]. That model assigns detriment-adjusted risk coefficients of 5.5×10^{-5} per mSv for cancer and 2.0×10^{-6} per mSv for heritable effects in the whole population (including infants, children and adults). Thus, the overall risk factor is 5.7×10^{-5} per mSv, which may be thought of as equivalent to the risk of death arising from the irradiation. Thus, for a reference accident giving rise to an effective dose of about 1.3 mSv, the risk conditional on that accident occurring and the wind blowing towards the proposed development is about 7.4×10^{-5} for a person outside on the proposed development during full the plume transit.
- 3.4 These assessed effective doses can be placed in a wider, risk-informed context. The effective dose is about 1.3 mSv in average conditions and 8.1 mSv in adverse weather conditions for the reference accident. As the average annual effective dose in the UK, mainly from naturally occurring radioactivity, is around 2.7 mSv, the effective dose from the reference accident, if it occurs under adverse weather conditions, corresponds to a little over two years of background exposure. Comparisons can also be made with medical exposures. For example, a Computed Tomography (CT) scan of the chest typically delivers 6.6 mSv and a whole-body CT scan typically delivers 10 mSv. There are also considerable regional variations in natural background, with the average annual radon dose to the people of Cornwall being 7.8 mSv, compared with a UK-wide average value of 1.3 mSv⁶. Furthermore, routine releases of radionuclides from nuclear installations are subject to constraints such that annual effective doses are no more than 0.3 mSv.

⁶ All the cited values are from <http://www.hpa.org.uk/Topics/Radiation/UnderstandingRadiation/>, downloaded 10 February 2014.

- 3.5 Thus, the radiological impact of the reference accident, if it were to occur under adverse atmospheric stability conditions with the wind blowing towards the proposed development, on an individual located in the proposed development on the plume centreline and who failed to shelter would be:
- About the same as the radiological impact due to exposure to natural background radiation for three years in a typical location in the UK,
 - About the same as regional variations in the annual exposure to natural background radiation in the UK, and
 - Slightly less than the typical exposure incurred from a medical whole-body CT examination.
- 3.6 Furthermore, the REPPiR [2019] Risk Framework at Appendix 2, Figure 1 on Page 197 describes doses in the range 1 – 10 mSv as “Minor” with no potential for deterministic effects, minimum health and safety impacts, unlikely to have life changing consequences other than a potential for self-imposed restrictive changes in normal life activities and assumed asset value depreciation.
- 3.7 This is not to argue that effective doses of 1 – 10 mSv are of no importance. Indeed, substantial efforts are being made to reduce high regional exposures to radon and the use of CT scanning in medicine is subject to a requirement for justification and optimisation on a case-by-case basis. However, it is important to emphasise that the radiation doses that could arise if a major accident occurred at the AWE Burghfield are within the range commonly experienced by members of the public during their everyday life.

3.2 Frequencies of Accidents Impacting the Proposed Development

- 3.8 The radiological impacts evaluated in Section 3.1 are conditional. They assume both that the accident occurs and that the wind is blowing towards the proposed development. This is relevant in emergency planning, because the off-site emergency plan is intended to mitigate the consequences of an accident to the exposed population as part of an overall defence-in-depth strategy. However, in the context of the planning balance, it is also relevant to consider the likelihood that such an accident will occur, because this determines the degree to which occupants of the proposed development would be placed in the way of harm. The likelihood of an accident occurring and impacting the residents of the proposed development is the product of the frequency of accidents with significant off-site consequences and the probability that the wind is blowing in the direction of the proposed development when the accident occurs.
- 3.9 The details associated with frequencies and consequences of potential accidents at AWE Burghfield are classified and cannot be published in the public domain [AWE, 2023]. However, ONR commented [ONR, 2018] that a Burghfield Report of Assessment (a REPPiR [2001] requirement) was written claiming that there were no reasonably foreseeable faults that could lead to a radiation emergency at AWE Burghfield. If accepted, this would have removed the need for a DEPZ around AWE Burghfield and the need for a local authority off-site emergency plan. When

- challenged to look harder for a potential reference accident, AWE proposed a chain of events involving earthquakes and inadvertent detonations of conventional explosives but then introduced operational restrictions such that the sequence is no longer reasonably foreseeable. They then agreed the detonation in a hot cell as the Reference Accident with ONR.
- 3.10 The reason the above paragraph is relevant is that it provides strong circumstantial evidence that the accidents used in the current Consequences Report are at the lower end of the range of probabilities considered for detailed planning in REPPiR [2001]. A numerical value for “reasonably foreseeable” was never officially agreed but was taken as about 10^{-5} y^{-1} with pressure to look down to about 10^{-6} y^{-1} for potential “cliff edge” effects.
 - 3.11 Because the explosive distribution fault has been used to define the size of the UPA, it is appropriate to assume that it is the fault that gives the largest effective dose of all those faults that are more likely than 10^{-5} y^{-1} (presented as 1 in 20,000 over 5 years in the Regulations), as this is the descriptor for the boundary between the needs for detailed emergency planning and outline emergency planning. The frequency could be as low as $1 \times 10^{-6} \text{ y}^{-1}$, because this is the limit of the sensitivity range that operators are advised to explore to prevent cliff edge effects affecting their conclusions.
 - 3.12 That result is consistent with AWE arguing that there were no “reasonably foreseeable” faults as the boundary of applicability of that term in REPPiR [2001] was, as discussed above, taken to be $1 \times 10^{-5} \text{ y}^{-1}$ with checks down to $1 \times 10^{-6} \text{ y}^{-1}$ to avoid cliff-edge effects.
 - 3.13 However, it is acknowledged that there could be several fault sequences giving rise to off-site doses comparable with (but slightly smaller than) those associated with the fault sequence used to define the size of the UPA. Therefore, for illustrative purposes, it is here assumed that up to ten such sequences could make comparable contributions. This leads to a reasonable upper-bound estimate of the frequency of accidents leading to significant off-site doses of $1 \times 10^{-4} \text{ y}^{-1}$. However, if there was only a single dominant fault sequence that was included to avoid cliff-edge effects, the frequency could be as low as $1 \times 10^{-6} \text{ y}^{-1}$. Even with the upper-bound frequency of $1 \times 10^{-4} \text{ y}^{-1}$ it is unlikely that an accident with significant off-site radiological impacts will occur within the remaining operational lifetime of AWE Burghfield.
 - 3.14 As to the frequency of the wind blowing toward the proposed development, reference can be made to the wind-rose for RAF Benson shown in Figure 3. (Public domain information has been used in constructing this figure. Provision of on-site wind-rose data from AWE Burghfield could be used to refine this figure but would not materially change it.)



Windrose Plot for [EGUB] Benson

Obs Between: 01 Jan 1973 12:00 AM - 03 May 2023 08:50 AM Europe/London

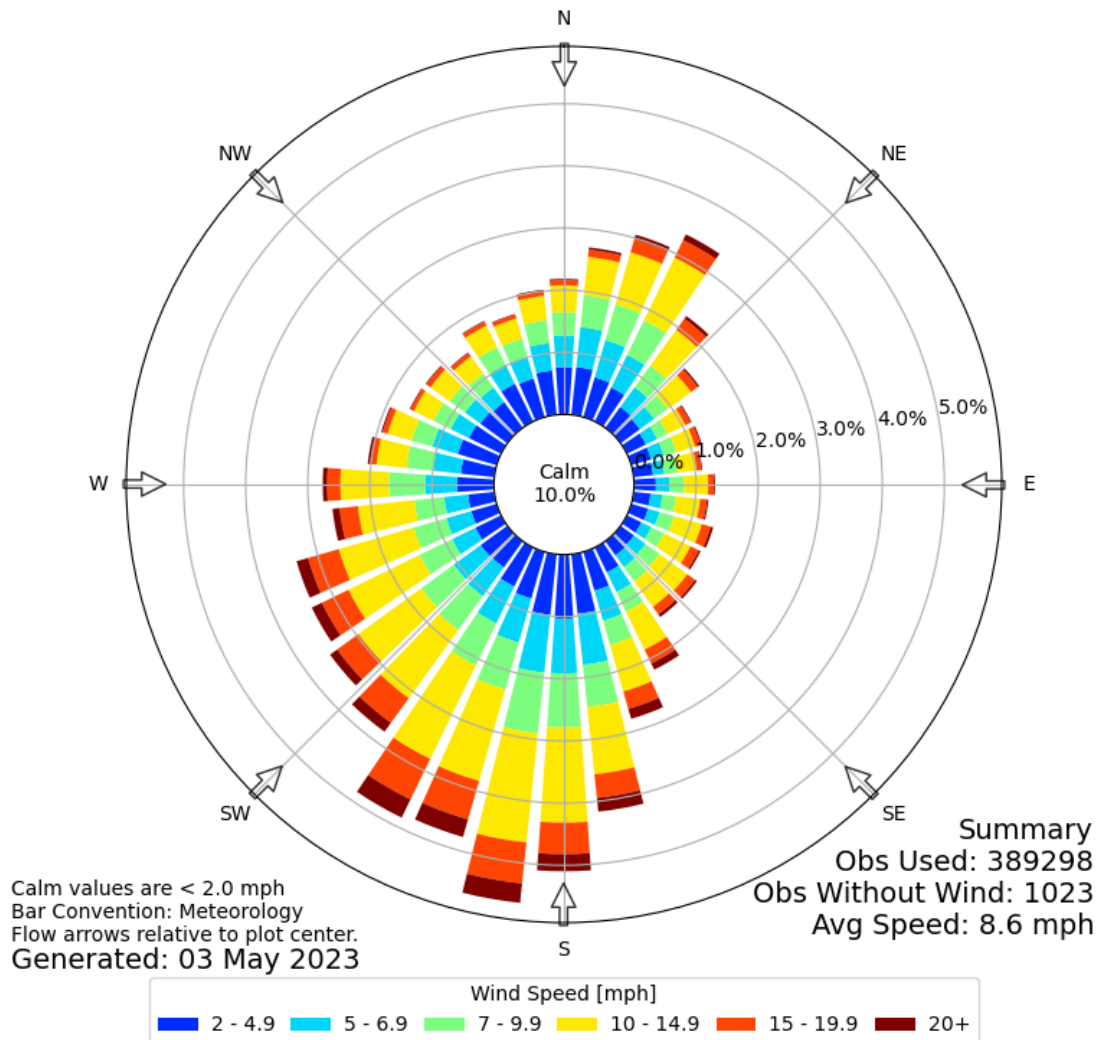


Figure 3: Windrose for RAF Benson (Benson, Ewelme, Wallingford OX10 6AA). The lengths of the bars show the frequency with which the wind blows from each sector and the colours show the contributions from different intervals of wind speed. Circular contours are at frequency intervals of 1%. From the Iowa Environmental Mesonet of Iowa State University.⁷ Downloaded 10 July 2023.

- 3.15 Because the proposed development would be located to the east of AWE Burghfield, it is winds from the west that blow towards it. Considering only a single ten-degree sector, the probability is about 2 to 3%. However, because the plume spreads laterally as it travels downwind, it is here cautiously assumed that the proposed development could be impacted if the wind was blowing into the sector including the application site, or into the two sectors to either side of this sector.⁸ Thus, the overall probability is no more than approximately 9%.

⁷ See: https://mesonet.agron.iastate.edu/sites/windrose.phtml?station=EGUB&network=GB_ASOS

⁸ This is particularly cautious because the dose calculations relate to exposure on the plume centreline and assessed doses decrease with increasing transverse distance from that plume centreline.

- 3.16 Combining an upper-bound frequency of accidents of $1 \times 10^{-4} \text{ y}^{-1}$ with a cautious estimate that the wind blows toward the proposed development for 0.09 of the time, the frequency of accidents impacting the proposed development is assessed as no more than $9 \times 10^{-6} \text{ y}^{-1}$.

3.3 Radiological Risks to Residents of the Proposed Development

- 3.17 At paragraph 3.3 it is demonstrated that a reference accident occurring under typical weather conditions would give rise to an effective dose of about 1.3 mSv at the downwind distance of the proposed development and that the risk of death conditional on that accident occurring and that dose being received is approximately 7.4×10^{-5} .
- 3.18 At paragraph 3.16 it is demonstrated that the frequency of accidents impacting the proposed development is projected to be no more than $9 \times 10^{-6} \text{ y}^{-1}$.
- 3.19 Combining these two estimates a cautious estimate of the annual risk of death for a resident of the proposed development is $7.4 \times 10^{-5} \times 9 \times 10^{-6} = 6.7 \times 10^{-10} \text{ y}^{-1}$. This is an annual risk of death of slightly more than one in two thousand million.
- 3.20 For comparison, the HSE in its report ‘Reducing Risks, Protecting People’ [HSE, 2001] has given annual risks of death from various causes. These include 1 in 16,800 from all forms of road accident, 1 in 29,000 from lung cancer caused by the radioactive gas radon in dwellings, 1 in 510,000 from a gas incident (fire, explosion or carbon monoxide poisoning) and 1 in 18,700,000 from lightning. From this comparison, the annual probability of death for a resident of the proposed development due to an accident at AWE Burghfield is two orders of magnitude less than the annual probability of being killed by being struck by lightning.
- 3.21 It is also relevant to note that, when assessing the significance of individual risk, the HSE [2001] comments that it “...believes that an individual risk of death of one in a million per annum for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and tolerable regions. As is very apparent from Tables 1-4 at Appendix 4 [of HSE, 2001], we live in an environment of appreciable risks of various kinds which contribute to a background level of risk - typically a risk of death of one in a hundred per year averaged over a lifetime. A residual risk of one in a million per year is extremely small when compared to this background level of risk. Indeed, many activities which people are prepared to accept in their daily lives for the benefits they bring, for example, using gas and electricity, or engaging in air travel, entail or exceed such levels of residual risk...”
- 3.22 The annual probability of death for a resident of the proposed development due to an accident at AWE Burghfield is cautiously estimated as more than three orders of magnitude below the boundary of the tolerable region, i.e. it is well within the region where the risk would be judged broadly acceptable. Although risks in this region should still be considered to show that they are as low as reasonably practicable (and the REPPiR-19 risk assessment process verifies this), they are generally regarded as being too low to be of regulatory concern.

4. **Setting the Size of the Detailed Emergency Planning Zone**

- 4.1 In this report, the terminology Detailed Emergency Planning Zone (DEPZ) is used (see, e.g. Richardson and Anstey [2020]). This term is defined in REPPIR [2019] as ‘*a zone determined in accordance with regulation 8 and covered by the local authority’s off-site emergency plan.*’
- 4.2 REPPIR [2019] places a duty on the local authority to determine the DEPZ for installations within its area of responsibility based on the operator’s recommendations.
- 4.3 The associated Approved Code of Practice (ACoP) [ONR, 2020] also states that the DEPZ must be based on the minimum geographical extent proposed by the operator in the consequence report and should:
- Be of sufficient extent to enable an adequate response to a range of emergencies, and
 - Reflect the benefits and detriments of protective action by considering an appropriate balance between dose averted and the impact of implementing protective actions in a radiation emergency across too wide an area.
- 4.4 The local authority may extend the area proposed by the Operator in consideration of:
- local geographic, demographic and practical implementation issues,
 - the need to avoid, where practicable, the bisection of local communities,
 - the inclusion of vulnerable groups immediately adjacent to the area proposed by the operator.
- 4.5 However, the REPPIR 2019 ACoP [ONR, 2020; Paragraph 231(b)] warns that the DEPZ should:
- (b) *reflect the benefits and detriments of protective action by considering an appropriate balance between:*
- (i) *dose averted; and*
 - (ii) *the impact of implementing protective actions in a radiation emergency across too wide an area.*

This means that the DEPZ can be too big.

- 4.6 There is a further requirement that in defining the boundary of the DEPZ geographic features should be used for ease of implementing the off-site emergency plan. Thus, physical features such as roads, rivers, railways or footpaths should be considered as well as political and postcode boundaries.
- 4.7 The DEPZ, as defined under REPPIR [2019], is illustrated in Richardson and Anstey [2020] and is shown in Figure 4. There have subsequently been some very

minor changes to the boundaries of the DEPZ, as discussed in Maddox and Richardson [2023].

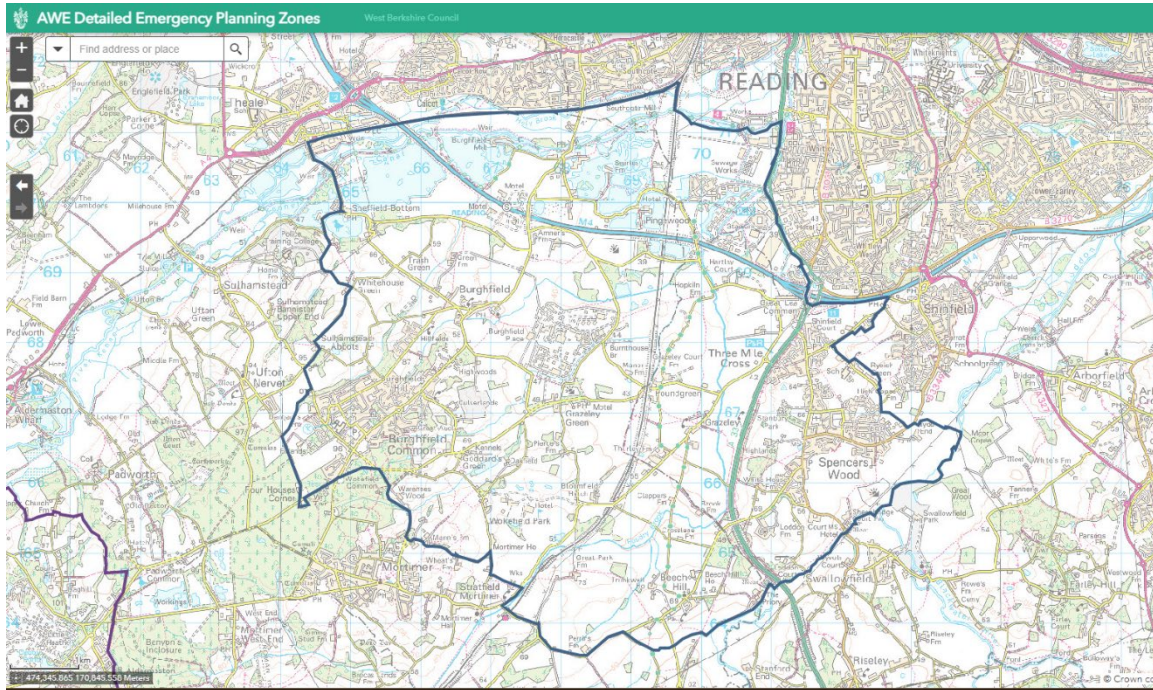


Figure 4: The DEPZ for AWE Burghfield as defined under REPPiR [2019]. The limit of the adopted DEPZ is shown by the irregular dark blue line [From: <https://westberks.maps.arcgis.com/apps/webappviewer/index.html?id=b32400ebd4174a04a2418666dea4f779> (accessed 6 July 2023).]

- 4.6 Taking account of local considerations, West Berkshire District Council (WBDC), which is the lead Local Authority for off-site emergency planning relating to AWE Burghfield has expanded the DEPZ from its minimum size to the considerably larger extent shown by the dark blue line in Figure 3. A substantial expansion has been made to encompass the whole of Spencers Wood. In contrast, just to the north of Spencers Wood, the boundary of the DEPZ lies approximately on the boundary of the UPA. This avoids including any part of the built-up area of Reading within the DEPZ.

5. *Implications of the Proposed Development being Located within the DEPZ*

- 5.1 Under REPPiR [2019], where a DEPZ has been specified an off-site emergency plan must be prepared in accordance with Regulation 11. The lead Local Authority, in this case West Berkshire District Council (WBDC), must also, in co-operation with the operator, ensure that the public are made aware of the relevant information and, where appropriate, are provided with it (Regulation 21). In the event of an emergency, the lead local authority has the responsibility to supply information about and advice on the facts of the emergency, of the steps to be taken and, as appropriate, of the protective actions advised (Regulation 22).
- 5.2 These provisions are broadly like those under REPPiR [2001]. Therefore, off-site emergency plans made under the former regulations were readily adapted to the new regulatory regime. Herein, reference is made to a redacted version of the current plan obtained through a freedom of information request [JEPu, 2022] and a REPPiR leaflet targeted at members of the public resident within the DEPZ that refers to and which is in conformance with REPPiR [2019] [West Berkshire Council, 2023].

5.1 Warning, Informing and Sheltering

- 5.3 In the event of an off-site emergency being declared, sheltering is the recommended protective action and is applied over the whole DEPZ and not just the downwind sectors of the UPA where it is thought to be appropriate on avertable dose grounds. This approach arises because the accidents of relevance are considered to occur without prior warning and their radiological impacts would occur mainly within minutes to a few tens of minutes. Thus, this protective action would be advised for the proposed development, even though under most atmospheric dispersion conditions it could only avert an increment of dose too small to require triggering of a sheltering response. When an incident has resulted in the declaration of an off-site nuclear emergency, the following warning and informing actions would take place [JEPu, 2022, Section 5.3]. The off-site emergency plan does not indicate how timely relaxation of the sheltering recommendation will be achieved.
- AWE would initiate the automatic telephone alerting system to the public round the affected site. The public would be advised to go inside, stay inside the nearest suitable building and to tune into the radio and television to hear public service broadcasts.
 - Information and warnings about the emergency would be regularly reported via TV, local and national radio; social media including the AWE Twitter account, and websites as appropriate.
 - Other activities, such as loud hailer may be employed to ensure messages are going out. The emergency plan states that all means necessary will be employed to get the messages across.

- Emergency Media Briefing Centres and Emergency Help Lines may also be put in place.

5.4 Thus, as summarised in the most recent REPPiR leaflet [West Berkshire Council, 2023]:

“Every household and business in the area will automatically receive a pre-recorded telephone message (landline only) from the AWE Alerting System. Local radio and TV stations will broadcast messages and emergency service responders will use news websites and social media to issue advice to the public. Other alerting systems may also be used such as the government’s Emergency Alerts. Please follow the advice IMMEDIATELY.”

5.5 Sheltering is the recommended protective action because the main potential radiological impact in the initial phase of an accident arises from inhalation of radionuclides from the plume of radioactive material as it disperses downwind of the accident and because the avertable dose is less than the lower Emergency Reference Level (ERL) for evacuation [Nisbet, 2019]. This advice is set out in some detail in West Berkshire Council [2023]:

- *Go indoors immediately and stay there. This is because contamination levels are likely to be higher outside buildings than inside. Staying inside is the most important advice because the fabric of the building will provide a layer of protection against any ionising radiation and will reduce exposure to any radioactive particles. If you are not at home, go into the nearest permanent building. If you are outside and in the downwind area, as advised by the emergency services, at the time of the incident, you may benefit from decontaminating yourself. Taking off your outer layer of clothing can remove up to 90% of radioactive material. If you can, shower using mild soap and shampoo; do not use conditioner, as this may bind contamination to the hair. If you cannot, wash your hands, face, and other exposed body parts at a sink or tap.*
- *As a precautionary measure, everyone within the DEPZ area will be advised to shelter in the initial response stages of a radiation emergency. Sheltering may be necessary for up to 48 hours.*
- *Keep your pets inside if they were not outside at the time of the emergency; those that have been outside should be kept in a separate room or building.*
- *Close all windows and doors to stop radioactive particles from entering the building.*
- *Turn off boilers and air conditioning units and put out fires and wood-burners. Fans, heating systems, boilers, gas fires and air conditioning all draw in air from outside so these should be shut down to minimise radioactive particles entering the building.*

5.6 West Berkshire District Council [2023] notes that, as a precautionary measure, the advice on sheltering will be sent to the entire DEPZ in the initial response stages of a radiation emergency. Thus, this advice could apply to about 7000 households. Meteorological modelling complemented by environmental monitoring will then

be used to confirm where sheltering needs to remain for longer and to identify those, much larger, areas where it is no longer required. Because the advice will be updated during an incident West Berkshire District Council [2023] emphasises the following:

- *Listen to local TV and radio for instructions and updates. During a radiation emergency, advice will be broadcast regularly. This will include the care of children at school, food and water supplies and care of farm animals and pets.*
- *Do not make phone calls by landline or mobile. This is important because the phone system could be overloaded, preventing the emergency services and other responders from receiving or making calls, or from contacting you. You can still call 999 in an emergency.*

- 5.7 It is worth noting that the government advice on the use of sheltering states that *“The health and wellbeing of sheltered populations may be affected by restricted access to medical care or assistance. In such situations, consideration should be given to supervised entry into the sheltered area by medical professionals and carers, or planned evacuation of these vulnerable groups”* [Wellings et al., 2019; Section 5.2.1.1] and earlier advice included *“To a large extent, these adverse effects of the countermeasure [Shelter] are small, particularly if the sheltering period is kept to a few hours...Significant problems can be reduced by advising individuals that short periods out of doors, for necessary activities, will not, in many situations, result in very high exposures. External exposures to people inside a building will not be significantly affected by opening and closing of outside doors, nor will occasional opening and closing of outside doors have a major impact on the radionuclide concentrations in air in the building, and hence on doses by inhalation”* [NRPB, 1990; Page 8, paragraph 8].

5.2 Discouraging Self-evacuation

- 5.8 Also, members of the public are strongly counselled against self-evacuation from the affected area. Section 6.7.2 of JEPU [2022] states that *“The possibility of self-evacuation by members of the public at any time cannot be ignored. The impact of which may cause disruption to the response and may make the situation worse should radioactive particles be resuspended. Case studies show that there is greater risk of accidents during such self-evacuation than a situation of shelter and controlled evacuation if needed. Public Information and local control will be needed to reduce the risk of this taking place.”* Further to this point, West Berkshire Council [2023] states *“Stay where you are. The main risk from AWE is from Alpha radiation, which is why you will be safer to stay where you are rather than travelling around outside; vehicles provide less protection against ionising radiation than houses and other solid buildings. If you try and leave the area, roads could quickly become gridlocked and prevent access for emergency services. By leaving, you could also end up in an area with more radioactive contamination. It is very unlikely that an evacuation would be necessary but if that does happen, details of what to do will be given.”*

5.3 Longer-term Protective Actions, including Evacuation

- 5.9 In the longer-term, protective actions other than sheltering might be initiated. These are set out in Section 6.5 of JEPU [2022]. Specifically, there may be situations in which an urgent evacuation or subsequent evacuation of areas close to the boundary of AWE Burghfield may be necessary. However, such measures would not apply at the application site (see below). The potential requirements for evacuation are set out in Section 6.5 of JEPU [2022]:
- Urgent evacuation, at the direction of the emergency services at the scene, may be required for non-radiological scenarios, e.g. releases of asphyxiating gases, or for persons close to the site boundary in some radiological scenarios, e.g. in respect of very severe accidents or those involving the on-site transport of radioactive materials. It may also be required for care homes, schools, caravan sites, boats (live aboard and pleasure). Also, individual vulnerable clients may require extra support in areas affected and to get this support effectively the individuals may need to be evacuated.
 - Subsequent evacuation, on a timescale of days to weeks, of people taking cover in buildings such as factories, offices and other workplaces, or other buildings that may not be suitable in terms of providing support for the people there for any length of period due to lack of facilities, food and bedding. Such evacuation may also be required as part of the post-accident recovery process, e.g. while decontamination activities are undertaken.
- 5.10 Details of areas potentially requiring urgent or subsequent evacuation are listed in Section 6.7 of JEPU [2022]. Although this information has been redacted in the version of the report supplied, Section 11AA of JEPU [2022] states that “*The closer to the site boundary the greater the risk for the need for urgent evacuation particularly out to approximately 150m with subsequent evacuation needed out to 600m*” (see Figure 2 for the areas that might be affected by urgent or subsequent evacuation). The need for evacuation will depend on the level of projected contamination and of the vulnerability of the community in the area. However, neither urgent nor subsequent evacuation would be required at the application site, even for accidents more extreme than those considered in defining the DEPZ. In this context, it is relevant to note that evacuation is not considered as a protective action in the underpinning Consequences Report [AWE, 2019]. Specifically, AWE [2019] states that “*Overall, the primary concern for early response decision-making to radiation emergencies involving possible accidents at the Burghfield Site only merits consideration of the first-pass inhalation dose and therefore sheltering is the recommended urgent protective action.*”
- 5.11 On evacuation, the guidance provided to the public is that ‘*You should not evacuate unless you are told to do so. Normally, the safest place for you is in a building, which may be for a number of days depending on the situation. However, if you need to be evacuated urgently from the area, you will be told how this will be done and what you need to do by the emergency responders.*’ [West Berkshire Council, 2023].

5.4 Off-site Traffic Movements

- 5.12 A relevant consideration is whether, in the event of an off-site emergency, traffic movements to and from the proposed development could adversely affect access to the AWE Burghfield site, e.g. for emergency services. In this context, it is relevant to note that access routes for emergency services to AWE Burghfield will be in part determined by meteorological conditions at the time of the accident, because it is appropriate to approach from upwind, where possible [Section 3.8 of JEPU, 2022]. However, the proposed development would be so far from AWE Burghfield that there is no possibility that access to that site would be adversely affected. Access to this Phase 2 development would be by the same route as for the already approved Phase 1 development. In the event of a medical emergency at the proposed development, emergency services would be expected to access the development, because the incurred radiation doses would be small and addressing life-threatening medical conditions should and would take priority.

5.5 Monitoring and Decontamination

- 5.13 During and following an accident that resulted in off-site contamination, there would be requirements for monitoring and, possibly, decontamination.⁹ These requirements are likely to relate to contamination of people, animals, pets and property, including gardens, homes and businesses [Section 7.3 of JEPU, 2022]. The decontamination process, if needed, would take place sometime after the initial response phase and normally after the risk of any further contamination from the AWE Burghfield site had stopped. However, in the outer part of the DEPZ, monitoring would be primarily for reassurance purposes and would not be likely to result in decisions to undertake decontamination. This is because the levels of contamination would be so low that annual doses to residents, which would arise mainly from the resuspension of activity, would be initially well below the dose limit for members of the public and would decrease from year-to-year as any plutonium on surfaces was lost (e.g. by leaching) or became less available for resuspension (e.g. by burial in soil).

5.6 Long-term Remediation

- 5.14 The remediation process following an accident large enough to result in significant off-site contamination would involve several phases. The early phase, with a duration of a few days, would involve prompt tie-down of contamination and the recovery of items from the localised area of heaviest (but low-level) contamination. The intermediate phase would involve treatment of the heaviest or most significant contamination over a few weeks, whereas the late phase would last at least several months and would, if necessary, involve reduction of environmental contamination to acceptable levels [Section 9.6 of JEPU, 2022].

⁹ Monitoring by AWE Burghfield would commence immediately using mobile equipment installed in two vans. Within a few hours, this initial resource would be complemented by mobile units from other nuclear licenced sites. In parallel, meteorological modelling would be undertaken. This modelling would be calibrated using local weather station and environmental monitoring data and, in turn, would help to optimise further monitoring.

- 5.15 The approach adopted to remediation would be strongly determined by the extent and nature of the contamination present after a specific accident. However, some options that would be suitable for the type of contamination likely to result from a uranium or plutonium release from AWE Burghfield are given in Section 9.6.1 of [JEPU, 2022]. These are:
- Various tie-down reagents (e.g. water, bitumen emulsion, strippable paints etc.) may be applied to reduce the spread of contamination and reduce re-suspension risks. Selection of the appropriate material and application technique is dependent on many factors (e.g. surface type, weather conditions, coverage required etc.).
 - Non-aggressive decontamination techniques (e.g. vacuum, brushing, hosing etc.) are relatively quick and cheap and generally produce small amounts of controllable waste. These are more applicable in areas where contamination is low level and loosely bound to the surface.
 - Aggressive decontamination techniques (e.g. road planning (*sic*), high-pressure water, grit blasting etc.) may be required in areas where contamination is higher level and fixed to the surface. These are much slower and expensive and can generate large volumes of waste.
- 5.16 Because of the distance of the proposed development from AWE Burghfield, it is extremely unlikely that decontamination would be required. Therefore, in the post-accident phase, the only disturbance to residents in the proposed development might be requests for access to obtain samples of environmental media for laboratory analysis to confirm that any contamination present was of no radiological concern (see also Section 6.6).

6. Acceptability of the Proposed Development

6.1 Introduction

- 6.1 With respect to the acceptability of developments within the DEPZ "...Policy TB04 of the 2014 Wokingham Borough Managing Development Delivery Local Plan (MDD) allows development in the vicinity of the Atomic Weapons Establishment (AWE) at Burghfield but only where the increase in density can be safely accommodated. It states that where it applies:

"Development will only be permitted where the applicant demonstrates that the increase in the number of people living, working, shopping and/or visiting the proposal (including at different times of the day) can be safely accommodated having regard to the needs of "Blue light" services and the emergency off-site plan for the Atomic Weapons Establishment site at Burghfield."

- 6.2 The ways in which the proposed development could impact on the off-site emergency plan relate to warning and informing members of the public, facilitating sheltering, changing requirements for evacuation, addressing the needs of vulnerable individuals, and adversely affecting the access of emergency services to the AWE Burghfield site. In addition, beyond the timeframe of the off-site emergency plan, there are potential impacts relating to the relocation of residents of the proposed development during a period of post-accident monitoring and decontamination. These points are addressed below.

6.2 Warning and Informing

- 6.3 If an accident occurred at AWE Burghfield during daytime, it is probable that some residents of the proposed development would be outdoors at the time of the accident. It is likely that they would respond to the automatic telephone warning or to one of the other methods of warning that would be implemented and would shelter. Because none of these methods requires responders to personally contact the residents, the warning procedure would not require any additional resources, i.e. the activities undertaken by responders would be identical irrespective of whether the development was present, bearing in mind also that the Phase 2 development would be closely integrated with the Phase 1 development that is currently being built out. Furthermore, if the accident occurred during daytime, the assessed effective dose is 1.3 mSv, which is only slightly more than the annual dose limit for a member of the public. Thus, a failure to shelter would be of only minor radiological significance.
- 6.4 If the accident occurred at night under stability category F conditions, the radiological impact on a downwind resident who did not shelter would be somewhat larger at 8.1 mSv. However, residents, particularly children, would be likely to be indoors at night, which would help ensure that the warning message was received in a timely manner and also that only minor actions would be required to achieve effective sheltering, e.g. closing windows and turning off central heating (see paragraph 5.5). Also, because of the low windspeed characteristic of category

F conditions (2 m s^{-1}), it would take about 25 minutes for the contaminated plume to travel from AWE Burghfield to the application site. Allowing for a delay of 15 minutes between accident initiation and implementation of the automatic warning system, this gives residents 10 minutes to shelter or take actions appropriate to improving the sheltering effectiveness of their house.

6.3 Sheltering

- 6.5 The Consequences Report [AWE, 2019] states that this “sheltering” action may be necessary for a period of up to two days (see also [West Berkshire Council, 2023]), or at least until the initial contaminated plume has passed and monitoring of ground contamination has been undertaken to determine the level of groundshine and subsequent potential for further dose uptake (e.g. from contaminated locally produced foodstuffs). If sheltering was required for a period of two days, residential properties would be almost ideal, because all usual facilities would be available¹⁰. However, in practice, sheltering would typically only be required until the contaminated plume had passed. For an explosive event, most of the release of radionuclides would occur within a few minutes, though there might be a continuing passive release at a much lower rate for longer than this. Furthermore, it is known that effective doses from groundshine and resuspension would be only about 1% of the effective dose from inhalation of the plume (paragraph 2.11). As this plume inhalation dose is assessed as 8.1 mSv under category F conditions, groundshine and resuspension would give effective doses of no more than about 0.08 mSv in the aftermath of an accident. Therefore, there should be little need of sheltering after the initial plume had passed, though monitoring of the general area might be undertaken subsequently to provide reassurance that these dose contributions are as small as initially estimated.
- 6.6 A further reason for relaxing sheltering advice after passage of the initial plume is that with limited ventilation, air concentrations of radionuclides within a house arising from resuspension of material that penetrated the structure during the passage of the initial plume could be higher than those in the outdoor air. In these circumstances, increasing ventilation after passage of the initial plume could be effective in reducing longer-term doses [NRPB, 1990].
- 6.7 In summary, sheltering is a short-term voluntary action that could be expected to last no more than a few hours (though up to two days has been suggested) if timely arrangements for relaxing the sheltering guidance are in place. This should not pose significant stress on residents and would not require any actions by responders. The special cases of residents being vulnerable individuals or a medical emergency occurring is addressed below.

¹⁰ The biggest issue for sheltering for more than a few hours is likely to be families that are split up as some were at home, some at work and some at school when the alarm sounded. This provides a strong incentive for relaxing sheltering requirements on this timescale for accidents in which the radiological impact is dominated by the initial release phase.

6.4 Evacuation

- 6.8 As discussed in paragraph 5.11, neither urgent nor subsequent evacuation would be required at the proposed development, even for accidents more extreme than those considered in defining the DEPZ. Specifically, the lower Emergency Reference Level (ERL) for which evacuation should be given consideration is 30 mSv [Nisbet, 2019; Wellings et al., 2019], which may be compared with the effective dose of 8.1 mSv at the proposed development under category F weather conditions.
- 6.9 A further consideration is that the potential available time between receiving a warning and implementing a protective action is about 10 minutes at the proposed development. Implementing evacuation on this timescale (or less for locations closer to AWE Burghfield) would not be feasible. Thus, for unforeseen explosive releases from AWE Burghfield, prompt evacuation is neither an appropriate nor a feasible option to mitigate the effective dose, most of which arises from inhalation of the passing plume. This conclusion is reinforced by noting that evacuation is not mentioned as a response in the Consequences Report [AWE, 2019].

6.5 Vulnerable Individuals

- 6.10 Residents of the proposed development could include vulnerable individuals, who might rely on one or more daily visits by carers. Therefore, the issue arises as to whether carers would have access to such individuals. In this context, it is relevant that government advice on sheltering states that *“The health and wellbeing of sheltered populations may be affected by restricted access to medical care or assistance. In such situations, consideration should be given to supervised entry into the sheltered area by medical professionals and carers, or planned evacuation of these vulnerable groups”* [Wellings et al., 2019] and earlier advice included *“To a large extent, these adverse effects of the countermeasure, Shelter are small, particularly if the sheltering period is kept to a few hours...Significant problems can be reduced by advising individuals that short periods out of doors, for necessary activities, will not, in many situations, result in very high exposures. External exposures to people inside a building will not be significantly affected by opening and closing of outside doors, nor will occasional opening and closing of outside doors have a major impact on the radionuclide concentrations in air in the building, and hence on doses by inhalation.”* [NRPB, 1990].
- 6.11 Because of the low dose rates that would be experienced after the initial plume transit, there should be no issue with carers visiting the proposed development soon after an accident. Furthermore, the emergency services could and should respond to a medical emergency at the proposed development as they would normally. In most accidents, the effective dose incurred by emergency personnel or carers involved in such activities would be less than the principal annual dose limit for members of the public. Whilst it is recognised that carers or other responders might be reluctant to enter a radioactively contaminated area, even if the degree of contamination is extremely low, this is a matter to be addressed as a general requirement in the training of carers and other responders who might be required to enter the DEPZ when the off-site emergency plan had been implemented; and does

not directly impact on the acceptability of the proposed development. The requirement in respect of this Phase 2 development is no different from that arising in relation to Phase 1.

- 6.12 In respect of the availability of emergency medical care during an accident at AWE Burghfield, it is noted that such an accident would initiate the call-in of resources from neighbouring areas. Therefore, the level of emergency care available should not be adversely affected.

6.6 Access to AWE Burghfield

- 6.13 The proposed development is 3.0 km from AWE Burghfield and is not on any direct route to AWE Burghfield, which lies on the opposite side of the A33. Accordingly, there is no possibility of traffic movements to or from the proposed development adversely affecting the access of emergency services to AWE Burghfield. It is also important to recognise that the adoption of sheltering will tend to decrease, rather than increase, traffic movements to and from the proposed development during the initial stages of an accident with significant offsite consequences. Traffic movements from the Phase 1 development, which shares a common access route with Phase 2, would also be decreased.

6.7 Monitoring and Relocation

- 6.14 Plutonium and highly enriched uranium, which are the radioactive materials that could be released in an accident at AWE Burghfield, are difficult to monitor. If it is necessary to detect low concentrations in environmental materials, it is usual to collect samples, separate the plutonium or uranium from them by radiochemical techniques, and then to determine the activity using alpha spectroscopy or Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
- 6.15 The analysis of samples by alpha spectroscopy or ICP-MS is complex and usually undertaken in a laboratory environment remote from the site of sampling. At the sampling site, activities are largely non-intrusive, comprising removal of samples of environmental media (e.g. soil) or wipe tests on impervious surfaces (e.g. glass, metal or polished stonework). Furthermore, wipe tests would only be useful in the short-term because weathering and wash-off processes would tend to remove activity from smooth, impervious surfaces on a timescale of a few days. Therefore, the only disruption to residents would be in granting access for sample taking at those few locations selected for sampling, mainly of soils and vegetation. The proposed development would not increase the number of samples required because the aim would not be to provide a detailed map of contamination, but rather to demonstrate that levels were low over the whole area of interest.
- 6.16 Such monitoring should be considered as complementary to mathematical modelling of the dispersion and deposition of radionuclides released in an accident. This can be done using the Met. Office NAME model (<https://www.metoffice.gov.uk/research/approach/modelling-systems/dispersion-model>). The NAME model can be used either with forecast or archived meteorological data. In this context, it would be used with retrospective time-course

- estimates of the release and archived meteorological data to provide estimates of the spatial pattern of deposition resulting from the accident. These results would provide a basis for focusing actual monitoring. This monitoring should be directed to confirming and refining the dispersion calculations, rather than attempting to provide a detailed map of the spatial pattern of contamination.
- 6.17 In summary, in the area around the proposed development, requirements for monitoring should be limited to the taking of a small number of environmental samples. The need for such sampling would be determined by the distribution of contamination in the environment as calculated by atmospheric dispersion modelling. It is likely that results from the dispersion modelling and limited monitoring would mean that no further monitoring would be required. At the site of the proposed development, it is projected that the dose rates that would arise after the passage of the initial plume would be so low that decontamination of the environment would not be required. Thus, disruption to residents of the proposed development in the period following the initial phase of an accident at AWE Burghfield should be minimal.
- 6.18 Although the very low doses projected to be incurred in the long term strongly suggests that long-term relocation of residents from the proposed development would be inappropriate, it is recognised that they might remain fearful of any residual contamination and wish to relocate irrespective of the tiny risk associated with that residual contamination. This is a consideration for the residents themselves and does not impact upon the responsibilities of the local authority.

7. **Conclusions**

- 7.1 A development is proposed of up to 63 homes on land at Stanbury House, Spencers Wood Shinfield, Wokingham, Berkshire. Until 2019, the application site would have been located about 1.5 km outside the boundary of the DEPZ for AWE Burghfield. However, under REPPiR [2019] a new basis for defining the extent of the DEPZ has been adopted. Based solely on the consequence analysis performed by AWE [2019] on this new basis, the application site lies just inside the UPA that sets a minimum size for the DEPZ. Because the proposed development lies within the expanded DEPZ, its implications for the off-site emergency plan must be addressed.
- 7.2 Because the proposed development would lie close to the limit of the UPA for AWE Burghfield as determined in the consequence analysis [AWE, 2019], the effective dose that might be received by a resident due to an accident at AWE Burghfield is estimated at about 1.3 mSv (which is only slightly more than the limit on annual effective dose to a member of the public from planned exposures and less than the 2.7 mSv annual effective dose received from natural background radiation), or 8.1 mSv under adverse weather conditions. Effective doses of this magnitude are of minor radiological significance and would not justify disruptive mitigation activities. Sheltering alone should be sufficient to decrease the effective dose received to less than about 1 mSv in average daytime meteorological conditions. The proposed development would also be so far from AWE Burghfield that neither immediate nor urgent evacuation would be required, even for extreme accidents; and longer-term relocation is extremely unlikely to be necessary.
- 7.3 Although the construction of additional residential properties in the DEPZ could in principle have an impact on the off-site emergency plan, the discussion in Section 6 of this report demonstrates that because the proposed development is located close to the outer boundary of the UPA, there is no significant impact on responders under the emergency plan; and no adverse impact on the access of emergency services to the AWE Burghfield site.
- 7.4 An important supplementary consideration is whether the proposed development would place an additional burden on first responders and carers in respect of dealing with medical emergencies and addressing the needs of vulnerable individuals. However, in most accident scenarios, sheltering would either not be required at the location of the proposed development (although it would be initially advised for everyone within the DEPZ) or would only be required for a few hours or, at most, two days. Therefore, even if visits were banned during the sheltering phase, this would be only a short hiatus.
- 7.5 Furthermore, the assessed effective doses are so low that visiting (including multiple visits) during the period of sheltering should be acceptable if it was considered necessary for the well-being of a resident. In this context, it would be important to emphasise to carers and other responders that entry into areas with low levels of radioactive contamination would not pose a threat to their health. This is a general aspect of their training and does not have any specific implications for the acceptability of the application proposal.

- 7.6 If residents of the proposed development decided to relocate following an accident at AWE Burghfield, it would primarily be to dispel anxiety and not required to avert effective dose.
- 7.7 Overall, whilst the location of the proposed development within the DEPZ of AWE Burghfield is a material planning consideration, the arguments presented in this report show that it is a consideration that should be given little weight when determining the overall planning balance in respect of the application proposal.
- 7.8 Finally, it is appropriate to consider the proposed development in the context of relevant local Development Plan Policy. As discussed in Section 6.1, in this respect, Policy TB04 of the 2014 Wokingham Borough Managing Development Delivery Local Plan (MDD) deals with development in vicinity of Atomic Weapons Establishment (AWE) Burghfield and states that:

Development will only be permitted where the applicant demonstrates that the increase in the number of people living, working, shopping and/or visiting the proposal (including at different times of the day) can be safely accommodated having regard to the needs of “Blue Light” services, and the emergency off-site plan for the Atomic Weapons Establishment site at Burghfield.

- 7.9 As this report has demonstrated, the application proposal has no material impact on the resources required in the event of implementation of the off-site emergency plan for AWE Burghfield; and can therefore be safely accommodated under that plan having regard to the needs of “Blue Light” services and other parties involved in implementing or responding to that plan. This means that the application proposal complies with MDD Policy TB04. Furthermore, it means that implementation of the proposed development would not have any potential to render the off-site emergency plan inadequate. In turn, this implies that implementation of the proposed development has no potential to adversely impact operations at AWE Aldermaston. This is important, because continued operation of AWE Burghfield is an essential input to maintaining the UK Continuous at Sea Deterrent.
- 7.10 This conclusion is consistent with that reached by the Inspector in a recent Public Inquiry relating to land west of Kingfisher Grove, Three Mile Cross, Reading, Berkshire, RG7 1LZ [Rollings, 2023]. That site, which is located close to the proposed Phase 2 development, lies about 2.8 km from AWE Burghfield, and the proposed development comprised 49 houses. In that context, the Inspector concluded at paragraph 22 of the Decision Letter as follows:

“...I therefore conclude that the proposal would not present a barrier to the ability of blue light services to safely carry out their duties, and nor would it affect the Council’s ability to execute and manage its obligations under the REPPiR plan. Furthermore, people living in or using the appeal site could be safely accommodated. Together, these considerations form the thrust of MDD Policy TB04 and, as such, I find no conflict with this policy. Additionally, the development would not adversely affect the continued operation of the AWE site, and there would be no conflict with the NPPF...”

- 7.11 In reaching this conclusion, the Inspector considered several previous planning decisions relating to AWE Burghfield. His reasons for dissenting from those decisions was set out in paragraph 21 of the Decision Letter, as follows:

“...I have been made aware of other appeal decisions in which siting within the DEPZ have been factors in their dismissal. In each of these cases the evidence was considered by way of written representations. The Inspector in the Diana Close appeal adopted a precautionary approach in the absence of detailed evidence. In comparison, the evidence presented to me in this appeal has been examined and tested. Given its bespoke circumstances, I do not consider that it would result in the creation of a precedent for allowing other development in the DEPZ that in any case must be assessed on its own merit...”

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Appendix A: Atmospheric Dispersion Calculations

A.1 Background

Radionuclides may be released to the atmosphere from stacks or by other controlled routes, or as fugitive releases from buildings or contaminated areas. Routine releases are often quasi-continuous, but they may be highly variable, depending on the nature of the operations that give rise to them. Where stack releases occur, they can be at a higher temperature than the surrounding air and may be associated with a significant amount of vertical momentum. Thus, thermally induced or momentum-driven plume rise may result in the effective height of the release being significantly greater than the height of the stack. However, if a release occurs from or close to a building, it may be entrained in the turbulent airflow downstream of the building and experience immediate dilution and dispersion. In accident conditions that involve fires, as at Chernobyl, the degree of thermally induced plume rise may be several hundred metres or more.

The physicochemical forms of radionuclides released to atmosphere include gases and vapours (e.g. $^{14}\text{CO}_2$, tritiated water, ^{41}Ar and ^{85}Kr), but also liquid and solid aerosols. The sizes of the aerosol droplets and particles range from less than $1\text{ }\mu\text{m}$ up to $10\text{ }\mu\text{m}$ or more. However, as they are transported downwind, the larger droplets and particles are rapidly lost from the plume by gravitational settling. Thus, at distances of more than a few hundred metres from the source, aerosols are typically associated with an Activity Median Aerodynamic Diameter (AMAD) of $1 - 5\text{ }\mu\text{m}$.

Releases from a stack can typically be treated as point releases, with thermal buoyancy and upward momentum being considered by defining the height of the point release to be greater than the height of the stack. The simplest models of dispersion that are routinely used treat the plume as exhibiting a Gaussian profile in both the horizontal and vertical directions. However, they also represent reflection of the plume at the ground surface and at the top of the mixing layer (see Figure A.1 for the parameters characterising a Gaussian plume, neglecting reflection).

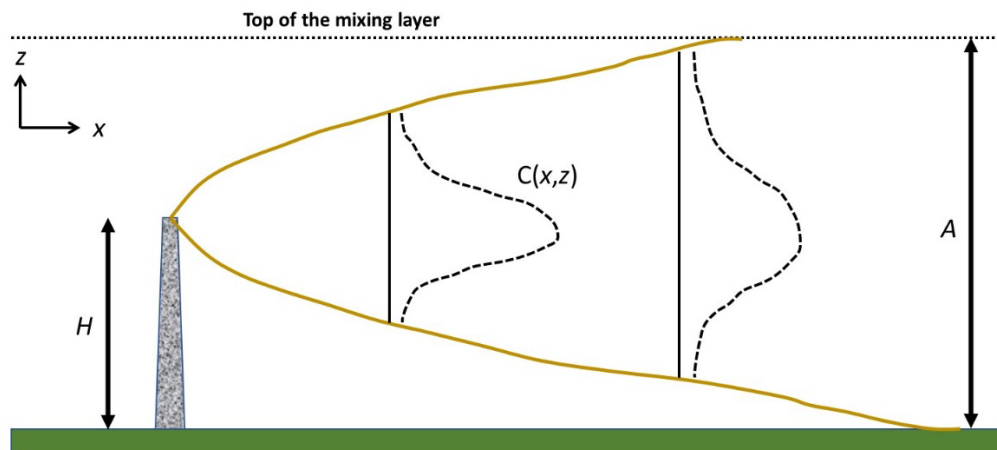


Figure A.1: Vertical Cross-section through a Plume

A.2 Mathematical Form of the Gaussian Plume Model

The usual form adopted [Clarke, 1979] is:

$$C(x, y, z) = \{Q/2\pi u_{10} \sigma_z \sigma_y\} \times \exp[-y^2/2\sigma_y^2] \times F(H, z, A) \quad (\text{Eqn. 1})$$

Where:

$C(x, y, z)$ (Bq m⁻³ or Bq s m⁻³) is the air-concentration or time-integrated air concentration at location x, y, z depending upon how the source strength Q is defined,

Q (Bq s⁻¹ or Bq) is either the release rate or the total release for a pulse release,

u_{10} (m s⁻¹) is the windspeed at a reference height of 10 m above the ground,

σ_z (m) is the degree of dispersion of the plume in the vertical and is a function of the downwind distance x ,

σ_y is the degree of dispersion of the plume in the horizontal perpendicular to the wind direction and is a function of the downwind distance x .

$\exp[-y^2/2\sigma_y^2]$ is the horizontal dispersion with a Gaussian profile being adopted,

$F(H, z, A)$ is the corresponding vertical profile that takes account of reflection of the plume from the ground and the top of the mixing layer.

A suitable form for $F(H, z, A)$ that takes first- and second-order reflections into account is:

$$F(H, z, A) = \exp[-(z-H)^2/2\sigma_z^2] + \exp[-(z+H)^2/2\sigma_z^2] + \exp[-(2A+z+H)^2/2\sigma_z^2] + \exp[-(2A+z-H)^2/2\sigma_z^2] + \exp[-(2A-z+H)^2/2\sigma_z^2] + \exp[-(2A-z-H)^2/2\sigma_z^2] \quad (\text{Eqn. 2})$$

However, at greater distances downwind, uniform vertical dispersion within the mixing layer can be assumed and equation 1 reduces to:

$$C(x, y, z) = \{Q/(2\pi)^{0.5} u_{10} A \sigma_y\} \times \exp[-y^2/2\sigma_y^2] \quad (\text{Eqn. 3})$$

These equations assume a constant, mean wind direction, although some variability about that mean can be accommodated through the specification of σ_y , as discussed below. However, for chronic releases, it is more usual to evaluate average radionuclide concentrations in 30- or 45-degree sectors. This approach replaces equation 1 by:

$$C(x, y, z) = \{Q/(2\pi)^{0.5} \alpha u_{10} \sigma_z\} \times F(H, z, A) \quad (\text{Eqn. 4})$$

Where α (radians) is the angular width of the sector.

Equation 3 simplifies to:

$$C(x, y, z) = Q/\alpha u_{10} A \quad (\text{Eqn. 5})$$

In equation 5, the concentration at downwind distance x (Bq m^{-3}) is simply the release rate divided by the volume of air passing through the outer boundary of the sector at that distance, i.e. the area $x\alpha A$ (m^2) multiplied by the wind velocity u_{10} (m s^{-1}).

In simple assessment calculations, typical values of the wind speed and mixing layer depth are used for various categories of atmospheric stability. The Pasquill stability scheme has often been used and reference values for these parameters for the standard Pasquill stability categories are given in Table A.1 [Clarke, 1979].

Table A.1: Typical Wind Speeds and Mixing Heights for Pasquill Atmospheric Stability Categories [Clarke, 1979]

Stability Category	Typical Wind Speed at 10 m Height (m s^{-1})	Typical Mixing Layer Depth (m)
A	1	1300
B	2	900
C	5	850
D	5	800
E	3	400
F	2	100
G	1	100

The least stable of these categories is A and the most stable is G. Categories C and D are the most common, with the most stable categories (F and G) occurring only at night [Clarke, 1979].

Values of σ_z are often estimated using a function of the form:

$$\sigma_z = (ax^b/1+cx^d) \times F(z_0, x) \quad (\text{Eqn. 6})$$

where a , b , c and d are coefficients that depend on the atmospheric stability category (see Table A.2) and $F(z_0, x)$ is a correction factor that takes account of the roughness of the ground, which, in turn, influences the turbulence of the near-surface atmosphere.

Table A.2: Coefficients Used to Estimate σ_z [Clarke, 1979]

Stability Category	a	b	c	d
A	0.112	1.060	5.38×10^{-4}	0.815
B	0.130	0.950	6.52×10^{-4}	0.750
C	0.112	0.920	9.05×10^{-4}	0.718
D	0.098	0.889	1.35×10^{-3}	0.688
E	0.0609	0.895	1.96×10^{-3}	0.684
F	0.0638	0.783	1.36×10^{-3}	0.672

$F(z_0, x)$ takes two alternative forms depending upon the value of the roughness length (z_0):

$$F(z_0, x) = \ln \{fx^g[1 + (hx^j)^{-1}]\} \quad \text{for } z_0 \geq 0.1 \text{ m} \quad (\text{Eqn. 7a})$$

$$F(z_0, x) = \ln \{fx^g[1 + hx^j]^{-1}\} \quad \text{for } z_0 < 0.1 \text{ m} \quad (\text{Eqn. 7b})$$

Values of the coefficients f , g , h and j are given in Table A.3.

Table A.3: Coefficients for the Roughness Correction Factor {Clarke, 1979}

Roughness Length (m)	f	g	h	j
0.01	1.56	0.0480	6.25×10^{-4}	0.45
0.04	2.02	0.0269	7.76×10^{-4}	0.37
0.1	2.72	0	0	0
0.4	5.16	-0.098	18.6	-0.225
1.0	7.37	-0.0957	4.29×10^3	-0.60
4.0	11.7	-0.128	4.59×10^4	-0.78

Values of z_0 are typically 1×10^{-4} m for the sea, 1×10^{-3} m for sandy desert, 5×10^{-3} m for short grass, 2×10^{-2} m for open grassland, 0.1 to 0.3 m for agricultural areas, 0.5 m for parkland and open suburbia, and 1.0 m for cities and woodlands.

Values of σ_y typically include both a turbulence-related term and a contribution from variations in the wind direction. These are treated as independent. Thus:

$$\sigma_y^2 = \sigma_{y-t}^2 + \sigma_{y-w}^2 \quad (\text{Eqn. 8})$$

The contribution due to variations in wind direction, σ_{y-w} , can be estimated from the standard deviation of horizontal wind directions when averaged over consecutive three-minute periods for the duration of the release. However, if these data are not available, a useful approximation is:

$$\sigma_{y-w} = 0.065 \{7T/u_{10}\}^{0.5} x \quad (\text{Eqn. 9})$$

where T is the release duration in hours.

Assuming that turbulent effects are similar in the horizontal and vertical directions, it is reasonable to approximate that $\sigma_{y-t} = \sigma_z$.

A.3 More Complex Dispersion Models

The basic principles of plume dispersion are appropriately illustrated by the simple model described above. However, more complex models are available for use in appropriate circumstances (e.g. the ADMS 5 software package; <https://www.cerc.co.uk/environmental-software/ADMS-model.html>). For example, the above model can be generalised to a 3D puff model, where the release is treated as a series of pulse releases with dispersion represented along the direction of travel as well as

transverse to it. The effects of changing wind direction can be represented in such a model by altering the direction of travel of each puff as the wind direction changes. Such models can be driven by real meteorological data, which are typically available at hourly or sub-hourly sampling intervals. For large-scale dispersion modelling, releases can be fed into regional-scale models of the atmospheric circulation. These can be retrospective reconstructions based on data from the global network of weather stations or projections made using the type of models adopted in forecasting future weather patterns. An example of such an approach is the NAME model developed by the UK Meteorological Office (<https://www.metoffice.gov.uk/research/approach/modelling-systems/dispersion-model>, see also Jones et al. [2007]).

Where release occurs into the turbulent zone downwind of a building, sometimes known as the building wake, a simple approach can be to treat the release as being at the mid-point of the downstream side of the building and to add in initial contributions to σ_y and σ_z with values of similar magnitude to the width and height of the building, respectively. As in equation 8, these initial contributions can be taken to be independent of the increasing downwind dispersion and added in quadrature. Alternatively, a virtual point source can be adopted located upstream of the actual release location.

In complex environments, e.g. in urban areas, it may be necessary to employ techniques based on a computational fluid dynamics approach or to scale estimates of dispersion based on wind-tunnel measurements of air flows and tracer dispersion using scale models of the environment of interest [Gallacher et al., 2016a; 2016b].

A.4 Deposition

Whatever type of atmospheric dispersion model is adopted, the output comprises a 3D-spatial, time-varying concentration of a radionuclide or other contaminant that can be denoted $C(x, y, z, t)$. This information is directly relevant to assessing the radiological impact of some exposure pathways, e.g. external irradiation from the plume and inhalation. However, other pathways, such as those relating to foodchain transfers, require estimation of the deposition of the contaminant. The main modes are dry and wet deposition. In dry deposition of aerosols, the droplets or particles comprising the aerosol located close to the ground surface interact with the ground and vegetation, e.g. by interception, impaction, gravitational settling and diffusion. In general, it is not possible to model these processes explicitly, so their effect is represented using an empirical deposition velocity, v_d (m s^{-1}). Thus, if the air concentration of a radionuclide at the ground surface is $C(x, y, 0, t)$ Bq m^{-3} , the rate of deposition, $D(x, y, t)$ $\text{Bq m}^{-2} \text{s}^{-1}$ is given by:

$$D(x, y, t) = v_d C(x, y, 0, t) \quad (\text{Eqn. 10})$$

Typical deposition velocities for aerosols are 0.001 to 0.01 m s^{-1} .

In the case of wet deposition, rain or snow is envisaged as falling through the full height of the plume and capturing aerosol droplets or particles as it falls. Therefore, the rate of deposition is given by:

$$D(x, y, t) = \lambda \int_0^A C(x, y, z, t) dz \quad (\text{Eqn. 11})$$

Where the washout coefficient, $\lambda \text{ s}^{-1}$ depend on the rate of precipitation. A typical value is $1 \cdot 10^{-4} \text{ s}^{-1}$.

Both wet and dry deposition deplete the plume of radionuclides and that depletion increases with distance downwind. This can be addressed by computing the degree of depletion as a function of distance and decreasing the source term, Q , in equation 1 by a factor that depends on the downwind distance. Under conditions of heavy rain, much of the activity may be deposited within a few kilometres of the release. Conversely, as illustrated by the Chernobyl accident, a plume with a large amount of thermal buoyancy may travel several thousand kilometres at an elevated altitude before a precipitation event results in high local deposition.

Where deposition occurs in the terrestrial environment, it needs to be partitioned between the vegetation and the underlying soil. This is of specific relevance in agricultural systems. For crops, the initial deposition on the foliage determines the degree of external contamination and provides the source for translocation into internal plant parts. Both external and internal contamination can contribute to the ingestion of activity by humans, with the amounts of activity ingested depending upon the amounts of different plant parts that are consumed, modified by the procedures adopted in food preparation. For pasture, the initial contamination of the foliage provides a source of activity to animals, either through grazing on the pasture or through the subsequent consumption of contaminated hay. In the longer-term, soil contamination provides a long-term reservoir for root uptake by plants, with a timescale determined by the degree of sorption of the radionuclide to the soil and its radioactive half life.

The partitioning of radionuclide dry deposition between plants and soils is generally estimated using the Chamberlain approach. This was originally developed for pasture but was then extended to a wide variety of crop types. The fraction of deposition associated with plants, f_p , is given by:

$$f_p = 1 - \exp(-\mu B) \quad (\text{Eqn. 12})$$

where B ($\text{kg}[\text{dry mass}] \text{ m}^{-2}$) is the above-ground biomass of the crop at the time of deposition and $\mu \text{ m}^2 \text{ kg}[\text{dry mass}]^{-1}$ is an empirical coefficient that is typically ≈ 3 . This form has appropriate behaviour in that, at $\mu B \ll 1$, $f_p \approx \mu B$, whereas at $\mu B \gg 1$, f_p approaches an asymptotic value of 1.0. Some compilations of data for both dry and wet deposition, adopt the small standing biomass approximation and report values of f_p/B .

A disadvantage of basing the approach on above-ground biomass is that it takes no account of foliar morphology. This can be addressed by replacing B by the Leaf Area Index (LAI), here denoted L . The LAI can be envisaged by considering vertical lines originating at the soil surface and upwardly directed through the plant canopy (see Figure A.2). The LAI is the average number of times that such a vertical line intersects the canopy. Thus, for a recently planted crop, where there are substantial areas of bare soil between the plants, the $\text{LAI} \ll 1$. In contrast, for a well-developed canopy with multiple layers of leaves, the $\text{LAI} \gg 1$ (ranging typically up to about 5).

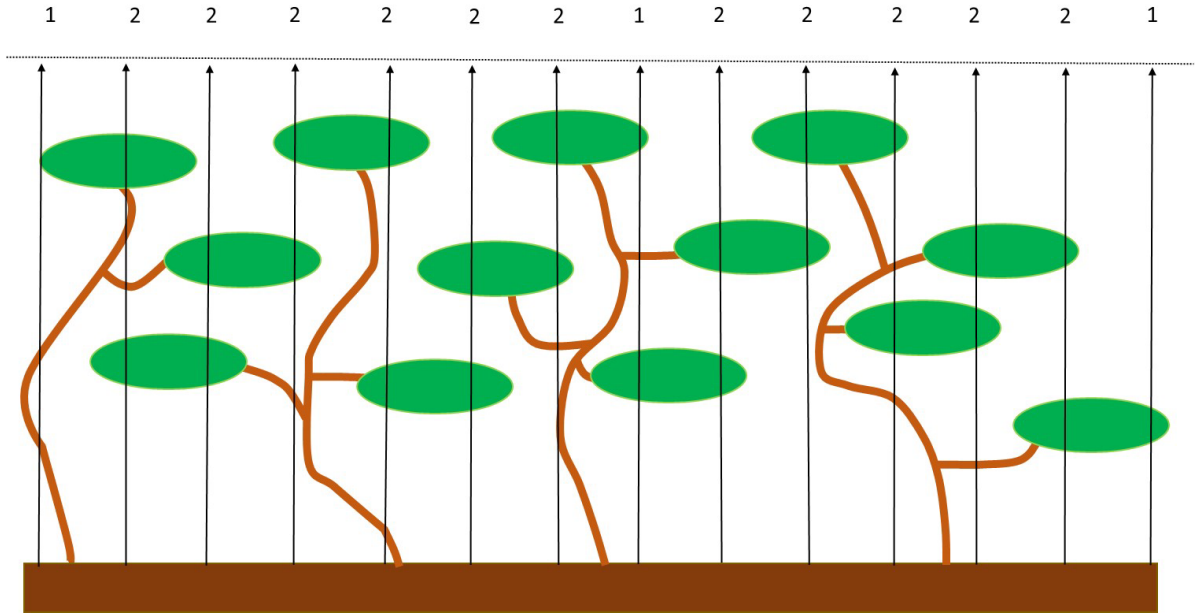


Figure A.2: Calculation of Leaf Area Index (LAI). In this example, the LAI is $25/14 = 1.79$.

In this approach:

$$f_p = 1 - \exp(-\zeta L) \quad (\text{Eqn. 13})$$

where ζ is a dimensionless coefficient of order one.

A.5 Resuspension

Finally, it is relevant to note that after a radionuclide has been deposited from an atmospheric plume, it may be subject to resuspension. Such resuspension can be induced by the wind, or it can be due to human actions, such as ploughing. Resuspension is typically represented using one of two approaches. These are a resuspension-factor-based approach and a mass-loading-based approach.

Following a deposition event at $t = 0$, the resuspension-factor approach estimates resuspension at time t (d) using:

$$R(t) = A \exp(-\lambda t) + B \quad (\text{Eqn. 14})$$

Where $A + B$ (m^{-1}) gives the initial resuspension factor, B is the resuspension factor measured in the long term and λ (d^{-1}) is the rate of decrease in the short-term component. Under European conditions, the value for $A + B$ measured after the Chernobyl accident ranged from 4×10^{-9} to $5 \times 10^{-8} \text{ m}^{-1}$. The initial rate of decrease in the resuspension factor corresponded to a half time of about 200 to 800 d [Thorne, 2012], i.e. the value of λ was in the range 3.5×10^{-3} to $8.7 \times 10^{-4} \text{ d}^{-1}$.

In the mass-loading-approach, the radionuclide concentration is calculated per unit mass of soil or sediment, e.g. as $\text{Bq kg[dry weight]}^{-1}$. This is then combined with an estimate of the dust concentration in air ($\text{kg[dry weight] m}^{-3}$) to give an estimate of the activity concentration in air (Bq m^{-3}) that can be used, for example, to estimate rates of radionuclide intake by inhalation. This approach is of limited usefulness at times soon after a deposition event, because the activity is likely to be present mainly as a thin surface deposit (particularly in urban areas) and it is difficult to define a layer of material in which the activity concentration should be calculated. Hence the resuspension-factor-approach is preferred at early times after deposition and where resuspension from hard surfaces needs to be estimated. However, in rural areas at times long after deposition, or where soil disturbance is involved, the mass-loading approach is preferred.

In applying the mass-loading approach, the main consideration is the concentration of dust in air that should be adopted. This can be estimated by air sampling, keeping in mind that some of the dust will be organic material derived from materials other than soils and sediments, and that some of the mineral dust present will be of distant origin rather than being derived from a local contaminated area. The US NCRP [1999], who provide a detailed account of alternative resuspension models, cite annual average values of 28 and 75 $\mu\text{g m}^{-3}$ for rural and urban conditions, respectively, but cite a value of 15 mg m^{-3} for measurements made behind a tractor. For assessment screening calculations, the NCRP [1999] adopted values in the range 20 to 150 $\mu\text{g m}^{-3}$ depending on the scenario under consideration.

A.6 Model Application in This Assessment

The sectorised Gaussian plume model described above was used to calculate plume atmospheric transport factors at different distances downwind for each of the atmospheric stability classes. Default values were used for the inversion height and windspeed in each stability class and the sector angle was taken as 0.52 radians (30 degrees). The roughness length was taken as 0.3 m. The resultant atmospheric transport factors (s m^{-3}) at 2 m above the ground for a ground-level release are listed in Table A.4. Note that these factors are conditional on the assumptions that the sector lies downwind, and that the stability category applies over the whole period of calculation.

Table A.4: Atmospheric Transport Factors

Downwind Distance (m)	Atmospheric Transport Factor (s m ⁻³)						
	A	B	C	D	E	F	G
100	7.97E-04	5.65E-04	3.00E-04	3.92E-04	9.82E-04	2.03E-03	4.06E-03
200	2.00E-04	1.53E-04	8.35E-05	1.13E-04	2.95E-04	7.08E-04	1.42E-03
300	8.92E-05	7.13E-05	3.95E-05	5.44E-05	1.44E-04	3.66E-04	7.32E-04
400	5.05E-05	4.15E-05	2.32E-05	3.24E-05	8.61E-05	2.27E-04	4.55E-04
500	3.25E-05	2.73E-05	1.54E-05	2.17E-05	5.79E-05	1.57E-04	3.14E-04
600	2.28E-05	1.95E-05	1.10E-05	1.57E-05	4.20E-05	1.16E-04	2.31E-04
700	1.69E-05	1.46E-05	8.34E-06	1.19E-05	3.20E-05	8.95E-05	1.79E-04
800	1.30E-05	1.14E-05	6.54E-06	9.39E-06	2.53E-05	7.17E-05	1.43E-04
1000	8.45E-06	7.55E-06	4.36E-06	6.33E-06	1.72E-05	4.95E-05	9.89E-05
1500	3.90E-06	3.60E-06	2.11E-06	3.11E-06	8.53E-06	2.53E-05	5.07E-05
2000	2.27E-06	2.14E-06	1.26E-06	1.89E-06	5.24E-06	1.58E-05	3.17E-05
2500	1.51E-06	1.43E-06	8.55E-07	1.29E-06	3.60E-06	1.10E-05	2.21E-05
3000	1.08E-06	1.04E-06	6.22E-07	9.46E-07	2.66E-06	8.23E-06	1.65E-05
3500	8.18E-07	7.92E-07	4.77E-07	7.30E-07	2.07E-06	6.44E-06	1.29E-05
4000	6.45E-07	6.27E-07	3.79E-07	5.84E-07	1.67E-06	5.21E-06	1.04E-05
4500	5.24E-07	5.12E-07	3.11E-07	4.81E-07	1.38E-06	4.33E-06	8.67E-06
5000	4.36E-07	4.27E-07	2.60E-07	4.04E-07	1.16E-06	3.68E-06	7.35E-06

Table A.5 shows the ratio of atmospheric transport factors for Category F to Category D. These ratios are approximately 8.7 at the distances of relevance. Therefore, the change in size of the UPA at AWE Burghfield between the REPPiR [2001] and REPPiR [2019] determinations can be entirely explained by the adoption of adverse atmospheric stability conditions that occur for only about 12% of the time and only at night.

Table A.5: Ratios for Atmospheric Transport Factors for Categories D and F

Distance (m)	D	F	Ratio F to D
100	3.92E-04	2.03E-03	5.18
200	1.13E-04	7.08E-04	6.27
300	5.44E-05	3.66E-04	6.73
400	3.24E-05	2.27E-04	7.01
500	2.17E-05	1.57E-04	7.24
600	1.57E-05	1.16E-04	7.39
700	1.19E-05	8.95E-05	7.52
800	9.39E-06	7.17E-05	7.64
1000	6.33E-06	4.95E-05	7.82
1500	3.11E-06	2.53E-05	8.14
2000	1.89E-06	1.58E-05	8.36
2500	1.29E-06	1.10E-05	8.53
3000	9.46E-07	8.23E-06	8.70
3500	7.30E-07	6.44E-06	8.82
4000	5.84E-07	5.21E-06	8.92
4500	4.81E-07	4.33E-06	9.00
5000	4.04E-07	3.68E-06	9.11

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