ONR research project: Defining distances for consultation zones around nuclear sites

A report from Orano Projects Ltd and RAS Ltd to the Office for Nuclear Regulation, via Frazer-Nash Consultancy Ltd

Project Number:	65P.030596.C.02
Orano Reference:	65P.030596-C02-RP-SAFE-0001 Issue 1.1
Other Reference:	ONR Ref RRR-099
Revision Date:	31/03/21
Author:	[redacted]
Security Marking:	Official

Document Approval:

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Date:	31/03/21	31/03/21	31/03/21

Revision History

Issue	Date	Reason for Issue	Author
Issue 1, Draft A	12/01/21	First draft, interim report, for internal reviews	[redacted]
Issue 1, Draft B	14/01/21	First draft interim report to clients (FNC and ONR) for review	[redacted]
Issue 1, Draft C	09/02/21	Second draft for internal review	[redacted]
Issue 1, Draft D	10/02/21	Second draft report to clients (FNC and ONR) for review	[redacted]
Issue 1, Draft E	10-15/03/21	Third draft for internal review	[redacted]
Issue 1, Draft F	16/03/21	Final draft report to clients (FNC and ONR) for review	[redacted]
Issue 1, Draft G	30/03/21	Final draft for internal review	[redacted]
Issue 1	30/03/21	Final issue to FNC and ONR	[redacted]
Issue 1.1	31/03/21	Minor corrections to Issue 1	[redacted]

Distribution List

Name	**Organisation**	**Reason for Issue**
[redacted]	[redacted]	Final issue
[redacted]	[redacted]	Final issue
[redacted]	[redacted]	Final issue
[redacted]	[redacted]	Final issue
[redacted]	[redacted]	Final issue
[redacted]	[redacted]	Final issue
[redacted]	[redacted]	Final issue
[redacted]	[redacted]	Record of submission to clients
[redacted]	[redacted]	Record of submission to clients

Summary

The Office for Nuclear Regulation (ONR) provides advice to planning authorities[1] about certain development applications within consultation zones on and around nuclear sites[2]. This report describes an independent review of ONR's recent proposals for updates to these zones.

Background

Land-use planning decisions can have an impact on the safety of nuclear sites through their potential effects on:

- Emergency planning - risks *from* the nuclear site related to emergency planning. For example, a proposed development may increase the population exposed to risk in the event of an incident at the nuclear site, or require a change to emergency planning arrangements.

and/or on:

- External hazards - risks *to* the nuclear site from hazards arising at or affected by the proposed development. External hazards are those natural or human-induced hazards to a nuclear site and facilities that originate externally to both the site and its processes, such that the site operator may have very little or no control over the initiating event. They include for example fire, toxic release, missiles, electromagnetic interference and flooding.

ONR therefore requests that planning authorities consult them about proposed developments, on and around nuclear sites, that meet certain criteria.

ONR currently has the following consultation zones:

- on the nuclear site: within the site boundary
- the detailed emergency planning zone (DEPZ), if one has been set under the Radiation (Emergency Preparedness and Public Information) Regulations 2019 (REPPIR)
- for certain nuclear sites, a circular outer consultation zone (OCZ), centred on a site reference point, within which ONR considers the potential for the development to impact on the operability and viability of the detailed emergency planning arrangements or to pose external hazards to sites.

ONR reviewed the consultation zones in 2020 with the aims of:

[1] The term 'planning authorities' as used in this report comprises local planning authorities, and – for nationally significant infrastructure projects (NSIPs) – the Planning Inspectorate (PINS) in England and Wales or the Scottish Government in Scotland. Hazardous substances authorities should also consult with ONR in cases where hazardous substances consent is required, but there is no associated planning application.

[2] For the purposes of this report, the term 'nuclear sites' means licensed nuclear sites, authorised nuclear sites and nuclear warship sites.

- making the land-use planning process more consistent and transparent, by providing further clarity as to when planning authorities should consult with ONR
- ensuring that ONR remains targeted and proportionate in the regulatory effort devoted to its consideration of proposed developments.

As a result, ONR proposed to:

- Set OCZs around all nuclear sites. These OCZs would have a minimum radius of 3km (based on external hazard considerations), centred on a site reference point, but some sites would have larger OCZs, based on emergency planning and external hazard considerations.
- Establish a larger zone, of 30km radius around all nuclear sites, for certain types of 'significant developments', due to their potential to pose external hazards, with greater hazard ranges than those considered in setting the 3km minimum OCZs.

Objectives

The overall purpose of this report was to validate the zones and criteria that ONR had proposed. More specifically, the objectives were to:

- carry out an independent review of the proposed 3km OCZ and 30km zone, proposing updates if required
- give guidance on any other developments that should be regarded as 'significant' and hence included in the larger (30km) zone.

Audience

In addition to meeting ONR's objectives as above, this report is intended to give planning authorities additional detail of when to consult with ONR, with an enhanced understanding of the rationale for the defined zones. It may also be useful to emergency planners, nuclear site operators, developers, local communities and other interested parties in the land-use planning process.

Scope

The focus of this report is on validating the proposed 3km minimum OCZ distance and the larger (30km) zone for significant developments, with the emphasis on external hazard considerations rather than emergency planning.

The report is concerned with external hazards that could have an impact in the short term, excluding longer-term potential impacts of developments, such as on climate change or coastal erosion. It also excludes security considerations, i.e. where a development could affect the risk of malicious acts.

Method

This report sets out to answer two top-level questions:

- What types of development can pose external hazards to a nuclear site?

- What are the appropriate consultation zones for such developments? This involved consideration of precedents and benchmarks for setting zones, and hazard range: the maximum distance over which each identified hazard type could affect nuclear site safety.

These tasks involved a combinations of literature review, operational experience and mathematical modelling.

Findings

The review indicated that, within the context of ONR's sampling-based regulatory approach:

- The proposed minimum 3km OCZ is appropriate.
- The proposed 30km zone for significant developments could be reduced to 12km if airports, launch sites, and hydraulic fracturing were moved to a new, special case category, as below. This would leave major hazard facilities, such as chemical plant and major pipelines in the 12km zone. During the review, it was identified that military installations storing munitions should also be considered as within the 12km zone.
- An additional special case category (irrespective of distance from nuclear sites) should be introduced for developments that can have very long-range impacts: airports and launch sites, reservoirs, hydraulic fracturing, military airspace use (e.g. training areas) and military practice, bombing or firing ranges.

Recommendations

Recommendations have been made to ONR relating to:

- Uncertainties in the information, data and models used, and regarding future technological change. The consultation zones, distances and criteria are based on current information and will be reviewed by ONR on a periodic basis. To assist ONR in maintaining a watching brief, the report highlights key uncertainties and areas in which technological change, potentially affecting the nature and scale of external hazards, may be anticipated.
- Details of the future operation of the consultation system. Due to the unlimited distance within which it is suggested that ONR requests consultation about special case developments, there is a potential for ONR to be asked to advise on disproportionately large numbers of applications. Some options for the treatment of this issue are discussed. Options are also described for the detailed determination of whether a development lies within a consultation zone.
- Developments that may occur without consultation. There are cases in which development can occur without planning permission, such that ONR might not be consulted. Examples are identified, to assist ONR in keeping potential gaps under review. A specific instance of this is where an application for hazardous substances consent (HSC) is made to the hazardous substances authority (HSA), but does not also involve a planning application. Although the HSA is usually the local planning authority (LPA), there are exceptions. It is therefore suggested that ONR should ask LPAs to ensure, if they are not themselves the HSA, that the relevant HSA is aware of ONR's request to be consulted.

Abbreviations

ACOP	Approved Code of Practice
ALARP	As low as reasonably practicable
BGS	British Geological Survey
CAA	Civil Aviation Authority
CA	Competent Authority
CCUS	Carbon capture, utilisation and storage
COMAH	Control of Major Accident Hazard (Regulations) 2015
DEPZ	Detailed emergency planning zone
DGHAR	Dangerous Goods in Harbour Areas Regulations 2016
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations 2002
EA	Environment Agency
EGIG	European Gas pipeline Incident data Group
FNC	Frazer-Nash Consultancy Ltd
GSR	General Safety Requirements (of IAEA)
HSA	Hazardous substances authority
HSC	Hazardous substances consent
HSE	Health and Safety Executive
HSR	Hazardous Substances Regulations, i.e. - The Planning (Hazardous Substances) Regulations 2015 - Town and Country Planning (Hazardous Substances) (Scotland) Regulations 2015 - Planning (Hazardous Substances) (Wales) Regulations 2015
IAEA	International Atomic Energy Agency
IGEM	Institution of Gas Engineers and Managers
LFL	Lower flammable limit
LNG	Liquefied natural gas
LPA	Local planning authority
LPG	Liquefied petroleum gas
NLR	Koninklijk Nederlands Lucht- en Ruimtevaartcentrum
NPS	National Policy Statement
NRW	Natural Resources Wales
NSIP	Nationally significant infrastructure project
OCZ	Outer consultation zone
ONR	Office for Nuclear Regulation

OPL	Orano Projects Limited
OPZ	Outline planning zone
PA62	Pipelines Act 1962
PINS	Planning Inspectorate
PSR	Pipelines Safety Regulations 1996
PSZ	Public safety zone
RAS	RAS Ltd
REPPIR	Radiation (Emergency Preparedness and Public Information) Regulations 2019
SAP	Safety assessment principle
SEPA	Scottish Environment Protection Agency
UAV	Unmanned aerial vehicle
UKOPA	United Kingdom Onshore Pipeline Operators' Association
WTG	Wind turbine generator

Contents

1. Introduction

The Office for Nuclear Regulation (ONR) provides advice to planning authorities about certain development applications within consultation zones on and around nuclear sites[3]. ONR has recently proposed updates to these zones. This report describes an independent review of the proposed zones. It is primarily concerned with whether the proposed zones are appropriate in relation to external hazards, i.e. hazards arising from, or affected by, a proposed development that may affect the safety of a nuclear site.

1.1. Background

This section summarises ONR's involvement in land-use planning decisions around existing nuclear sites in Great Britain. Further detail is available at http://www.onr.org.uk/land-use-planning.htm.

Land-use planning and the safety of nuclear sites

Land-use planning decisions can have an impact on the safety of nuclear sites through their potential effects on:

- **Emergency planning** - risks *from* the nuclear site related to emergency planning. For example, a proposed development may increase the population exposed to risk in the event of an incident at the nuclear site, or require a change to emergency planning arrangements, due to effects on transport links.

and/or on:

- **External hazards** - risks *to* the nuclear site from hazards arising at or affected by the proposed development. External hazards are defined in para 228 of the ONR Safety Assessment Principles [1] as 'those natural or man-made hazards to a site and facilities that originate externally to both the site and its processes… ' such that the nuclear site operator may have very little or no control over the initiating event. They include for example fire, toxic release, missiles, electromagnetic interference and flooding.

ONR therefore requests that planning authorities[4] should consult them about proposed developments, on and around nuclear sites, that meet certain criteria.

Current consultation zones

ONR has the following consultation zones:

- On the nuclear site: within the site boundary.
- The detailed emergency planning zone (DEPZ), if one has been set. DEPZs are determined by the local authority in liaison with the site operator, as required under the

[3] For the purposes of this report, the term 'nuclear sites' means licensed nuclear sites, authorised nuclear sites and nuclear warship sites.

[4] The term 'planning authorities' as used in this report comprises local planning authorities, and – for nationally significant infrastructure projects (NSIPs) – the Planning Inspectorate (PINS) in England and Wales or the Scottish Government in Scotland. Hazardous substances authorities should also consult with ONR in cases where HSC is required, but there is no associated planning application – see Section 8.4.

Radiation (Emergency Preparedness and Public Information) Regulations (REPPIR) 2019.

- For certain sites, a circular outer consultation zone (OCZ), centred on a site reference point. The OCZ extends from the DEPZ to a distance determined by the nature of the site. For sites without a DEPZ, the OCZ extends from the site perimeter. ONR asks to be consulted about planning applications within the OCZ in order to gain a view on the potential for the development to impact on the operability and viability of the detailed emergency planning arrangements or to pose external hazards to sites.

ONR's proposed consultation zones

ONR reviewed the consultation zones in 2020 with the aims of:

- making the land-use planning process more consistent and transparent, in particular by providing further clarity as to when it will be appropriate for planning authorities to consult with ONR.
- ensuring that ONR remains targeted and proportionate in the regulatory effort devoted to its consideration of proposed developments.

As a result, ONR proposed to:

- Set OCZs around all nuclear sites. These OCZs would have a minimum radius of 3km, (based on external hazard considerations), centred on a site reference point, but some sites would have larger zones, based on considerations of emergency planning arrangements and an initial assessment of external hazards.
- Establish a larger zone, of 30km radius, for certain types of 'significant development', due to their potential to pose external hazards, with greater hazard ranges than those considered in setting the 3km minimum OCZs.

Table 1 gives additional detail of these proposed zones, showing the minimum distances (radii) within which ONR proposed to request consultation for the various nuclear sites. The proposed minimum OCZ distance (3km) and the larger (30km) zone for significant developments are highlighted in **bold**.

Table 1 ONR's proposed OCZs and larger zone for significant developments

Site Type	Radius
Operating reactor sites	8km
Reactor sites that are not operational but are not de-fuelled	8km
Reactor sites that are de-fuelled (adjacent site[5] included in a National Policy Statement	8km
Reactor sites that are de-fuelled (adjacent site not included in a National Policy Statement)	3km
Sellafield	10km
Dounreay	8km
AWE Aldermaston & AWE Burghfield	5km
All other nuclear sites - minimum distance for consideration of developments, due to their potential to pose an external hazard	**3km**
All nuclear sites, for certain types of 'significant' development, due to their potential to pose an external hazard	**30km**

Consultation criteria

In order to remain targeted and proportionate as a regulator, ONR does not ask to be consulted on all developments, but operates on a sampling basis, looking at those that meet certain criteria.

The criteria that were proposed by ONR are shown in Table 2. As the focus of this report is on the minimum OCZ distance (3km) and the larger 30km zone, and on the criteria that relate to external hazards, these are highlighted in **bold**.

[5] This means that an adjacent site has been designated for a new nuclear power station in a National Policy Statement. ONR proposes a larger OCZ in such cases, in order to ensure that the suitability of the adjacent site is not compromised by development that could adversely affect the safety of a new station.

Table 2: ONR's proposed consultation criteria

Zone	Consultation Criteria
On the nuclear site	Any development.
DEPZ	Any new development, re-use or re-classification of an existing development that could lead to an increase in residential or non-residential populations thus impacting on the off-site emergency plan. Any new development, re-use or re-classification of an existing development that could pose an external hazard to the site. Any re-use or re-classification of an existing development that could introduce vulnerable groups to the DEPZ.
OCZ (minimum 3km radius)	Any new residential development of 200 dwellings or greater. Any re-use or re-classification of an existing development that will lead to a material increase in the size of an existing development (greater than 500 persons). Any new non-residential development that could introduce vulnerable groups to the OCZ. **Any new development, re-use or re-classification of an existing development that could pose an external hazard to the site**
Larger (30km) zone for significant developments	**Major hazard facilities i.e. those within the scope of the Control of Major Accident Hazard Regulations 2015, the Offshore Installations Regulations 2015, the Offshore Installations (Safety Case) Regulations 2005, or the Pipelines Safety Regulations 1996 (PSR).** **Airports or other launch facilities.** **Hydraulic fracturing sites.**

Types of applications

Where the consultation criteria in Table 2 are met, ONR requests consultation about:

- Local and neighbourhood plans that include developments within a DEPZ or OCZ. ONR does not ask to be consulted on such plans within the larger 30km zone, as they are unlikely to cover 'significant developments' as defined by ONR.
- Applications within any of the consultation zones for new developments, or re-use or re-classification of existing developments. Such applications include:
  - applications for planning permission, made to local planning authorities
  - applications for hazardous substances consent (HSC), made to hazardous substances authorities (HSAs). The HSA is usually the local planning authority (LPA)
  - applications for Development Consent Orders for nationally significant infrastructure projects (NSIPs), made to PINS or the Scottish Government

- applications under section 73 of the Town and Country Planning Act 1990. i.e. where an applicant wishes to change specific conditions of a permission, or to carry on development without compliance with one or more conditions
- applications for approval of reserved matters[6] not already notified to ONR at outline matters stage.

1.2. Objectives

The overall purpose of this research report is to validate the zones and criteria that ONR has proposed. More specifically, the objectives are to:

- carry out an independent review of the proposed minimum 3km OCZ and larger (30km) zone, proposing updates if required
- give guidance on any other developments that should be regarded as 'significant' and hence included in the proposed larger (30km) zone.

1.3. Audience

This report is intended to be a supporting document to the information about ONR's land-use planning approach that will be published on the ONR website. In addition to meeting the ONR's research objectives, as above, it is primarily intended for planning authorities, providing additional detail of when to consult with ONR, and an enhanced understanding of the rationale for this. It may also be of use to:

- local authority emergency planners, by clarifying the relationship between zones defined for external hazards and for emergency planning purposes
- operators of nuclear sites, in developing their own procedures for monitoring of and commenting on planning applications that may affect their sites (NB: see 'Uses of the suggested zones' in Section 1.4)
- developers, in understanding ONR's potential interests in planned developments
- local communities and other interested parties in the land-use planning process.

1.4. Scope of review

Focus on generic zones and external hazards

The focus of this review is on:

- the proposed generic minimum OCZ distance (3km) and the larger (30km) zone for significant developments, rather than the site-specific OCZs
- external hazard considerations, rather than emergency planning.

However, the definition of zones needs to be seen in a broader safety and land-use planning context. The review therefore also took account of interfacing factors and considerations such as coherence with emergency planning considerations.

[6] Where outline permission has been granted, an application for the reserved matters, i.e. those excluded from the outline application, can be made.

Hazard types and impact mechanisms

The review aims to consider all types of external hazards that may be relevant. Where possible, it considered how the nature and scale of external hazards may be affected by the future evolution of industries: for example, in relation to the potential growth of the hydrogen economy.

The review took into account that external hazards can affect safety through effects on:

- safety-related plant and equipment, e.g. by impact damage from missiles or by blast overpressure
- supporting services, e.g by disruption to offsite power supplies or blockage of cooling water intakes
- personnel operating the plant, e.g.by incapacitating them or preventing access to the site.

Exclusions: long term and security hazards

The review is concerned with external hazards that could have an impact in the short term. It excludes the longer-term effects that developments may have, for example by driving climate change, or soil and coastal erosion. It also excludes security considerations - i.e. where a development may increase the likelihood of, or facilitate, deliberate malicious acts affecting nuclear sites.

Nuclear site operators, on the other hand, should consider the potential for such impacts from proposed developments, and monitor long-term changes in their environment.

Uses of the suggested zones

It is essential to note that this review is concerned with the definition of consultation zones to assist ONR in its sampling-based approach to regulation, focussing regulatory effort on the areas of greatest risk. **Nuclear site operators must not assume that the consultation zones suggested here are also adequate as limits on their own monitoring of and response to planning applications or on periodic review of external hazards.**

1.5. Report structure

Section 2 gives an overview of the review method.

Section 3 describes the identification of external hazards that could affect a nuclear site and of the development types that can create these hazards.

Section 4 is a review of precedents and benchmarks for setting consultation zones around developments such as those identified in Section 3.

Section 5 presents estimates of hazard ranges: the maximum distances over which the identified external hazards could affect a nuclear site.

The findings from Sections 3, 4 and 5 were synthesised in Section 6, in order to assess the validity of the proposed 3km OCZ and the larger 30km zone, and hence suggest updates where appropriate.

Section 7 summarises the suggested updates to the zones and criteria in the form of key information for planning authorities.

Section 8 discusses topics that go beyond the basic objectives of the review.

Section 9 concludes the review by summarising the key findings and recommendations.

2. Review Method

2.1. Overall approach

In simple terms, the review set out to answer two top-level questions:

1. What types of development can pose external hazards to a nuclear site (Section 3)?
2. What are the appropriate consultation zones for such developments? This involved consideration of:
   - precedents and benchmarks for setting zones (Section 4)
   - hazard range (Section 5): the maximum distance over which each hazard type could affect the safety of a nuclear site.

Figure 1 gives an overview of the tasks and their interrelationships.

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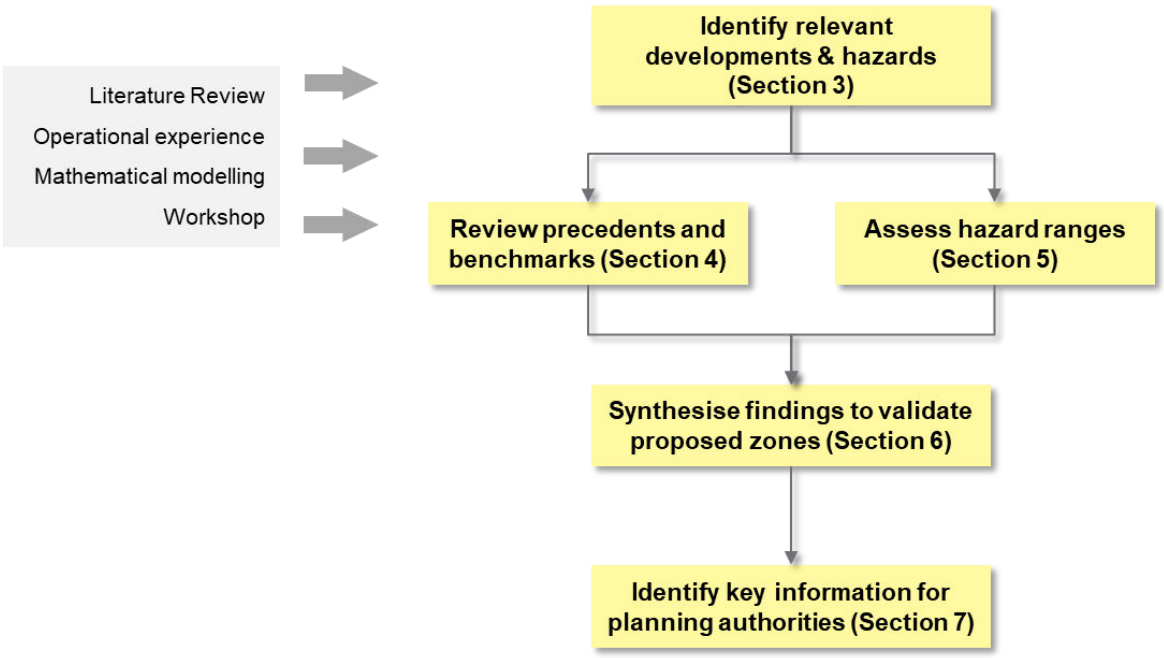

Figure 1 Overall approach

The tasks described in Sections 3, 4 and 5 involved combinations of inputs from:

- literature review
- operational experience from past incidents
- mathematical modelling (predictive consequence assessment) where historical evidence was insufficient
- structured workshop sessions between OPL and RAS.

Sections 2.2 to 2.5 respectively outline the approaches to obtaining these inputs.

2.2. Literature review

The literature review included:

- legislation, government policy and regulatory guidance
- ONR's guidance relating to safety assessment and risk criteria for external hazards:
- public registers relating to hazardous sites (HSC applications)
- incident data: primarily from RAS Ltd's own accident database, which is used to support Control of Major Accident Hazard (COMAH) studies
- published research
- 'grey literature': material produced outside of traditional commercial or academic publishing channels, such as by industry bodies. Examples included information on the size and specifications of wind turbines and views on how new industries, such as carbon capture, may evolve.

2.3. Operational experience

Operational experience was drawn from the consultant team's own experience in work for hazardous industries, industry groups and regulators. Information was also obtained (via ONR) from Health and Safety Executive (HSE) inspectors.

2.4. Mathematical modelling

Some simple Excel spreadsheets were developed to carry out bespoke scoping analyses. An industry standard, proprietary software tool, DNV GL Phast, was used to predict hazard ranges from certain representative releases.

2.5. Workshops

Structured workshop sessions were held within the consultant team to help ensure thorough identification of development types and hazards. Keywords and prompts applied included:

- Use Classes and NSIP categories, as used in land-use planning
- types of hazardous energies (kinetic, thermal, electrical …),
- release pathways (air, water…)

- types of harm (to personnel, to nuclear structures and systems, to supporting services…)

The workshops were also used to facilitate informed judgements where no robust objective evidence, data or predictions were available.

3. Relevant Developments and Hazards

The first substantive step in the review process was to identify, as comprehensively as possible, the external hazards that could potentially affect a nuclear site, and the development types (facilities, installations, activities or industries) that can generate these hazards. These development types will need to be captured in the advice to planning authorities.

3.1. Method

Developments and hazards were identified:

- Top down: by reviewing the legislation and regulatory guidance that define categories of development that can create, or be affected by, external hazards and that set related safety or land-use planning requirements. Key examples of legislation were the Planning Act 2008 and the COMAH Regulations 2015. Guidance documents included the ONR Safety Assessment Principles [1] and Nuclear Safety Technical Assessment Guide on external hazards NS-TAST-GD-013 [2], and the IAEA Safety Guide on human-induced external hazards in site evaluation for nuclear installations [3].
- Bottom up: from the consultant team's experience of specific industries, research and specific accidents / incidents.

3.2. Findings

Table 3 lists the identified development types and shows the main hazards typically associated with each, i.e. those that, for the specific type of development, are likely to have the greatest hazard range. The hazards in Table 3 are illustrative, and by no means exhaustive: they are intended only as a starting point to assist planning authorities in determining whether a development could pose an external hazard to a nuclear site.

The hazards for any specific development, and their relevance to the safety of a given nuclear site, will depend on many factors. The potential for consequential hazards should be also considered - e.g. a fire following an aircraft crash, or flooding due to debris from seismicity blocking a river channel and causing flooding.

Table 3: Development types and example external hazards (non-exhaustive)

As a broad indication of hazards associated with each development type, the following colour coding has been applied:

'Distinctive' hazards which may have the greatest range for the specific development type. For example, many developments could exacerbate flooding hazard, but for otherwise 'innocuous' developments this may be the longest-range hazard.

Other hazards that are likely to occur

Other hazards that are less likely to occur, but not impossible

Development type	Hazards typically associated with each development type (non-exhaustive)								
	Accidental radioactive release (emergency situation)	Missiles (other than from explosion), crashes	Fire, explosion (blast, missile), dust, smoke, toxic releases[7],	Leaks/spills to water (may impact nuclear site intakes/ outfalls)	Induced seismicity, vibration, subsidence	Flooding	Electromagnetic interference	Biological, nanotechnology or other novel hazards	Exacerbation of other hazards e.g. flooding or offsite power loss
Airports /airfields (including arrival/ departure routes, holding patterns)									
Carbon capture and storage									
Energy storage – heat or chemical: e.g. battery, fuel cell, molten salt, hot rock etc									
Energy storage: kinetic or elastic, e.g. flywheel, compressed air									
Explosives sites – manufacture or storage									
Flour mills, sugar refining, saw mills, certain metal operations etc that may create dust									
Hydraulic fracturing for geothermal power or CO_2 injection									
Hydrogen production, use, distribution									
Industrial/research/communication facilities with high electrical demand, voltage or electromagnetic field									

[7] Includes toxicity by any route and including other forms of harm to health such as asphyxiant and corrosive substances. Includes combustion products from fires.

Development type	Hazards typically associated with each development type (non-exhaustive)								
	Accidental radioactive release (emergency situation)	Missiles (other than from explosion), crashes	Fire, explosion (blast, missile), dust, smoke, toxic releases[7],	Leaks/spills to water (may impact nuclear site intakes/ outfalls)	Induced seismicity, vibration, subsidence	Flooding	Electromagnetic interference	Biological, nanotechnology or other novel hazards	Exacerbation of other hazards e.g. flooding or offsite power loss
'Innocuous' development, e.g. housing, education, sports and culture, retail, office, light industry[8]									
Launch sites (e.g. for satellites)									
Launch/ recovery sites for unmanned aerial vehicles (UAVs)									
Major hazard (e.g. COMAH) sites: production, storage or use of hazardous substances									
Manufacturing, warehousing									
Marine works e.g. ports, barrages, flood defences, dredging									
Medical, pharmaceutical, research and development[9]									
Military installations, e.g. munitions stores, airspace use (e.g. training areas) and practice, bombing or firing ranges.									
Mining, quarrying, blasting, oil and gas extraction (other than by hydraulic fracturing)									
(other) Nuclear sites									
Power stations (gas, oil, biomass, waste-to-energy etc)									
Piling, tunnelling, other major construction or demolition									
Pipelines									

[8] Such developments can exacerbate existing hazards such as flooding (by increasing run-off) or loss of off-site power (by increasing demand). They may also be particularly important for emergency planning considerations, challenging the capacity and resilience of emergency arrangements, for example by increasing the population, or by placing additional demand on transport networks.

[9] Novel hazards may be distinctive, but not necessarily have the greatest hazard range: this will depend on the substances and activities involved.

Development type	Hazards typically associated with each development type (non-exhaustive)								
	Accidental radioactive release (emergency situation)	Missiles (other than from explosion), crashes	Fire, explosion (blast, missile), dust, smoke, toxic releases[7],	Leaks/spills to water (may impact nuclear site intakes/ outfalls)	Induced seismicity, vibration, subsidence	Flooding	Electromagnetic interference	Biological, nanotechnology or other novel hazards	Exacerbation of other hazards e.g. flooding or offsite power loss
Reservoirs									
Transport infrastructure, e.g. roads, railways, petrol stations									
Waste sites e.g. tyre dumps, incinerators, waste-to-energy plant									
Wind turbines and wind farms, including balance of plant e.g. onshore substations									

The categorisation of development types in Table 3 is intended to provide simple, readily recognisable descriptions of developments for which planning authorities may receive applications. More formal categories, in terms of the legislation that requires planning permission to be sought, are in Table 5.

4. Precedents/Benchmarks for Consultation Zones

The next step was to identify and review precedents and benchmarks from other industries and contexts for setting safety-related consultation zones around developments. Precedents and benchmarks are potentially important, in that they could either provide support for the proposed zones or challenge them.

Both consultation zones *per se* and other potentially relevant constraints on proximity, such as control or exclusion zones, were considered.

4.1. Method

We identified legislation and planning guidance and practice (see Appendix A) defining constraints intended to protect either hazardous sites, or sites in general, against external hazards arising from (other) hazardous sites. Precedents and benchmarks related to emergency planning were also considered.

Such constraints are designed for a variety of risk management and land-use planning contexts and functions, so their shape and size cannot necessarily be simply 'copied over' to the present context. The constraints on what is reasonably practicable, and the impacts of preventing or constraining otherwise beneficial development or activities will affect the consideration of ALARP (as low as reasonably practicable) issues involved in deciding the size, shape and other criteria for each zone.

We therefore identified, for each potential precedent / benchmark, not just its shape and size, but also context factors, as follows:

- the developments to which the zone applies: these can be defined in terms of type and size, activity, substances handled, quantity of substances etc
- what risk the zone is intended to control, in terms of from what, and to what or whom; zones vary in terms of the things, places and population groups that they are intended to protect and these vary in their vulnerability
- at what stage in the development lifecycle the control is imposed (e.g. planning or operation), i.e. whether the constraint is placed on proposed or existing developments
- the role of the zone in the wider land-use planning and safety regulatory process, for example does it define an absolute limit, or is it only a screening criterion within which further consultation or assessment would be required
- which parties (developer, operator, planning authority, regulator etc) are involved and what are the duties on each - e.g. to consult, to respond to consultation, to keep operations within certain limits, to make decisions etc.
- the risk management approach underlying the zone: for example whether it is risk-based (taking account of both the likelihood and consequences of events, or based only on consequences).

4.2. Findings

The detailed findings of the review of precedents and benchmarks are presented in Appendix B. The only examples identified of zones designed to protect one type of hazardous development against external hazards were in relation to:

- COMAH sites. Under Reg 24 of COMAH, competent authorities (CAs) must identify groups of sites ('domino groups') for which an accident at one may affect another. The CA and site duty holders must share information and co-operate in such cases. Domino groups are identified by HSE, using their consultation zones, so there would be no additional information on distances to be gathered by identifying where domino groups are established. The subsequent information sharing and any resulting actions will be highly specific to the sites, their locations, inventories, event scenarios and frequencies, and their vulnerabilities, so it would not be practicable to attempt to extract experience that could be applied to nuclear site consultation zones.
- The IAEA Safety Guide on human-induced external hazards in site evaluation [3] (an update to which was in draft at the time of writing, March 2021) gives screening distance values for use in siting new nuclear installations, and for nuclear site operators to use in reviewing external hazards.
- Airport safeguarding. Various limitation and consultation zones are defined around airports in relation to developments that may affect the safety of aircraft, such as sites that attract birds, tall structures that present obstacles, and wind turbines in terms of potential interference with radar. However, none of the associated hazards to aircraft are relevant to nuclear sites.

Zones designed to protect sites in general from hazards arising at a hazardous development were identified in relation to hazardous substances and explosives. As detailed in Appendix B, consultation or separation distances of approximately 2km are defined in guidance/ regulations relating to explosives and hazardous substances. This provides some assurance that the proposed 3km OCZ (and larger 30km zone) are, in a broad sense, large enough.

In all of these precedent/ benchmark cases, the context factors are quite different from that of regulatory consultation on proposed developments around nuclear sites. The validation of zone distances was therefore based more on considerations of hazard range (Section 5 following) than on precedents.

The key documents considered in reviewing precedents and benchmarks related to emergency planning were the REPPIR Regulations and Approved Code of Practice (ACOP), the IAEA General Safety Requirements (GSR) on radiological emergencies [4] and the HERCA-WENRA approach [5].

Under the REPPIR Regulations, the key emergency planning zones that may be defined around a nuclear site are a detailed emergency planning zone (DEPZ) and (for extremely unlikely but more severe events) a larger, outline planning zone.

It was concluded that, because of their very different purposes and contexts, the definitions (shape, size and other criteria) for emergency planning zones did not usefully inform the setting of the 3km OCZ or larger (30km) zone. There is no strong argument for these external hazard consultation zones to be more closely aligned with REPPIR emergency planning zones, even though this could potentially simplify the system by reducing the number of zones in use.

5. Hazard Ranges

This section presents and reviews estimates of hazard ranges: the maximum distances over which external hazards from the developments identified in Table 3 could affect the safety of a nuclear site.

5.1. Method

The review primarily considered hazard ranges, i.e. maximum possible distances, rather than trying to develop risk-based distances taking account of the likelihood (probability or frequency) of a hazardous event actually impacting the safety of a nuclear site.

The advantages of the hazard range approach are that:

- It is conservative, maximising the confidence that ONR will be consulted on developments that may affect the safety of nuclear sites. While it is possible that this could lead to disproportionate regulatory effort being given to developments that are so far away as to have negligible probability of affecting the nuclear site, ONR can take likelihood considerations into account once notified of an application.
- It is simpler, in that a risk-based approach would require additional data, models and assumptions. In many cases, very little information is available on such aspects.

However, the hazard range approach has the disadvantage that the probability distributions of hazard effect distances do not generally have a hard cut-off, so it is not usually possible to define a clear limit to a range. More often, there will be a long tail of low probability, high-consequence events. Even if there were some absolute physical limits on pathways (i.e. post-release propagation of a hazard), the range may still depend on assumptions about the source or receptor. For example, the distance over which a toxic plume could incapacitate nuclear site personnel will depend on the assumed inventory, and on assumptions about the vulnerability of those exposed.

Some uncertainty and subjective judgement are therefore inevitable even in an approach based on hazard ranges. We have tried to be transparent about such judgements.

The hazard ranges were derived from a combination of:

- literature review and operational experience, including historical evidence from real events and experience from HSE inspectors obtained via ONR. It should be noted that accident reports are often unclear about longer range impacts – the focus is naturally on the most severe consequences, which tend to be on or close to the site where the hazard arose
- mathematical modelling: scoping estimates.
- structured judgement in workshop sessions.

Where information was available, we have documented not just the hazard range estimates, but also an outline of the assumptions on which they are based, their variability and the key uncertainties.

5.2. Findings

The hazard range findings are collated in Appendix C. The key findings were that:

- for most developments, the hazard range would not exceed 3km
- for major hazard facilities (e.g. COMAH sites, major pipelines), the hazard range would not exceed 12km
- some developments can have very long-range impacts, beyond 12km (and beyond ONR's originally proposed 30km zone). For airports and launch sites, this is because crash risk contours follow the flight paths, and hence have elongated, site-specific, shapes. For reservoirs, in the event of a dam collapse, flooding will propagate along the downstream river valley and so, depending on topography, can extend for tens of kilometres. For hydraulic fracturing, impacts from induced seismicity beyond 12km cannot be ruled out. For military airspace use (e.g. training areas) and military practice, bombing or firing ranges, impacts beyond 12km cannot be ruled out.

There are uncertainties in the information, data and models on which these findings were based, and the hazards associated with the various development types vary greatly in nature and scale. Details of these uncertainties, and of assumptions made, are given in Appendix C, but some key examples that limit the validity of the analysis in this review are:

- assumptions about the scale of hazard events at proposed developments; depending on for example the assumed maximum inventory of LNG (Appendix D1), the maximum

blade tip speed for wind turbines (120m/s) and the maximum pipeline pressure (100 bar)

- uncertainty in what technologies will be used, and at what scale, for new and emerging industry sectors, such as the hydrogen economy, energy storage and carbon capture and storage
- uncertainty in the extent to which induced seismicity may occur from mining, quarrying and geothermal developments.

To ensure that these and other assumptions and uncertainties are clearly captured, a watch list of development types and other factors that ONR should monitor is included with the recommendations in Section 8.6.

6. Validation and Update of Proposed Zones

This section draws together the findings of Sections 3, 4 and 5 in order to assess the validity of the proposed 3km OCZ and larger 30km zone and suggest updates where appropriate.

In summary, the review indicates that:

- the proposed minimum 3km OCZ is appropriate
- the proposed larger 30km zone for significant developments (major hazard facilities, airports and launch facilities, and hydraulic fracturing sites) could be reduced to 12km if airports, launch sites, and hydraulic fracturing are moved to the new, special case category outlined in the next bullet point
- an additional special case category should be introduced for developments that can have very long-range impacts: airports and launch sites, reservoirs and hydraulic fracturing. Military airspace use (e.g. training areas) and military practice, bombing or firing ranges should also be in this category.

Sections 6.1 to 6.3 following expand on these findings for the minimum (3km) OCZ, the 12km zone and the special cases respectively.

6.1. Minimum (3km) OCZ

For developments other than those listed in Sections 6.2 and 6.3, all precedents and hazard ranges identified indicate that the proposed 3km OCZ is sufficient.

6.2. Significant developments zone – reduce 30km to 12km

ONR had proposed that major hazard facilities, airports and launch facilities, and hydraulic fracturing sites were the ‘significant developments’ that should be included in the 30km zone.

The review found that some **major hazard facilities** can have hazard ranges of more than 3km. Scoping modelling (Appendix D) indicated that a reasonable bounding case may be set by the largest liquefied natural gas (LNG) storage facilities, for which a range of 12km was estimated. It is therefore suggested that all such sites should remain in the ‘significant development’ category, but that the zone radius should be reduced from 30km to 12km.

Airports, launch sites, and hydraulic fracturing should be moved to the new, special case category described in the next Section.

This would leave major hazard sites, pipelines subject to the Pipelines Safety Regulations 1996 in the 12km zone.

During the review, it was identified that military installations storing munitions should also be considered within the 12km zone as these facilities could have hazard ranges of more than 3km.

6.3. Special cases

A new category of special cases is suggested for developments, as outlined below, that have the potential for very long-range impacts, beyond 12km.

In principle, these very large hazard ranges necessitate equally large consultation zones, so there is a potential for ONR to have to advise on very high numbers of applications. To avoid this becoming unduly onerous, we have where possible aimed to set some limits on exactly which developments within the special case categories require consultation. Some options for the treatment of special cases, in terms of setting zones or other processes, are identified and briefly evaluated in Section 8.2.

Despite these efforts, there remains considerable uncertainty in setting limits, and in the numbers of applications that ONR may be asked about in practice. It is therefore recommended that ONR considers the special cases further.

Airports and launch sites

It is suggested that airports (including civil airports and military airports and airfields) and launch sites should be moved to the special case category, as levels of crash risk that could need further consideration can extend for tens of kilometres from the site, underneath flight paths.

Beneath the arrival and departure routes of the busiest airports, airport-related crash risk may be at levels above background beyond 30km, with individual fatality risk levels around 10^{-6} or 10^{-7} per year. These levels are used in the Netherlands to define development restriction zones [6] and so may also be relevant in terms of risk to nuclear sites or personnel operating them. Details are presented in Appendix E.

The level of aircraft crash risk at a given nuclear site will depend on many factors, such as the frequency of aircraft movements, aircraft types and sizes, the nature of aircraft operations (passenger, cargo, military etc), distance from the site and the orientation of the runway(s) and flight paths. It is not straightforward, therefore, to make even a preliminary, screening assessment to establish the nature or scale of airport-related developments for which ONR should request consultation.

At one extreme, some airport developments may clearly have no significant impact on the factors that affect crash risk – for example an application for an office building. At the other extreme, an application for an additional runway, or to relax an existing planning limit on aircraft movements, would clearly merit some consideration. In between, applications for

developments such as improved terminal facilities, public transport interchanges or additional car parking may enable an increase in air traffic.

Some information could potentially have been inferred from the public safety zones (PSZs) that have been established and published for major airports, as these have to date been based on modelled crash risk contours. However, the Civil Aviation Authority (CAA) has recently consulted on the technical basis and administration of the PSZ system and may move to a less explicitly risk-based system. Planning applications for airport development rarely present risk contours.

So, in the absence of clear mechanisms for setting explicitly risk-based criteria, it is suggested that the consultation criteria could be worded as follows:

"Airport developments that:

(a) qualify as NSIPs under the Planning Act 2018 or

(b) would enable a material increase in the number of aircraft movements; or material changes in aircraft types and sizes, in the nature of aircraft operations (passenger, cargo, military etc), in the number and orientation of runways, or in flight paths"

No usable information was found on risks from launch sites. Conservatively, it is suggested that they should also be placed in the special case category.

Hydraulic fracturing industries

The current UK moratorium on hydraulic fracturing for shale gas means that further developments are now frozen. ONR should nevertheless maintain a watching brief in case the government's position changes.

However, similar hydraulic fracturing operations are or may be used for purposes other than gas extraction, such as geothermal power and CO_2 injection. There is the potential for these industries to induce seismicity that could have impacts beyond 12km.

Reservoirs – dam collapse

It is suggested that reservoirs should also be treated as special cases. Environment Agency (EA) flood risk mapping (Appendix F) shows that, in the event of dam collapse, significant flooding can propagate along the watercourses below the dam for distances beyond 30km.

This would apply for reservoirs with a maximum impounded capacity of 25,000m^3 (25 Ml) or more, this being the threshold at which, in England, registration with the EA is required. Note however that reservoir safety requirements are complex, and this is a devolved matter, with differences between England, Scotland and Wales. The thresholds and requirements should therefore be kept under review.

Military airspace use and ranges

Military airspace use (e.g. training areas) and military practice, bombing or firing ranges are also suggested to be in the special case category.

7. Key information for Planning Authorities

This Section presents the suggested updates to the zones and criteria in the form of key information for planning authorities.

Section 7.1 presents the suggested updated zones.

Section 7.2 gives an alternative presentation of the key outputs, in terms of the legislation that should trigger a planning application for the various development types, together with the suggested consultation zones.

7.1. Updated consultation zones

Table 4 summarises the suggested updated zones. Where a development could fall within more than one category, the category with the largest range should be used. For example, manufacturing sites are assigned to the 3km zone, but if such a site was also a major hazard facility under COMAH it should be in the 12km zone.

Table 4: Suggested updated zones

Zone	Risks the zone aims to control	Consultation Criteria	Comments	Change from existing zones
OCZ (3km minimum or as defined by ONR for specific nuclear sites)	Emergency planning and external hazards	Any new residential development of 200 dwellings or greater Any re-use or re-classification of an existing development that will lead to a material increase in the size of an existing development (greater than 500 persons) Any new non-residential development that could introduce vulnerable groups to the OCZ. Any new development, re-use or re-classification of an existing development that could pose an external hazard to the site.	Table 3 gives non-exhaustive examples of developments that can pose external hazards	All nuclear sites would have OCZs (only some do at present).
12km zone	External hazards from significant developments	Major hazard facilities, i.e. those within the scope of the Control of Major Accident Hazard Regulations 2015, the Offshore Installations Regulations 2015, the Offshore Installations (Safety Case) Regulations 2005, or the Pipelines Safety Regulations 1996. Military installations storing munitions.	For COMAH sites, consultation with ONR can be triggered by a planning application to the planning authority, or by an application for HSC consent to the HSA. See comments in Table 5 and Section 8.4	New zone (originally proposed as 30km by ONR)

Zone	Risks the zone aims to control	Consultation Criteria	Comments	Change from existing zones
Special Cases	External hazards from developments with potentially very large hazard ranges	Airport developments (including civil airports and military airports and airfields) that: (a) qualify as NSIPs under the Planning Act 2018 or (b) would enable a material increase in the number of aircraft movements; or a material change in aircraft types and sizes, the nature of aircraft operations (passenger, cargo, military etc), the number and orientation of runways, or in flight paths. Launch sites. Hydraulic fracturing sites. Reservoirs with a maximum impounded capacity of 25,000m^3 or more. Military airspace use (e.g. training areas) and military practice, bombing or firing ranges.		New zone, irrespective of distance from nuclear sites

7.2. Legislation initiating planning applications

Table 5 gives an alternative presentation of the key findings, showing the legislation that can trigger planning applications, the development types covered by this legislation, and the suggested consultation zones for each development type.

Table 5: Development categories and zones, by legislation initiating the application

Application made under (legislation)	Development type	Examples (non-exhaustive) and comments	Zone
• Planning (Hazardous Substances) Regulations 2015 • Town and Country Planning (Hazardous Substances) (Scotland) Regulations 2015 • Planning (Hazardous Substances) (Wales) Regulations 2015. *Collectively, these Regulations are abbreviated as the 'HSRs' in this report*	Major hazard sites	Chemical plant, fuel or fertiliser stores. For COMAH sites, consultation with ONR can be triggered by different routes: • A planning application for a major hazard development, which the planning authority recognises as appropriate for consultation with ONR. • An application for HSC, made to the HSA as required under the HSRs . (COMAH itself does not require the application). This consent is required irrespective of any consideration of hazards in a planning application. • An application for HSC is also required even if planning permission is not required (e.g. where a change in substances or quantities stored is proposed without any change to the infrastructure). In all cases, therefore, either the planning authority or the HSA should become aware of applications relating to any major hazard facilities about which ONR would wish to be consulted. NB: the HSA will usually be the LPA, but there are exceptions – see Section 8.4	12km
Pipelines Safety Regulations 1996[10]	Pipelines within the scope of the Pipelines Safety Regulations 1996	Pipelines for natural gas, hydrogen, CO_2 etc.	12km

[10] Most large onshore pipeline projects require an assessment to be carried out to identify the likely impacts on the environment, to determine the significance of those impacts and to establish mechanisms to minimise any adverse impact. The Electricity and Pipeline Works (Assessment of Environmental Effects) Regulations 1990 apply to cross-country pipelines as defined under the Pipelines Act 1962 (PA62) and detail the procedures to be followed when considering the need for an environmental statement to accompany an application for a pipeline construction authorisation from the Secretary of State for Trade and Industry. The Town and Country Planning (Assessment of Environmental Effects) Regulations 1988 apply to PA62 local pipelines. These do not need HSC like COMAH sites, but there is a requirement to notify the HSE rather than the local authority.

Application made under (legislation)	Development type	Examples (non-exhaustive) and comments	Zone
Planning Act 2008[11] (sections 15-19)	NSIPs – Energy: 15.Generating stations 16.Electric lines 17.Underground gas storage facilities 18.LNG facilities 19.Gas reception facilities	'Generating stations' includes wind farms and wind turbines. Onshore facilities associated with offshore wind farms – e.g. substations, should also be considered	3km
Planning Act 2008 (sections 20-21) (and Pipelines Safety Regulations 1996 as above)	20.Gas transporter pipelines 21.Other pipelines	Pipelines	12km
Planning Act 2008 (sections 22-26)	NSIPs – Transport 22.Highways 23.Airports – see also below 24.Harbour facilities 25.Railways 26.Rail freight interchanges	In relation to handling, storage or transport of dangerous goods such as fuels or fertilisers.	3km
Planning Act 2008 (section 23)	NSIPs – Transport: 23.Airports	In relation to aircraft crash. Include consideration of arrival/ departure routes and holding patterns. Planning authority should be consulted in accordance with CAA CAP 1616 Airspace Change [7]	Special case
Planning Act 2008 (section 27)	NSIPs - Water 27.Dams and reservoirs		Special case
Planning Act 2008 (sections 28 – 28A)	28.Transfer of water resources 28A.Desalination plants		3km

[11] In Wales, the Planning (Wales) Act 2015. Under this Act, developments of national significance are defined in regulations or within the National Development Framework.

Application made under (legislation)	Development type	Examples (non-exhaustive) and comments	Zone
Planning Act 2008 (section 29)	NSIPs - Waste water 29.Waste water treatment plants		3km
Planning Act 2008 (section 29)	Waste 30.Hazardous waste facilities 30A.Radioactive waste geological disposal facilities	Applications for radioactive waste geological disposal facilities should also be notified to ONR in any case under other legislation.	3km
Town and Country Planning Act 1990 (as amended) Town and Country Planning (Scotland) Act 1997	Launch sites (e.g. for satellites or UAVs)		Special case
	Other developments that may pose external hazards. NB some of these developments are potentially NSIPs, depending on scale and other factors. If so, use the zone set for the relevant NSIP type.	See Table 3	3km

Note: other legislation requires contact with local planning authorities (and authorisation by other bodies), but does not itself require planning permission:

- The Explosives Regulations 2014 do not require planning application as such, but explosives sites are required to submit a safeguarding plan to the relevant licensing authority (HSE, Police or local authority) and to the local planning authority within 28 days of a licence being granted, or varied in a way that affects the separation distances.
- The Dangerous Goods in Harbour Areas Regulations 2016 (DGHAR) and ACOP. Carrying or handling explosives in a harbour area is prohibited unless a licence (from HSE or ONR) is in place. The emergency plan must be prepared in consultation with the appropriate emergency services, such as the local authority emergency planning officer.

8. Discussion

This section identifies some discussion points that go beyond the basic questions of whether the proposed zone distances are appropriate and what developments should be classed as 'significant'.

8.1. Consultation zone shape and position

Except for the special cases of airports, launch sites and reservoirs, for which the hazard ranges have elongated, irregular and site-specific shapes, there seems no strong reason against adopting a simple circular zone shape. In principle this could be adjusted to take account of asymmetric factors, such as the wind rose, but this would introduce additional complexity and data requirements. Consultation zones are a screening tool, and a circle whose radius is that for the worst case (e.g. wind blowing the toxic release directly toward the nuclear site) is in keeping with the conservative approach appropriate to screening.

As proposed by ONR, centring the circle on a reference point within the nuclear site, defined by ONR in liaison with the licensee and taking account of site-specific factors, seems most appropriate, and consistent with the approach to emergency planning in REPPIR. The zones have been defined with sufficient margin to ensure that the required distance is maintained from any relevant features within the site.

An alternative approach would be to define zones by a fixed distance from the nuclear site boundary. However, this is more complex to draft, and the resulting shape may be no more representative of the true risk, which is a function of both the vulnerability of the various site features to external hazards, and the potential for escalation of consequences if they are impacted.

In determining whether a proposed development lies within a consultation zone, it is suggested that, by default, the distance from the nuclear site reference point should be measured to the nearest point of the application site boundary. In other words, a development should considered as within a zone if any part of it lies within the zone. This will be particularly important for large sites. ONR may, however, wish to consider whether to ask planning authorities to make a judgement in cases where only 'innocuous' elements of the development, such as landscaping or open space, lie within the zone.

8.2. Treatment of special cases

As noted in Section 6.3, due to the unlimited consultation distance suggested for special case developments, there is a potential for ONR to have to advise on disproportionately large numbers of applications. Some options for the treatment of special cases, in terms of setting zones or other processes, have been identified. These are listed and briefly evaluated below, broadly in decreasing order of the extent to which ONR would need to be involved.

1. The option suggested in this report is to set an effectively unlimited zone, i.e. ask to be consulted on *all* special case applications, irrespective of distance from any nuclear sites. Applications for new or significantly expanded airports, launch sites, developments involving hydraulic fracturing, reservoirs, military airspace use (e.g. training areas) and military practice, bombing or firing ranges are unusual, such that the burden may not be that great.

2. Set a zone larger than 12km for all significant developments, to include the special cases. This would, however, be disproportionate for the other types of significant development.
3. Set an additional, larger zone specifically for the special cases. This would have the advantage of setting some limit, but it would be difficult to derive a justifiable value, given the highly site-specific nature of the hazard ranges.
4. Rely instead on other mechanisms within the planning process. Airports and reservoirs (above certain sizes) are both nationally significant infrastructure projects (NSIPs) under the Planning Act 2008. As such they are covered by national policy statements (NPSs)[12], which require thorough consultation with interested parties (although ONR is not explicitly listed as a consultee[13]). With regard to aircraft arrival / departure routes (which determine the risk contours around airports) significant changes in these (but not just traffic growth) should be subject to the CAA's Airspace Change process [7], which again requires wide consultation. If ONR could be sufficiently confident that these national mechanisms would alert them to applications for special cases, and provided that the limitations of the consultation zone approach are clear to all parties, it may be unnecessary to define an additional or larger OCZ. Hydraulic fracturing as an activity in itself is not a NSIP, however.

It is recommended that ONR should consider the options above and keep special cases on the 'watch list' for review as experience is gained with the updated consultation system.

8.3. Developments that may occur without consultation

There are some cases in which development, potentially with safety implications, can occur without planning permission, and therefore 'fall through the gaps' of the consultation system. This can occur for example:

- Where there are permitted development rights, deemed consents or historical rights.
- For sites regulated under other processes, e.g. sites subject to the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) or the Explosives Act 2014, for which certain changes may not require planning permission
- For certain bodies or sites, such as Crown lands and defence sites. In general, planning law applies to the Ministry of Defence (MoD) in the same way as to other applicants, and the legislation applicable to the military, together with MoD policies and procedures, is intended to provide an equivalent level of safety to the civil legislation. However, there are some differences. For example, military establishments are exempt from hazardous substance consent requirements under the HSRs (https://www.gov.uk/guidance/hazardous-substances#Exceptions-from-hazardous-substances-consent). There may also be restrictions on information sharing, in the interests of security.

[12] The existing Airports NPS (2018) has been extensively challenged, including in the courts, mainly on climate change grounds, and may well change significantly. Also, it was focussed on decision-making on development consent applications for an additional runway at Heathrow, rather than on airport development in general. Nevertheless, the requirement for wide consultation seems to be a constant in all the NPSs.

[13] There are NPSs covering many of the types of development of interest - see list in Appendix A.

- For launch sites for UAVs. The regulation of UAVs is emerging and there will not necessarily be any planning or aviation legislation that would trigger a planning application.

There is also a potential for developments to be missed due to transboundary issues between planning authorities and/or between the UK nations, especially for pipelines that cross boundaries, or developments close to a border. It needs to be clear which authority is responsible for consulting with ONR. Experience is that the applicant discusses with the relevant authorities, who will between them decide which will take responsibility for the application.

8.4. Communication with planning authorities

The reference to this report from the ONR website should assist authorities in identifying where a development may pose an external hazard to a nuclear site. Authorities should contact ONR if they are in doubt.

Some applications for HSC consent do not involve a planning application, so in such cases it will be for the HSA to contact ONR. In practice, the HSA will usually be the LPA, but there are exceptions (see https://www.hse.gov.uk/landuseplanning/hazardoussubstances.htm and https://www.gov.uk/guidance/hazardous-substances). To avoid any potential for a consultation to be missed, it is suggested that the ONR website should explicitly ask LPAs to ensure that, if they are not themselves the HSA, the relevant HSA is aware of ONR's request to be consulted about HSC applications.

8.5. New and emerging technologies

Appendix H provides a summary of new and emerging technologies related to the net zero agenda. It is intended to provide background information to assist ONR in anticipating likely changes in the pattern of planning applications for potentially relevant facilities over the next several years.

8.6. Watch list and other recommendations

Table 6 summarises the areas in which it is recommended that ONR should keep the consultation zones and criteria under review, and other recommendations.

Table 6 Watch list and other recommendations

Topic	Report section	Description	Recommendation to ONR
1. Definitions of zones and criteria	General	There are uncertainties in the information, data and models used in the review. For example: • to keep the system simple, we have used hazard-related criteria where they already exist, e.g. by defining major hazard facilities as those within the scope of COMAH or other specific legislation and reservoirs as those with a maximum impounded capacity of 25,000m^3 or more, this being the threshold at which, in England, registration with the EA is required. This gives an element of consistency in terms of the risk levels that trigger actions. However, criteria such as COMAH thresholds were not designed specifically with the hazard to nuclear sites in mind • there is uncertainty in the extent to which induced seismicity may occur from mining, quarrying and geothermal developments.	Consultation zones, distances and special cases are based on current information and will be reviewed by ONR on a periodic basis.
2. Limits of validity on this analysis	5.2	The suggested consultation zones depend, in part, on assumptions about the scale of hazard events for some development types, depending for example on the assumed maximum inventory of LNG (Appendix D1), the maximum blade tip speed for wind turbines (120 m/s) and the maximum pipeline pressure (100 bar)	Maintain watching brief on technological developments.
3. Contaminant transport in watercourses	Appx C	In the event of a leak or spill from a major hazard site or pipeline, there is a high degree of uncertainty in the hazard range for transport of contaminants that could affect nuclear site water intakes or outfalls.	Keep under review the extent of potential contaminant transport via watercourses.

Topic	Report section	Description	Recommendation to ONR
4. Hydraulic fracturing	6.3	The likely purposes and scale of hydraulic fracturing in the UK are currently rather unclear. There is limited use for geothermal heat but CO_2 injection is likely to increase. At the time of writing this report (March 2021), there is a moratorium on hydraulic fracturing for shale gas.	Maintain a watching brief on: • any increased or new (to UK) applications of hydraulic fracturing, such as waste water injection or groundwater abstraction • any changes in the government position on hydraulic fracturing for shale gas.
5. Measuring the distance to the nuclear site	8.1	In determining whether a proposed development lies within a consultation zone, it is suggested that, by default, the distance from the nuclear site should be measured to the nearest point of the application site boundary.	ONR could consider whether to ask planning authorities to make a judgement in cases where only 'innocuous' elements of the development, such as landscaping or open space, lie within a zone.
6. Treatment of special cases	8.2	Due to the very large hazard ranges associated with special case developments, there is a potential for ONR to have to advise on disproportionately large numbers of applications.	Some options for the treatment of special cases have been identified, and these should be kept under review in order to ensure a proportionate approach.
7. Developments that may occur without consultation	8.3	There are cases in which development can occur without planning permission, and therefore 'fall through the gaps' of the consultation system. There is also a potential for developments to be missed if there is any lack of clarity about responsibilities for developments that are close to, or cross boundaries between authorities or between the UK nations.	Maintain awareness of these potential gaps, especially if there are changes in legislation or policy.

Topic	Report section	Description	Recommendation to ONR
8. Consultation by HSAs	8.4	Some applications for HSC do not involve a planning application, so in such cases it will be for the HSA to contact ONR. While the HSA is usually the LPA, there are exceptions.	To avoid any HSC applications being missed, the ONR website should explicitly ask local planning authorities to ensure, if they are not themselves the HSA, that the relevant HSA is aware of ONR's request to be consulted about HSC applications
9. New and emerging technologies	8.5	It is anticipated that there will be significant changes and growth over the next several years in sectors that contribute to net zero ambitions. The use of satellites and UAVs is another area that seems likely to expand, potentially with an increase in planning applications for launch sites.	Maintain a watching brief on nature and scale of developing technologies and associated hazards.

9. Conclusions

9.1. Summary of findings

The review has indicated that, within the context of ONR's sampling-based regulatory approach:

- ONR's proposed minimum 3km OCZ is appropriate.
- The proposed larger 30km zone for significant developments (major hazard facilities, airports and launch sites, and hydraulic fracturing sites) could be reduced to 12km if airports, launch sites, and hydraulic fracturing are moved to the new, special case category outlined in the next bullet point. This would leave major hazard facilities, such as chemical plant and major pipelines in the 12km zone. During the review, it was identified that military installations storing munitions should also be considered as within the 12km zone.
- An additional special case category, irrespective of distance from nuclear sites, should be introduced for developments that can have very long-range impacts: airports and launch sites, reservoirs, hydraulic fracturing, military airspace use (e.g. for training) and military practice, bombing or firing ranges.

Detail of the zones and associated consultation criteria are given in Table 4.

9.2. Recommendations

1. Definitions of zones and criteria

There are uncertainties in the information, data and models used in the review, and variability in the developments that may be proposed. For example, there is uncertainty in the extent to which induced seismicity may occur from mining, quarrying and geothermal developments. Consultation zones, distances and special cases are based on current information and will be reviewed by ONR on a periodic basis.

2. Limits of validity on this analysis

The suggested consultation zones depend in part on assumptions about the scale of hazard events for some development types, depending for example on the assumed maximum inventory of LNG (Appendix D1), the maximum blade tip speed for wind turbines (120 m/s) and the maximum pipeline pressure (100 bar). ONR should therefore keep technological developments under review.

3. Contaminant transport in watercourses

The hazard range for contaminants that could affect nuclear site water intakes or outfalls, in the event of spill or leak from a major hazard facility into a watercourse, is an area of particular uncertainty that should be kept under review.

4. Hydraulic fracturing

ONR should maintain a watching brief on any increases in the nature and scale of applications of hydraulic fracturing, and on any changes in the current moratorium on hydraulic fracturing for shale gas.

5. Measuring the distance to the nuclear site

In determining whether a proposed development lies within a consultation zone, it is suggested that, by default, the distance from the nuclear site should be measured to the nearest point of the application site boundary. ONR could consider whether to ask planning authorities to make a judgement in cases where only 'innocuous' elements of the development, such as landscaping or open space, lie within a zone.

6.Treatment of special cases

Due to the unlimited consultation distance suggested for special case developments, there is a potential for ONR to have to advise on very large numbers of applications. Some options for the treatment of special cases, in terms of setting zones or other processes, have been identified in Section 8.2. These should be kept under review in order to ensure a proportionate approach.

7. Developments that may occur without consultation

There are cases in which development can occur without planning permission, such that ONR might not be approached for consultation. There is also a potential for developments to be missed if there is any lack of clarity about responsibilities surrounding developments that

cross local or UK nation boundaries. ONR should maintain awareness of these potential gaps, especially if there are changes in legislation or policy.

8. Consultation by HSAs

Where an application for HSC does not also involve a planning application, it will be for the hazardous substances authority (HSA) to consult with ONR. While the HSA is usually the LPA, there are exceptions. To avoid any HSC applications being missed, the ONR website should explicitly ask LPAs to ensure, if they are not themselves the HSA, that the relevant HSA is aware of ONR's request to be consulted about HSC applications.

9. New and emerging technologies

ONR should maintain a watching brief on the development of new technologies and their associated hazards. It is anticipated that there will be significant change and growth over the next several years in sectors that contribute to net zero ambitions. The use of satellites and UAVs is another area that seems likely to expand, potentially with an increase in planning applications for launch sites.

10. References

Note: legislation and ACOPs are listed in the Bibliography (Appendix A)

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Appendix A Legislation, Policy and Regulatory Guidance

This Appendix provides a bibliography of relevant legislation, policy and regulatory guidance, including but not limited to those specifically referred to in this report.

Legislation and ACOPs

Air Navigation (Restriction of Flying) (Nuclear Installations) Regulations 2016

Control of Major Accident Hazard Regulations (COMAH), 2015

Dangerous Goods in Harbour Areas Regulations 2016 (DGHAR) and ACOP. HSE L155, 2016[14].

Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002 and ACOP L138, 2013

Explosives Regulations 2014

Offshore Installations Regulations 2015

Offshore Installations (Safety Case) Regulations 2005

'Hazardous Substance Regulations' (HSRs):

- The Planning (Hazardous Substances) Regulations 2015
- The Planning (Hazardous Substances) (Wales) Regulations 2015.
- The Town and Country Planning (Hazardous Substances) (Scotland) Regulations 2015

Pipelines Safety Regulations 1996

Radiation (Emergency Preparedness and Public Information) Regulations 2019 Approved Code of Practice and guidance. HSE, L126 Second Edition, 20 Nov 2020.

Reservoirs Acts (as amended):

- Reservoirs Act 1975 as applied in England
- Reservoirs Act 1975 as applied in Wales
- Reservoirs (Scotland) Act 2011

Town and Country Planning (General Permitted Development) (England) Order 2015

[14] At the time of writing (March 2021), HSE was carrying out a post-implementation review of DGHAR, to consider whether the regulations achieved their original objectives and remain the best option for achieving them.

Town and Country Planning (Safeguarded Aerodromes, Technical Sites and Military Explosive Storage Areas) Direction 2002. Updated 22 December 2016

- England & Wales Circular (1/2003): https://www.gov.uk/government/publications/safeguarding-aerodromes-technical-sites-and-military-explosives-storage-areas
- Scotland Circular (2/2003): http://www.gov.scot/Publications/2003/01/16204/17030

Policies

NPS for Overarching Energy (EN-1)

NPS for Fossil Fuels (EN-2)

NPS for Renewable Energy (EN-3)

NPS for Oil and Gas Supply and Storage (EN-4)

NPS for Electricity Networks (EN-5)

NPS for Nuclear Power (EN-6)

NPS for Ports

NPS for National Networks (road and rail)

Airports NPS

NPS for Hazardous Waste

NPS for Waste Water

Draft NPS for Water Resources

Geological Disposal Infrastructure NPS

Regulatory guidance

ONR land-use planning web pages: http://www.onr.org.uk/land-use-planning.htm

HSE land-use planning web pages: https://www.hse.gov.uk/landuseplanning/current-legislation.htm

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CAP 764 Policy and Guidelines on Wind Turbines. Issue 6. CAA, 2016. https://publicapps.caa.co.uk/modalapplication.aspx?catid=1&pagetype=65&appid=11&mode=detail&id=5609

Planning Inspectorate (PINS) Advice Notes https://infrastructure.planninginspectorate.gov.uk/legislation-and-advice/advice-notes/

- PINS Advice Note Nine: Rochdale Envelope

- PINS Advice Note Eleven: Working with public bodies in the infrastructure planning process (PDF 264 KB) Republished November 2017 (version 4):

  Annex F Nuclear Regulators – The Office for Nuclear Regulation, the Environment Agency and Natural Resources Wales

  Annex G Health and Safety Executive

Appendix B Development Types with Safety-Related Planning Controls

This Appendix provides details of the review of precedents and benchmarks in Section 4.

Development type	Risk from	Risk to	Definition of zone or other constraint and roles of parties	References	Relevance / applicability to OCZs
COMAH sites	Existing COMAH sites	Other existing COMAH sites	The competent authority (CA) must identify groups of COMAH sites ("domino groups") where an accident at one site could affect another. The CA and COMAH duty holders are then required to share information and co-operate in such cases, Upper tier COMAH sites must give information to the local authority so that external emergency plans can be drawn up, but there are no 'emergency planning zones' around COMAH sites. The local authority must consult a range of parties but there is no explicit requirement to consult with ONR: it is up to the local authority to decide. All COMAH sites must have HSC – see following row.	Reg 24 of COMAH PINS Advice Note 11 – Annex G	Distances involved in domino group considerations will be specific to the sites and their inventories. There are no pre-defined, generic distances.

Development type	Risk from	Risk to	Definition of zone or other constraint and roles of parties	References	Relevance / applicability to OCZs
Major hazard sites	Proposed production, use or storage of hazardous substances	Existing sites in the area	The HSRs refer to a **2km** distance within which the hazardous substances authority may be required to consult with certain parties (e.g adjacent local authorities) prior to granting consent. Once consent is given, a map is produced by HSE with three risk contour zones (Inner, Middle and Outer) defining distances within which HSE must be consulted about planning applications in the vicinity.	HSRs 2015 HSE Land Use Planning [8]	The 2km consultation distance is the most directly comparable to ONR consultation zones. The extent of the HSE risk zones will be specific to the site. There are no pre-defined, generic distances. Also, these zones are based on risk (i.e. taking frequency into account) not on hazard range and so are not directly comparable. HSE's zones are based, for example, on assumptions about the exposure and vulnerability of a generic population and so will be different to the issue of harm to personnel and facilities on a nuclear site.
Explosives sites	Existing sites that produce or store explosives	Existing sites in the area	Duty holders for explosives sites are required to maintain separation distances between explosives and on- and off-site buildings and other places. The distance depends on the nature and quantity of explosives, and on the vulnerability of the potentially affected site. The maximum (worst case) distance specified in the Regulations is **2.079km**. This is for 90,000 - 100,000kg of Hazard Type 1 explosive in relation to a Class E (vulnerable) building.	Explosives Regs 2014	Relevant, but note the different purpose: this relates to *existing* explosives sites, placing requirements on the site duty holder, not to consultation requirements at planning stage

Development type	Risk from	Risk to	Definition of zone or other constraint and roles of parties	References	Relevance / applicability to OCZs
Developments that may affect the safety of aircraft	Developments including: Those that may attract birds Tall structures Wind turbines (potential for radar or other communication, navigation and surveillance interference as well as in terms of their being tall obstacles) Solar arrays (glare)	Aircraft using an existing airport	Consultation or control zones are defined around airports to safeguard the airport against developments that may create such hazards. Restricted airspace zones around nuclear sites are typically up to 2 nautical miles in radius.	CAP 738 [9] CAP 764 [10] Air Navigation (Restriction of Flying) (Nuclear Installations) Regulations 2016	None of these hazards to aircraft are relevant for nuclear sites.

Development type	Risk from	Risk to	Definition of zone or other constraint and roles of parties	References	Relevance / applicability to OCZs
Harbours	Proposed handling of explosives in harbours (landside and on vessels)	Existing sites in the area	Determined by HSE. In general, the separation distances required will be as defined in the explosives licence for the site. The guidance document '*Applying for a port licence?*' says, that "Applicants for a licence to handle explosives at a harbour are required to present a plan including the surrounding district for **at least 2km** in all directions"	Dangerous Goods in Harbour Areas Regulations 2016 (DGHAR) and ACOP L155. Applying for a port licence? Guidance for applicants for a licence to handle explosives at a harbour or other place HSE 2006 [11]	It can be inferred from the at least 2km extent of the required plan that HSE is interested in potential impacts out to this distance. There is therefore an indirect comparability with the purpose of the ONR consultation zones.

Appendix C Hazard Ranges

This Appendix provides details of the review of hazard ranges in Section 5 and of the suggested consultation zones.

Where a development could fall within more than one type category, the category with the largest range should be used. For example, manufacturing sites in general are assigned to the 3km zone, but if a manufacturing site was also a major hazard under COMAH it would be in the 12km zone.

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Airports /airfields (including arrival/ departure routes, holding patterns)	Missiles - aircraft crash or falls of ice or aircraft components.	Special case	For the busiest airports, airport-related risk may exceed background beyond **30km** underneath the arrival/ departure paths, and so be relevant for nuclear sites. The associated levels of individual risk (around 10^{-6} or 10^{-7} per year) are used in the Netherlands to define development restriction zones [6]. See Appendix E.	-	Ice and component falls are assumed to be relatively insignificant in terms of consequence, even if not probability.
Carbon capture and storage	Asphyxiant (CO_2)	12km, unless hydraulic fracturing is involved, which would be a Special Case	There is no indication that larger consultation zones are required than for major hazard (COMAH) substances, see HSE assessment of the major hazard potential of carbon dioxide [12] so assigned to 12km zone. Special Case if the application involves hydraulic fracturing for injection.	-	This is an expanding industry in which new policy, regulation and guidance can be expected, so it is suggested that ONR should monitor developments in the industry and its regulation.
Energy storage – heat or chemical: e.g. battery, fuel cell, molten salt, hot rock etc	Explosion, fire	3km	No robust collated data.	-	

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Energy storage: kinetic or elastic, e.g. flywheel, compressed air	Explosion overpressure. Missiles from flywheel disintegration.	3km	No robust collated data.	-	
Explosives sites – manufacture or storage	Explosion, fire, smoke, missiles	3km	As in Appendix B, the maximum (worst case) distance specified in the Explosives Regs 2014 is **2.079 km.** This is for 90,000 – 100,000 kg of Hazard Type 1 explosive in relation to a Class E (vulnerable) building Dangerous Goods in Harbour Areas regs and ACOP notes that "for Division 1.2 explosives (projection hazard but not a mass explosion hazard) …. "people in the open should be evacuated as far as possible, at least 400 m … As a guide, the limit of fragment throw may be 1250m from 5 tonnes (net explosives quantity) and 2000m from 16 tonnes". It does not give distances for other explosives.	-	This is an example of a development type that may not require planning permission, such that ONR may not be consulted on it. For an inventory of explosives of more than 10 or 50 te (depending on explosive type) the site would fall under the COMAH regulations.
Flour mills, sugar refining, saw mills, certain metal operations etc (that may create dust)	Explosion, fire	3km	Based on experience and the RAS database, assumed to be no greater than for other non-COMAH facilities. There are many occurrences, often linked with other events. In all cases the dust explosion effects were limited to the facility. Where other events also occurred (such as fires) the effects sometimes reached offsite, but always to a limited extent.	-	

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Hydraulic fracturing for geothermal power, or CO_2 injection	Induced seismicity	Special Case	Impacts from induced seismicity beyond 12km cannot be ruled out.	-	For geothermal power generation, or potentially CO2 disposal in wells. Not currently used for groundwater abstraction or waste water injection in UK There is currently a moratorium on hydraulic fracturing for shale gas in the UK.
Hydrogen production, use, distribution	Explosion, fire	3km 12km if COMAH	No current indication that larger consultation zones are required than for other major hazard substances. See HSE Horizon Scanning report SR25 [13] See Appendix D for hydrogen sites that fall under COMAH.	-	Hydrogen is an expanding sector in which new policy, regulation and guidance can be expected, so it is recommended that ONR should monitor developments in the industry and its regulation.
Industrial/research /communication facilities with high electrical demand, using high-voltages or strong electromagnetic fields	Electromagnetic interference, disruption of offsite power supplies	3km	No current indication that larger consultation zones are required than 3km	No robust data.	

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
'Innocuous' development, e.g. housing, education, sports and culture, retail, office or light industry	Potential to exacerbate hazards such as flooding, due to effects on catchment run-off and dynamics, or disruption of offsite power supplies due to additional demand.	3km	Flood risk assessments are standard for most larger developments. Developments of this nature that meet the emergency planning criteria (Table 2) should be passed to ONR for advice in any case .	No robust data.	To avoid ONR being consulted on every small housing project (for example) it is suggested that it should be left to planning authorities to judge whether there is an external hazard. This will depend on factors such as local topography and catchment characteristics. Rather than attempting to codify these in national guidance, it is suggested that planning authorities, with their local knowledge, are better placed to judge this.
Launch sites (e.g. for satellites)	Missiles: rocket/ payload crash, ice or component fall.	Special Case	Conservatively, include as Special Case, since rocket crash could occur at a large distance from the site and there are no robust data to justify a smaller zone size.	-	

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Launch/ recovery sites for UAVs	Missiles: UAV crash, ice or component fall.	Special Case	Conservatively, include as Special Case, since a crash could occur at a large distance from the launch/ recovery site and there are no robust data to justify a smaller zone size. UAVs are becoming become larger, more numerous and more varied in their uses.	There is not necessarily any planning or aviation legislation that would trigger a planning application.	It is suggested that ONR should liaise with the aviation regulator, CAA, as the industry and its regulation (licensing of UAVs, exclusion zones etc) develop. There are no-fly zones around airports already see https://www.caa.co.uk/Consumers/Unmanned-aircraft-and-drones. This is an example of a development type that may not require planning permission, such that ONR may not be consulted on it.

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Major hazard (COMAH or Offshore regulations) sites: production, storage or use of hazardous substances (e.g. chemicals, fuels, refineries)	Fire, explosion, toxics, smoke.	12km	Modelling indicated a bounding hazard range of **12km**, for the Isle of Grain LNG storage installation – see Appendix D. HSE provided the following information on the extent of the largest consultation zones set for land-use planning. These are risk-based – i.e. they take account of probability factors and so are not the furthest possible extent of the hazard. For example, HSE indicated that a toxic hazard could go twice as far as the LUP consultation zone under worst-case wind direction and weather conditions. The distances below are approximate and measured from the boundary of the hazardous installation. Furthest toxic zones = **7km** ('an outlier due to the way that the HSC entitlement was claimed') Typical toxic = **3km** Furthest flammable = **3km** (from large LNG storage site) Storage of liquefied toxic gases. At both Runcorn and Greatham the zones are approximately **3km** at their furthest extent. These are dominated by large chlorine releases from storage vessels under low wind speed, stable atmospheric conditions. For storage and import of liquefied flammable gases, the furthest extent of the zones is also about **3km**, associated with LNG import terminals, for large scale releases from the import pipelines for ship-to-shore transfers. Further part-independent verification of these distances for chlorine is discussed in Appendix D3.	HSE's approach to advice on risk of harm to people from major hazards will be different to (ONR's) for external harm to the staff and facilities on a nuclear site. HSE's zones are based on assumptions and judgements about e.g. occupancy, population and building vulnerability and risk tolerability criteria as per R2P2 [14]	The modelled 12km is proposed as the bounding case. This is much greater than the 3km zone used by HSE for planning applications in the vicinity of LNG terminals. This is likely to be because the 12km is based on a worst possible case, whereas HSE's zones are risk-based, taking account of the likelihood of a release occurring and the probability of causing harm at the prescribed distance. To keep the system simple, we have used hazard-related criteria where they already exist, e.g. by defining major hazard sites as those within the scope of COMAH. This also gives an element of consistency in terms of the risk levels that trigger actions. However, criteria such as COMAH thresholds were not designed specifically with the hazard to nuclear sites in mind

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Major hazard sites: *(continued)*	Leaks / spills to water	12km	Contaminant transport in a river or estuary, arising from a development with a large inventory of harmful substances, could enter a watercourse and affect a nuclear site cooling water intake many km downstream. One possible benchmark is the guidance to use a 10km radius for consideration of environmental effects in the COMAH SRAM [15], though it must be noted that this is intended for environmental (e.g. ecotoxic) impacts, rather than impact on engineered plant. Taking account of this, and as it would seem disproportionate to consult on all COMAH developments beyond 12km, it is suggested that the 12km zone should apply for releases to water as well as to fire, explosion, toxics and smoke.	The distance transported will be very dependent on the pathways – i.e. on local topography and drainage, so it is not obvious how to set a limiting distance.	This is an area of particular uncertainty and should be kept under review.
Manufacturing, warehousing	Fire, explosion, smoke, toxics	3km	Based on experience and RAS database, assumed to be no greater than for other non-COMAH facilities.	No robust data	
Marine works e.g. ports, barrages, flood defences, dredging	Flooding or blockage of water intakes or outfalls, or effluent outfalls by sediments, debris, algae, marine growth, fish, jellyfish etc. Damage to or blockage of intakes or outfalls by leaks, spills or releases of substances or materials. Vessel collision.	3km	Major works, such as barrages, could have wider impact but will be NSIPs – wide consultation will be required.	-	

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Medical, pharmaceutical, research and development	Biological hazards Nanotechnology and other novel hazards Fire, explosion, toxic releases, leaks/ spills	3km	No current indication that larger consultation zones are required than for other developments in the 3km zone	-	
Military installations storing munitions	Missiles, explosions, smoke	12km	No robust data. Assigned to the 12km zone, noting the 8km screening distance value proposed in [3].		This is an example of a development type that may not require planning permission, such that ONR may not be consulted on it. Also exempt from HSRs.
Military airspace use (e.g. training areas) and military practice, bombing or firing ranges	Aircraft, rocket or other missile crash	Special case	No robust data. Assigned to special case category, noting the 30km screening distance value for practice, bombing or firing ranges in [3]. (Military airports and airfields, as a subset of airports, are already assigned to the special case category.)		This is an example of a development type that may not require planning permission, such that ONR may not be consulted on it.

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Mining, quarrying, blasting, oil and gas extraction (other than by hydraulic fracturing)	Fire, explosion Leaks/ spills to water. Ground vibration, subsidence, induced seismicity,	3km	For **fire, explosion and leaks/ spills to water** no current indication from RAS database that larger consultation zones are required than for other developments in the 3km zone. The British Geological Survey (BGS) website, https://earthquakes.bgs.ac.uk/earthquakes/dataSearch.html, states that 'activities such as blasting during quarry operations can also result in **ground vibrations** that are comparable to small earthquakes'. In the past, **subsidence** from mining was a widespread issue in the UK, for example in the Cheshire brinefields, but modern mining practices and controls should significantly reduce the risk from new developments. A detailed, worldwide review of **human-induced seismicity** by Foulger et al, 2018 [16] concluded that, due to severe under-reporting, reporting biases and wide variations in site-specific factors, it is extremely difficult to predict where and to what extent induced seismicity will occur. In the UK, recent BGS data show only minor events induced by the geothermal project at Carharrack in Cornwall. Larger mine and quarry, CO_2 storage and underground gas (natural gas or hydrogen) storage will qualify as NSIPs in any case, and so be required to consult widely with parties who may be affected. Based on the above, it is considered disproportionate to include such developments in a larger than 3km zone.	-	Hydrogen storage in certain onshore geological features is being considered. Hydraulic fracturing is considered as a separate development type.

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
(Other) Nuclear sites	Accidental release of radioactivity (emergency situation). Fire, explosion, toxics. Leaks/ spills to water.	n/a	ONR will be aware of such sites in any case. Distances should be based on the safety case for the proposed and existing nuclear sites, rather than a generic, pre-defined distance. Other premises where work with ionising radiation is carried out (e.g. hospitals) have smaller inventories / hazards.	-	This is the 'mirror image' case, in which a new nuclear site is proposed in the vicinity of existing developments, which may include hazardous installations.
Power stations: gas, oil, biomass, waste-to-energy etc	Fire, explosion, toxics smoke. Depending on the fuel, there is also possibility of dust explosions. Missiles from disintegration. Leaks/spills to water	3km 12km if under COMAH	No current indication that larger consultation zones are required than for other developments in the 3km zone (unless a COMAH site) Gas power stations, and biomass stations that use methane for startup, could come under COMAH and therefore be in the 12km zone. Hazardous water treatment chemicals are also in turbines but quantities unlikely to reach COMAH thresholds. Major generating stations developments are covered by the NPS for Energy and as such require wide consultation.	-	
Piling, tunnelling, other major construction or demolition	Ground vibration, subsidence, induced seismicity,	3km	As for mining etc above, no current indication that larger consultation zones are required than for other developments in the 3km zone.	-	

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Pipelines	Fire, explosion, Toxic release. Leaks/ spills to water.	12km	HSE stated that for onshore major accident hazard pipelines the furthest consultation zone is **435m**, measured from the pipeline. There are only a small number of pipelines that form part of the national transmission system with zones this large. The remainder of the transmission and distribution system has much smaller zones. Other references for proximity distances include IGEM TD/1 [17] for high-pressure pipelines (7 – 100 bar) . The distances recommended go up to about **120m**. Nevertheless, in the RAS database, the largest LNG event found was a 2005 leak in Nigeria that resulted in a fire that engulfed 27 km^2. Based on experience, large flammable clouds are typically half as wide are they are long, therefore it is assumed that the maximum distance from the release was approximately **7km**. Pipelines have therefore been assigned to the12km zone, as for major hazard sites	-	Very few current pipelines have pressures over 100 bar, and the IGEM report is also only for pipelines up to 100 bar. It is therefore suggested that a limit of 100 bar should be placed on the validity of the present assessment. Pipelines will generally start and end at sites requiring HSCs, and this is where the largest inventories will be. However, pipelines may be more vulnerable to catastrophic damage (usually third-party interference) and there can be a very large release if there is a long way between isolation points or if they are not closed quickly. Third-party interference is one of the commonest causes and results in the largest releases - see for example EGIG [18] and UKOPA[19].

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Reservoirs	Flooding due to dam collapse Reservoir construction can also induce seismicity, but this is likely to be over a smaller range.	Special case	EA flood risk mapping shows that, in the event of dam collapse, significant flooding (2m/s velocity and 2m depth) can occur along watercourses below the dam for distances well **beyond 30km**. See Appendix F.	-	
Transport infrastructure, e.g. roads, railways, petrol stations	Fire, explosion, toxic release from fuel infrastructure or in the event of an accident involving dangerous goods in vehicles.	3km	No current indication that larger consultation zones are required than for other developments in the 3km zone Hazard ranges are likely to be much smaller than for fixed, COMAH sites, which can have much larger inventories.	-	Note also that major transport developments are covered by the NPS for National (road and rail) Networks and as such require wide consultation.
Waste sites e.g. tyre dumps, incinerators, digesters, landfill	Fire, smoke, toxic release	3km	No current indication that larger consultation zones are required than for other developments in the 3km zone (unless a COMAH site)	-	

Development type	Key hazards (non-exhaustive)	Suggested zone	Basis of hazard range	Assumptions / uncertainties	Comment
Wind turbines, including balance of plant e.g. onshore substations	Missiles: blade detachment or disintegration. Ice throw Electrical and other hazards may arise from balance of plant e.g. onshore substations	3km	There were two main sources of information on blade throw: • Sarlak & Sørensen 2015 [20] • Rogers et al 2011 [21] "… at tip speeds of about 70 m/s (normal operating conditions), pieces of blade (with weights in the range of approximately 7-16 ton) would be thrown out less than 700m for the entire range of wind turbines, and turbines operating at the extreme tip speed of 150 m/s may be subject to blade throw of up to **2km** …" For the ice throw cases, maximum distances of approximately 100 and **600m** are obtained for standstill and normal operating conditions of the wind turbine, respectively, with the ice pieces weighing from 0.4 to 6.5 kg." Bredesen [22] gives an ice throw distance of **240m**	Although distances of around 2km are estimated, a 3km minimum OCZ is appropriate, to allow for any sensitive features that may be close to the perimeter of the nuclear site. See also Comment column.	Tip speed, which is a key factor controlling throw distance, is not directly determined by any of the obvious design parameters such as turbine power or diameter. However, tip speeds for conventional designs seem unlikely to exceed the 150 m/s noted in the refs. See Appendix G1. A scoping calculation has been carried out on the additional throw distance when (as will often be the case) the turbine is on high ground and the nuclear site at low elevation. As a result, we suggest a limit of 120 m/s on the tip speed for which the analysis in this review is valid. See Appendix G2.

Appendix D Bounding Cases for COMAH Site Hazard Ranges

Using RAS Ltd's experience of Upper Tier COMAH sites in the UK, the following potentially bounding cases were identified for further investigation:

- LNG
- Hydrogen
- Chlorine

D1 LNG

The Grain LNG terminal currently has a LNG throughput capability of 15 million tonnes per annum, equivalent to 20% of UK gas demand. It is the largest LNG facility in Europe. The Grain LNG terminal is larger than any LPG facility in the UK. The total inventory is 564,746 te of LNG

It is much larger than the Avonmouth LPG project (34,564 te). Releases of methane from the UK gas transmission and distribution network would be much smaller inventories than from Grain.

Information on the Grain LNG terminal is publicly available via the local authority Planning Portal. The most relevant information for this assessment is from the HSC application made in 2015 (see https://publicaccess1.medway.gov.uk/online-applications/applicationDetails.do?keyVal=ZZZZP9KNPM522&activeTab=summary)

The Grain LNG terminal has permission to store a total inventory (in tanks, pipework etc) of 564,746 te of liquified natural gas.

The worst-case release from the site would be a catastrophic failure of one of the storage tanks.

The HSC application gives the following information for the tanks:

Tank No	Installed above ground (Yes/No)	Buried (Yes/No)	Mounded (Yes/No)	Max capacity (m^3)	Highest vessel design temperature (°C)	Highest vessel design pressure (bar absolute)
T351-T355	YES	NO	NO	206,700 in each tank	AMBIENT Normal operating temperature = –160°C)	1.32

From experience it is known that flash fires give the largest hazard ranges. Flash fires affect people outside, but have limited impact on people inside, or on buildings or other process equipment due to short event duration.

If a flammable cloud enters a confined or congested space, there is a potential for explosion, which could cause damage to buildings and process equipment.

In modelling, the size of a flash fire is determined by the distance to the lower flammable limit (LFL), outside of which the cloud does not contain a flammable mixture of vapour and air. Flammable clouds have the possibility of flammable pockets within the cloud out to a concentration of half of the LFL so this should be used as limit of the hazard range for determining the maximum potential hazard for flammable materials. As the size of the cloud increases, the probability that the cloud will find an ignition source tends towards unity. The sooner the cloud is ignited, the smaller the potential hazard distance. Modelling therefore conservatively assumes that the cloud is not ignited until it reaches its maximum extent.

The extent of a flammable cloud is very weather-dependent as dispersion of the release increases with wind speed and atmospheric instability. The largest clouds are seen under low wind speeds and stable atmospheric conditions.

Mathematical Modelling

Consequence analysis was carried out using Phast 8.23 (https://www.dnv.com/software/services/phast/index.html), an industry standard, proprietary software package developed by DNV GL. Phast combines source, dispersion, consequence and effect analysis models. It examines the progress of a potential incident from initial release through formation of a gas/vapour cloud or liquid pool to final dispersion, calculating – as appropriate to the case - the concentration of flammable or toxic components in the dispersing cloud or plume, or fire radiation or explosion overpressure end points.

The weather stability class is defined by the conditions that are found during day or night. The weather classes used to exemplify the site location are Pasquill stability classes D and F. Stability class D occurs during overcast conditions during the day or night, is independent of wind speed and is the most common condition. A wind speed of 5 m/s is assigned to class D to give D5 weather conditions. Class F is a stable class that only occurs on a clear or fairly clear night with low wind speed and allows minimum dispersion with correspondingly long hazard distances. A wind speed of 2m/s is assigned to class F to give F2 weather conditions.

Both D5 and F2 are ‘standard weather conditions’ modelled and used in appropriate proportions in calculations. This is an industry-wide practice, recommended by HSE. D5 modelling results are used for estimating daytime consequences. D5 and F2 modelling results are used for estimating night-time consequences. This mixture represents UK average day and night time conditions, and the weather conditions at the Grain site are typical of this. However, to obtain a worst-case estimate for this bounding calculation, modelling was carried out only for F2 weather conditions.

The modelling inputs, as shown in Table E1, were taken from the information supplied in the HSC application – see https://publicaccess1.medway.gov.uk/online-applications/applicationDetails.do?activeTab=documents&keyVal=ZZZZP9KNPM522.

Table E1 Phast model inputs

Model Inputs	Details
Material	Releases have been modelled as methane
Source pressure	1.32 bar (a)
Source temperature	-160 °C
Release phase	Liquid
Release case	Catastrophic rupture
Is the available inventory limited?	Yes – release inventory is taken as the contents of one of the five storage tanks: 206,700 m^3
Release duration	N/A – catastrophic vessel failure modelled
Weather conditions	F2

The Phast model predicted distances of 9 km to LFL and **12km to 0.5 LFL.**

Sensitivity study – release of entire inventory

Catastrophic failure of the single largest inventory – in this case one tank - is what is normally required by the HSE when setting consultation distances for COMAH assessments.

It is however possible that more could be released, for example in the event of a major seismic event or an aircraft crash destroying more than one tank.

Such events are unlikely but, as a sensitivity test, the model was re-run for the extreme case of failure of the whole site inventory.

This gave distances of **17.2 km to LFL** and **25.7 km to 0.5LFL** (under F2 weather).

If the zone were set on this basis, it would increase in area by over four times, compared to the suggested 12km zone. It is an illustration of the difficulty of defining a truly 'consequence-only' hazard range when this almost inevitably includes some notions of likelihood. It also illustrates the variation in outcome that can result from assumed event conditions.

For the purpose of ONR sampling of applications with the greatest risk, it is suggested that the 12km zone should be used, noting that assuming a single tank failure is in line with industry practice, and that there are other conservatisms in the analysis.

Global comparison

The RAS global incident database was reviewed for LNG incidents. The way that incidents are reported and recorded results in variable levels of detail in the collated

database. Nevertheless, the largest LNG event found was the 2005 leak from LNG pipework in Nigeria that resulted in a fire that engulfed 27 km^2. Industry experience indicates that large flammable clouds are typically half as wide are they are long. With this assumption the maximum distance from the release would have been approximately 7km.

This does not challenge the modelled hazard range of 12km as above. This event has however been used in estimating the hazard range for pipelines, and on the basis of which it is suggested that pipelines should also be in the 12km zone.

D2 Hydrogen

As hydrogen is an area of global growth as part of meeting net zero targets for climate change, hydrogen has also been considered for modelling.

Hydrogen is already a widely used chemical feedstock in the UK.

There is very limited information available on inventories / operating conditions for proposed large Net Zero projects in the UK so a worst-case inventory has not been identified and no modelling has been carried out.

Although hydrogen is more easily ignited than methane and more likely to result in an explosion, it is considered to produce smaller hazard ranges than predicted for LNG as no projects are predicted to be as large as the Isle of Grain.

The RAS global incident database was reviewed for hydrogen incidents. The way that incidents are reported and recorded results in variable levels of detail, but the largest hydrogen incidents found were:

- 1989, Pasadena, California, USA. Polyethylene manufacturing, flammable cloud containing hydrogen explodes. Debris was found up to 10 km from the site of the explosion, the windows of buildings located within a radius of 2.5 km were broken, and houses and buildings were damaged within a perimeter of 6 to 7 km.
- 2020 North Carolina, USA. Hydrogen fuel cell plant explosion. The explosion was felt at 16km but with no damage or injury at this distance.

As the debris and damage distances from these largest incidents were below the 12km estimated in Section D1 for LNG, hydrogen is not considered to be the bounding case.

D3 Chlorine

Chlorine is a widely used feedstock chemical. In RAS experience it is the most common toxic material at UK COMAH sites. It is a named substance in the COMAH Regulations with low qualifying quantities. It produces a toxic vapour that affects breathing and impedes the ability to escape safely from the vapour cloud.

Chlorine has therefore been considered as the potential bounding case for toxic releases.

Information in the public domain on the largest chlorine manufacturing sites in the UK (Inovyn Runcorn, formerly Ineos Vinyls), redacts data needed for modelling (inventories and operating conditions), so no modelling was carried out. However, Halton Borough Council's report Planning for Risk [23] includes maps showing the locations of the hazardous installations and the extents of the risk contours. The maximum zone distance

from the Ineos/Inovyn sites is approximately 1.9km. This is in accordance with the 3km suggested by HSE for toxics (Appendix C).

The RAS incident database was reviewed for chlorine incidents. The review showed that effects are often limited to site boundaries, albeit with large surrounding areas evacuated by emergency services. The way that incidents are reported and recorded results in variable levels of detail in the collated database. The actual extent of harmful concentrations from the incidents could not be determined from the available information. Due to its odour, chlorine is detectable at low concentrations, encouraging people to escape and take shelter before being exposed to a potentially lethal dose.

From the estimates above, e, it appears that chlorine, as the bounding case for toxic releases, has a smaller hazard range than LNG.

D4 Aqueous ecotoxic materials

Some COMAH sites are designated as such because of their inventory of aqueous ecotoxic materials rather than flammables or toxics. Because pathways in ground or surface water are so site-specific it is not possible to estimate a generic hazard range. It is suggested that ONR should still ask to be consulted about such sites and – in the absence of better information – use the same 12km zone as for other major hazard effects

Although ecotoxic effects themselves may not appear to be of direct concern for nuclear site safety there may be indirect effects. An ecotoxic substance may also affect site cooling water systems. Other scenarios are conceivable, for example that large numbers of dead fish could block an intake, or that the nuclear site may be required to stop extracting or discharging to a watercourse while emergency remedial actions are taken. Further consideration of contaminant transport in watercourses is given in Appendix C, and the issue is also identified as one to keep on the ‘watch list’ (Section 8.6).

Appendix E Aircraft Crash Risk

Beneath flight paths to and from busy airports, airport-related individual risk levels from aircraft crash can be of the order of around 10^{-6} or 10^{-7} per year beyond 30km from the airport. These levels of risk are used in the Netherlands[15] to define development restriction zones [6], and so may need consideration in terms of the safety of personnel or facilities at nuclear sites.

For example, Figure E1 shows the restriction zones around Schiphol airport. Five different zones or limitation areas are specified:

LIB-1 (purple) and LIB-2 (red) are demolition zones, due to external safety (LIB-1) and noise (LIB-2). No new objects / houses may be added. When residents leave, these homes are demolished. LIB-1 is derived from an individual risk level of 10^{-5} per year.

LIB-3 (orange): restriction areas for vulnerable sites (where many people are present). No new buildings are allowed, except small office or commercial buildings with less than 22 employees per hectare. LIB-3 is derived from an individual risk level of 10^{-6} per year.

LIB- 4 (green) is a limitation zone based on noise levels, for noise-sensitive objects/buildings.

LIB-5 (yellow) is an area in which development can occur only after considering trade-offs that take into account noise and external safety. This zone is meant for local government (municipalities) to weigh/assess local new housing development plans taking noise and third-party risk in consideration. The LIB-5 zone is newly introduced since 2017/2018. The zone is derived from a noise contour with an obsolete unit (‘20 Ke’).

The updated text (2017) defining the LIB areas, including LIB-5, can be found in [6] and additional explanation / discussion, including for other airports is given in [24].

[15] The UK currently has a less restrictive, and simpler system of public safety restrictions around airports, which is currently under review, following a CAA consultation (https://consultations.caa.co.uk/aerodrome-standards-department/public-safety-zones/)

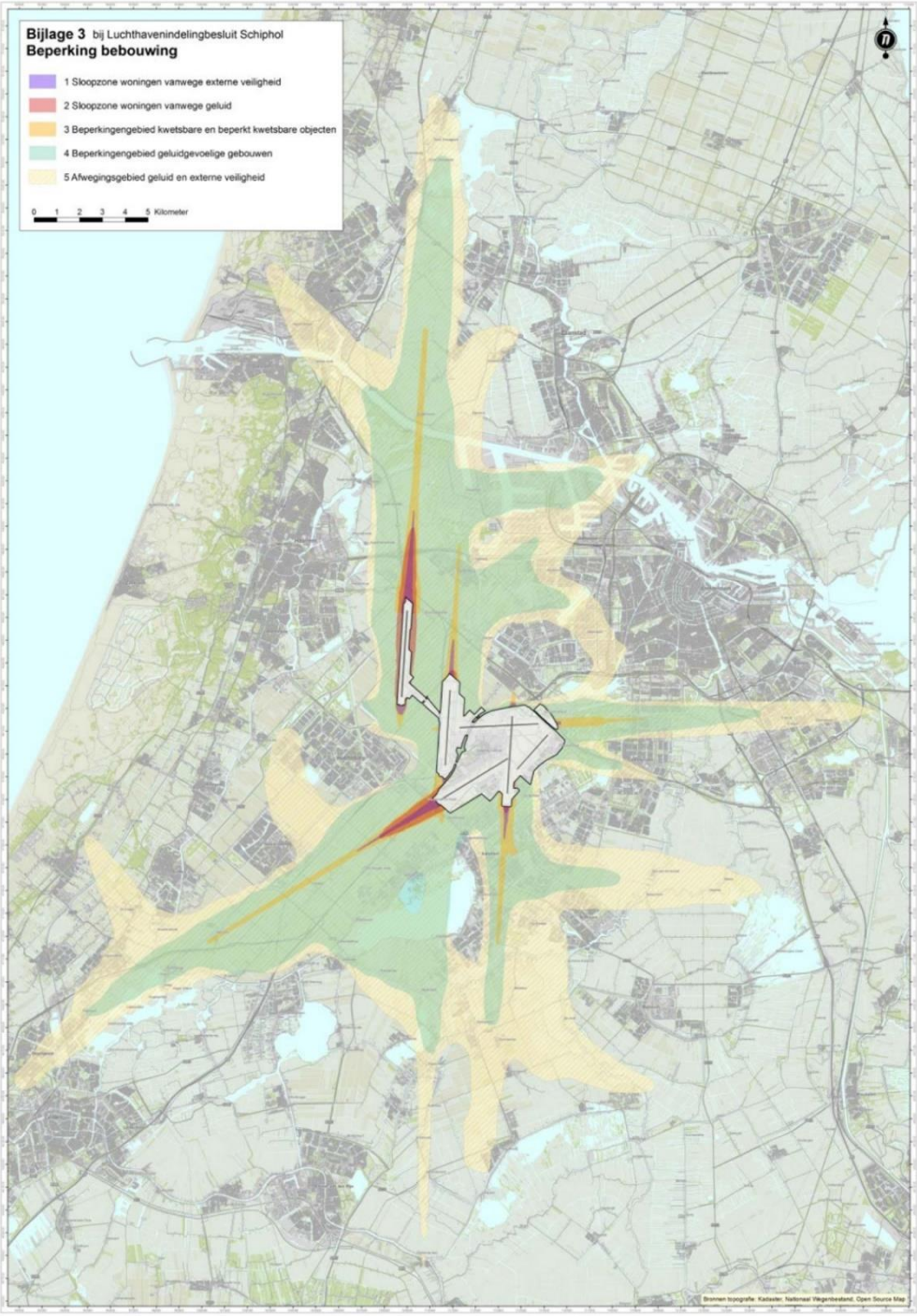

Figure E1 Risk- and noise-related restriction zones around Schiphol airport

Reproduced from [6]

Appendix F: Reservoirs - Dam Collapse

The Environment Agency (EA) online flood risk mapping tool (https://flood-warning-information.service.gov.uk/long-term-flood-risk) provides estimates of the speed, depth and extent of floods from reservoirs (as well as from rivers, sea and flood water) in England. (The corresponding SEPA and NRW sites, for Scotland and Wales respectively, give less detailed information.)

Caution is needed in interpreting the EA maps, as in some cases the flooding appears to be the combined result of simultaneous failures at more than one reservoir – an extremely unlikely event unless the reservoirs are in cascade. Nevertheless, Figures F1 – F4 show examples in which significant flooding can extend for several tens of kilometres downstream of a dam failure.

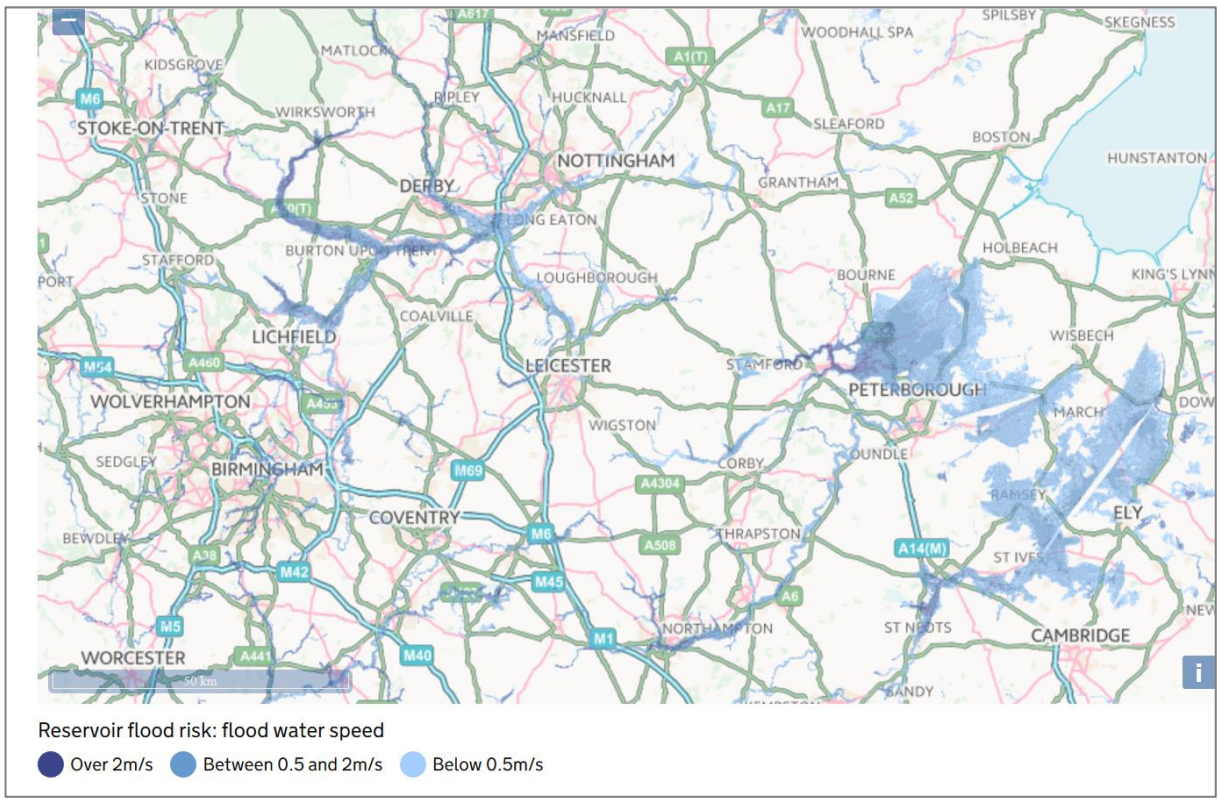

Figure F1 Flood water speeds, East Midlands

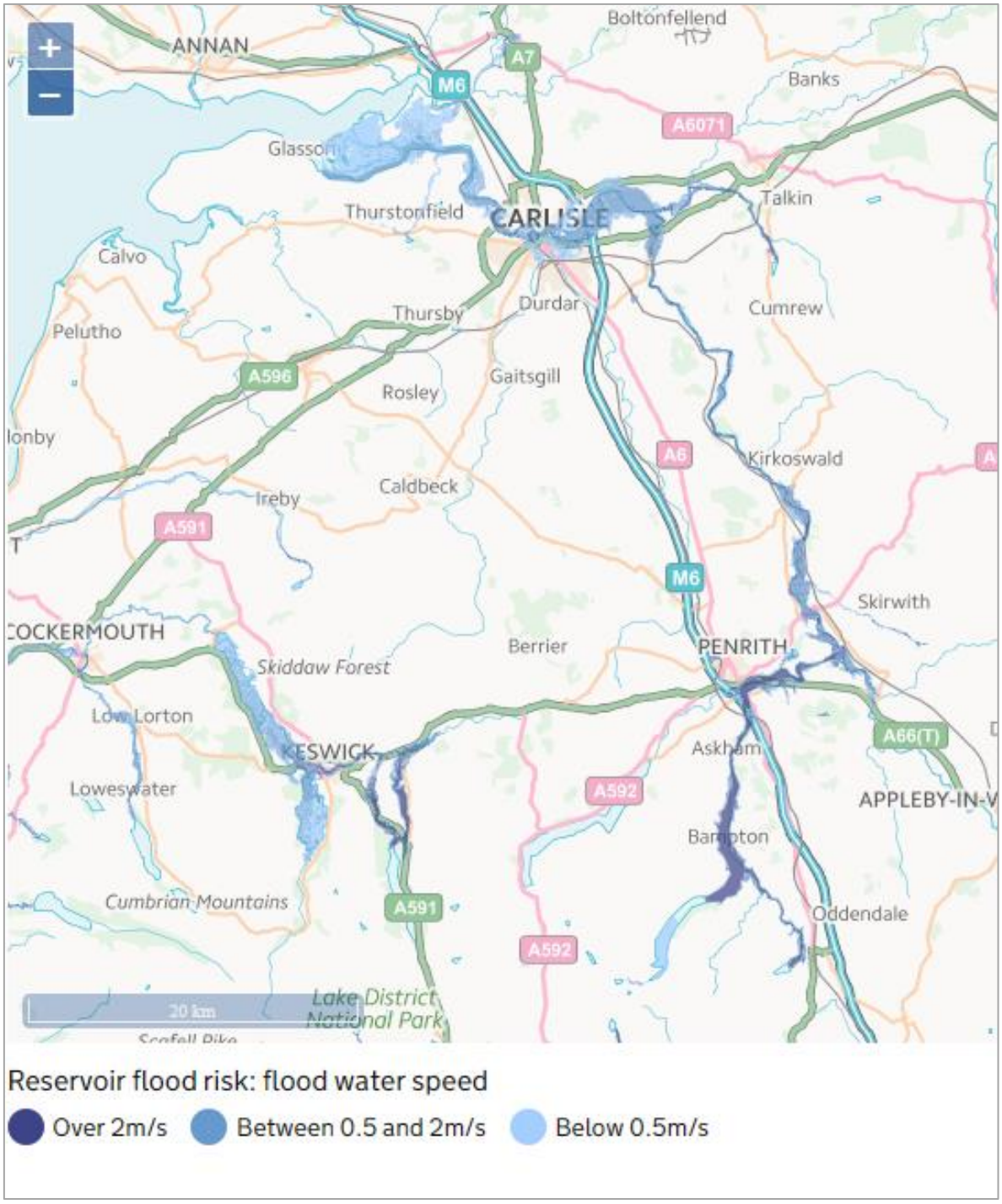

Figure F2 Flood water speeds from Haweswater, Cumbria

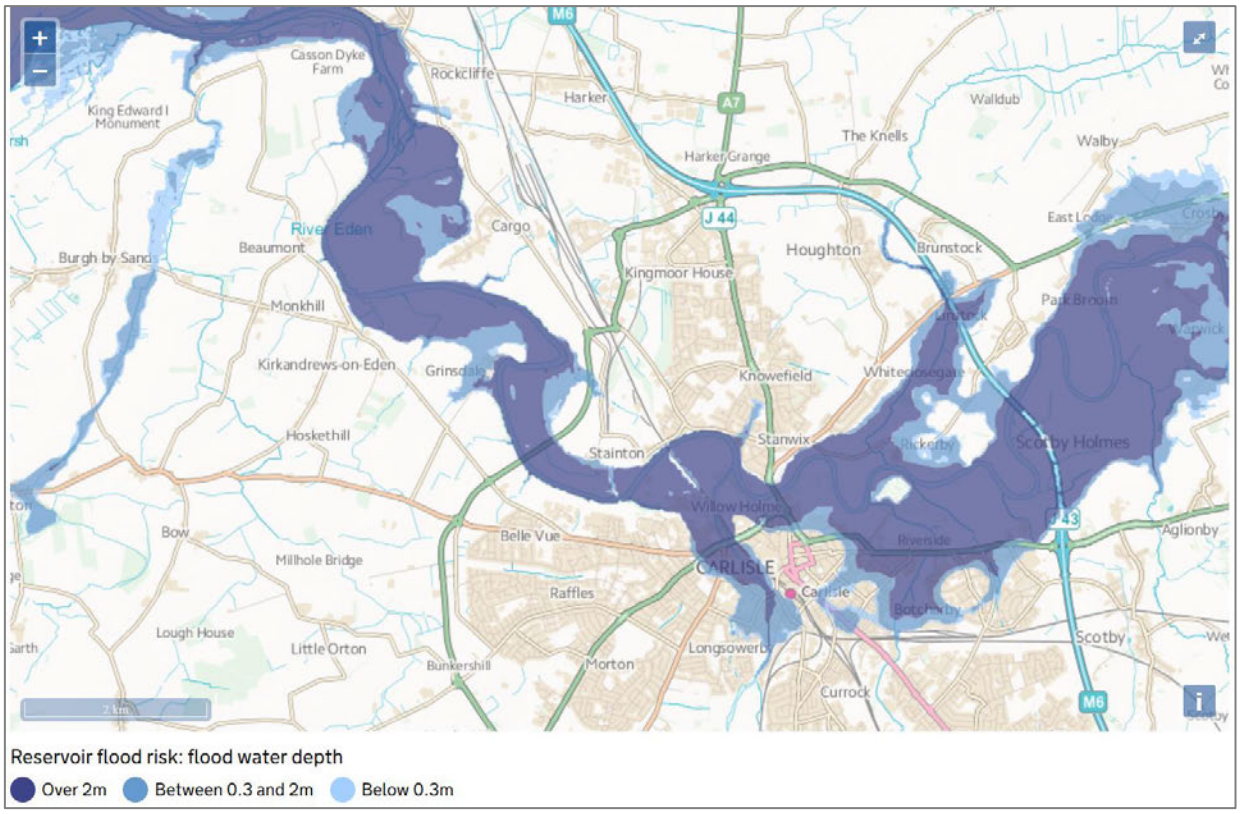

Figure F3 Flood water depths from Haweswater, Cumbria – larger scale view of lower reaches

As shown below, even small reservoirs can create extensive flooding.

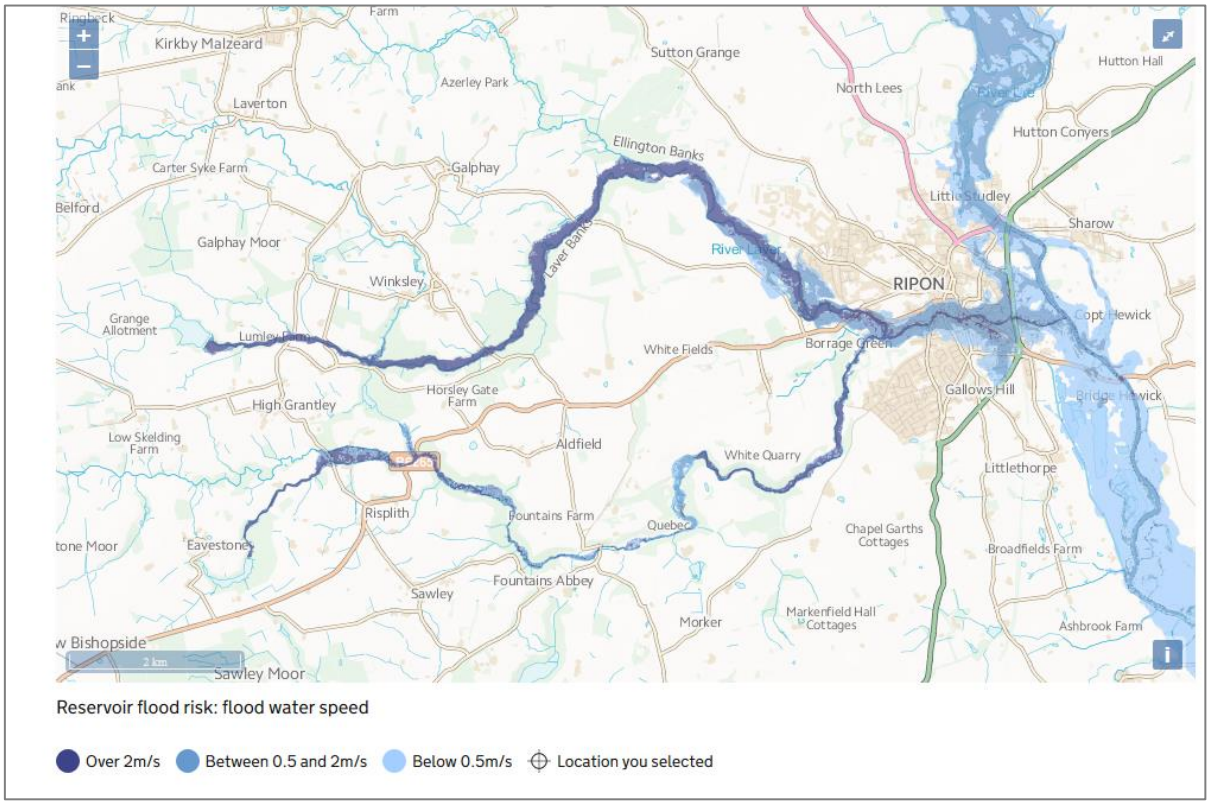

Figure F4 Flood water speed from example small reservoirs

Appendix G: Wind turbine blade tip speeds

G1 Tip speed

Tip speed is a key factor controlling blade / ice throw distance from wind turbine generators (WTGs). However, as shown in Figure G1, it is not directly determined by any of the most obvious and easily obtainable design parameters (turbine power or diameter).

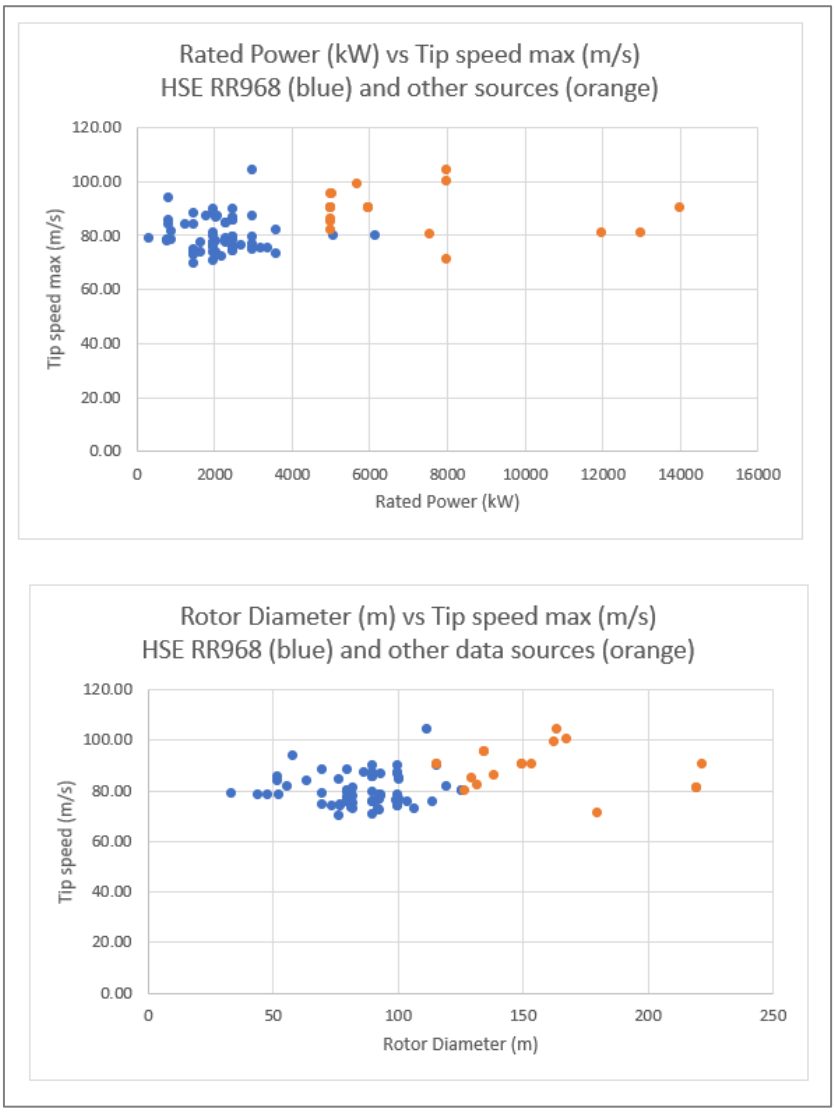

Figure G1 Tip speed relationship to turbine power and rotor diameter
Based on data from HSE RR968 [25] and - for more recent, larger turbines - industry sources as collated at https://en.wind-turbine-models.com/turbines and manufacturer websites

It is therefore not possible to define, in a readily understandable parametric way, bounds on the size or design of WTGs for which the estimated hazard ranges are valid.

There is also no clear basis for setting bounds by reference to technological factors, as the factors that determine and limit tip speed are complex and interacting. In brief, faster tip speeds have some advantages in relation to torque on the drive train, structural, gearing, and energy capture considerations, but lead to increased noise, and blade erosion from impact with raindrops, particulate matter, hail, ice and salt. See for example [26] and [27].

Tip speeds for conventional designs seem unlikely to exceed the 150 m/s maximum assumed in the references used for blade throw distance. Monitoring of developments in WTG design and operation would be advisable, however.

G2 Sensitivity study: effect of wind turbine elevation

A sensitivity study was carried out on the additional throw distance when (as will often be the case) the turbine is on high ground and the nuclear site low down.

The scoping analysis used the standard equations of motion. It ignored aerodynamic effects: drag and lift. This is likely to be conservative, since there will always be air resistance to a thrown object, whereas it seems unlikely that a blade would remain in an orientation that gave it significant lift (a gliding or 'frisbee' effect). A 45 degree launch angle was assumed, to maximise throw without aerodynamic effects.

From the basic 'SUVAT' equations of motion it can be shown that

$$T, \text{ time of flight} = (V_v + \sqrt{(2gH_r + V_v^2)})/g$$

Where

V_v = vertical velocity component of tip speed (m/s)

H_r = height of blade tip at launch above nuclear site (m)

g = acceleration due to gravity (m/s^2)

The throw distance, S is then given by:

$$S = V_h t$$

where

V_h = horizontal velocity component of tip speed (m/s)

Table G2 shows an example set of input parameters for which the throw distance would be around 2km.

Table G2 Sensitivity study on wind turbine elevation

Parameter	Value (fixed/ user input / calculated)	Comment
Gravity acceleration (ms^{-2})	9.81	
Rotational speed (rotations/s)	0.16	
Radius (~ blade length) (m)	120	
Turbine hub height (m) above ground level	150	
Height of turbine base (m AOD)	600	Typical upland UK hilltop height AOD. Strictly, should be height above nuclear site (or its vulnerable parts) but assume, somewhat conservatively, that the nuclear site is at sea level (as many of them are).
Additional tip height at launch	84.9	Assume blade pointing up at 45 degrees at launch
Launch Height (m)	834.9	Turbine hub height, plus height of turbine base plus additional height to tip
Blade tip speed (m/s)	**120.6**	Limiting case for 2km throw
Horizontal velocity (m/s)	85.3	Assume 45 degree launch angle, to maximise throw without aerodynamic effects. Assume full tip speed, as it could be a fragment, or ice, coming off the tip. (If it were the whole blade we would use approximately half the tip speed.)
Vertical velocity (m/s)	85.3	
Time of flight (s)	24.4	Used in calculation of throw distance
Throw distance (m)	**2079.2**	Just over 2km

It can be seen from the table that a tip speed of 120m/s can gives a 2km throw distance for a large turbine with a 120m blade length on a 600m hill.

As a result, we suggest a tip speed of 120m/s (rather than the 150m/s in the literature sources) as the limit for which the assessed hazard range in this review is valid.

Appendix H Net zero: new and emerging technologies

This Appendix provides a summary of new and emerging technologies related to the net zero agenda.

The primary driver for relevant change is likely to be the government's net zero targets. It is expected that there will be a huge transition in the energy sector. Firstly there is a drive to increase energy efficiency, followed by developing additional technologies to achieve net zero carbon emissions. There are four areas in which new technology is likely to be developed and scaled up:

1. Increase in renewable energy and energy storage
2. Carbon capture, utilisation and storage (CCUS)
3. Hydrogen and hydrogen related fuels, including green hydrogen production via electrolysis of water, and hydrogen storage
4. Bioenergy from sustainable biomass energy (combined with CCUS)

Renewables

It is expected that there will be an increase in applications for renewable generation developments. Wind farms are of particular relevance, because of the external hazard of blade throw. The balance of plant should be considered as well as the turbines themselves. For example, hazards from any onshore substations that form part of an offshore wind farm application may need to be considered, as well as blade throw from the turbines.

With an increase in intermittent, variable forms of renewable energy (mainly wind and solar), there will need to be a large increase in the capacity to store energy so that it can be used when required. There are many ways that energy can be stored and the technology for this is being developed and scaled up in parallel with increasing renewable energy production.

An increase in renewable electricity will run in parallel with an increase in electric vehicles.

CCUS

During the transition to zero carbon energy, there is a need to capture and store carbon from traditional hydrocarbon fuels. This can be done in a variety of ways including extracting the carbon prior to combustion and scrubbing carbon from exhausts post-combustion. Once captured, the carbon needs to be stored. Projects for this are being developed across the UK, focussed around industry clusters. The current proposals are for the industries within each cluster to collect their carbon (as CO_2) and store it in offshore spent oil and gas fields. This allows for enhanced recovery of oil and gas in the fields and uses geological features that are known to be stable for long term storage. In order to optimise transport, export and injection, the CO_2 will be compressed to become a 'dense fluid' or 'super critical fluid' where the CO_2 becomes a dense, highly compressible fluid that demonstrates the properties of both liquid and gas.

Some industry clusters are not well located for access to offshore storage locations and may look to export the captured CO_2 via ship to a location with an offshore connection.

It is expected that industry will try to find other uses for the captured CO_2.

Hydrogen

As part of the transition to net zero, 'blue' hydrogen can be produced from hydrocarbon fuels and the associated carbon captured and stored.

'Green' hydrogen is produced from water via electrolysis. The electrolysis will use renewable energy. During the transition to net zero, it is planned for hydrogen to be blended into the existing UK gas network. It is planned for the gas network to be transitioned to run on pure hydrogen.

Hydrogen can also be used as fuel for vehicles. Current plans are for this to be used for commercial vehicles.

Green hydrogen can also be used to produce ammonia, which can be used as a fuel. It is expected that this will be used for container ships.

Hydrogen fuel cells can also be used to produce electricity.

Bioenergy

Bioenergy refers to electricity and gas that is generated from organic matter, known as biomass. This can be anything from plants and timber to agricultural and food waste and even sewage.

Dry, combustible feedstocks such as wood pellets are burnt in boilers or furnaces. Wet feedstocks, like food waste for example, are put into sealed tanks where they rot and produce methane gas (also called biogas).

Bioenergy is a very flexible energy source. It can be turned up and down quickly to meet demand, and so can be used as a backup for weather-dependent renewable technologies such as wind and solar.

In order to meet net zero targets, the projects must be combined with CCUS.