Office for Nuclear Regulation

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Accidental Aircraft Crash Hazard			
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LIST OF ABBREVIATIONS

AIAA	Areas of Intense Aerial Activity
ATS	Air Traffic Service
AVGAS	Aviation Gasoline
CAA	Civil Aviation Authority
CTA	Control Area
CTR	Control Zone
DBE	Design Basis Event
IFR	Instrument Flight Rules
LC	Licence Condition
MATZ	Military Air Traffic Zone
MCA	Military Combat Aircraft
MCE	Maximum Credible Event
MTWA	Maximum take-off weight authorised
NATS	National Air Traffic Service
ONR	Office for Nuclear Regulation
PMP	Provost Marshal Prohibition
SAP	Safety Assessment Principle(s)
TAG	Technical Assessment Guide(s) (ONR)
TAP	Technical Advisory Panel
TMA	Terminal Manoeuvring Area
VFR	Visual Flight Rules

GLOSSARY

Term	Description
Aeronautical VFR charts	Aviation charts published by the CAA specifically aimed at pilots flying visually under 'Visual Flight Rules' (VFR). VFR rules require pilots to be clear of cloud and in sight of the surface at all times. Instrument Rules (IR) apply to pilots flying outside the limits of VFR, ie in Instrument Meteorological Conditions (IMC).
Aircraft	Includes aeroplanes, helicopters, remotely piloted aircraft systems and any other airborne vehicle.
Byrne model	The Byrne model is a generic name given to the evolution of models created by the nuclear engineer John Byrne in the 1980s to enable the British nuclear industry to examine aircraft crashes into nuclear facilities. Various studies were carried out collecting background crash rate data and a model for airport related crashes was created by Jowett and Cowell (1991) [1]. The Byrne revision was published in 1997 and it was updated by a revision of the accident data (Kingscott, 2002 [2]) with the latest version (ESR Technology, 2008 [3]) being applied as an acceptable means of compliance with the evaluation of aircraft crash requirements onto licensed nuclear sites in Great Britain.
Civil Aviation Authority (CAA)	The UK's independent specialist aviation regulator, established by Parliament in 1972.
Controlled airspace	Controlled airspace is a volume of airspace, specified by geographical extent and height limits, where aircraft movements are controlled by procedural rules. Pilots must generally seek authorisation to enter and transit such airspace from a local Air Traffic Control (ATC) unit. Such airspace is classified and the rules vary according to class. Controlled airspace is established around major airports and along prescribed transit routes where traffic density is high and safe separation of aircraft is controlled by pilot compliance with ATC instructions.
Pilot-in-Command	The Pilot-in-Command is the person who: 1. Has the final authority and responsibility for the operation and safety of the flight; 2. Has been designated as pilot-in-command before or during the flight; and 3. Holds the appropriate category, class, and type rating (licence), if appropriate, for the conduct of the flight
Technical Advisory Panel (TAP)	The Technical Advisory Panel (TAP) was established in 2012 to provide independent, objective, authoritative, professional scientific and technical advice to the Chief Nuclear Inspector in the area of accidental aircraft crash hazard analysis.
The TNT equivalence method	The term "TNT equivalence" is a normalisation technique for equating properties of an explosive to an equivalent quantity of trinitrotoluene.
Turboprop	Turboprop, also called P Jet, is a hybrid engine that provides jet thrust and also drives a propeller.

INTRODUCTION

1. This annex provides guidance on accidental aircraft crash hazard considered relevant to nuclear safety on nuclear licensed and authorised sites. It applies the general principles set out in the head Technical Assessment Guide (TAG) 13 document [4] and provides guidance to inspectors in the application of the Safety Assessment Principles (SAPs) [5] to the assessment of accidental aircraft crash hazard. Figure 1 summarises a typical approach to assessing the risk posed by accidental aircraft[1] crash at GB nuclear sites and links to relevant SAPs [5]. Unlike many other external hazards, it is not possible to calculate a hazard frequency curve for aircraft crash. Therefore, SAP EHA.8 expects the total predicted frequency of aircraft crash on or near any nuclear facility to be determined. According to EHA.19, if an aircraft crash has no significant consequential effect on the safety of a nuclear facility, or it has a total initiating event frequency that is demonstrably below once in ten million years, it can be screened out from fault analysis. However, if it cannot be screened out on either criterion, a design basis event (DBE) should be derived in accordance with EHA.3.

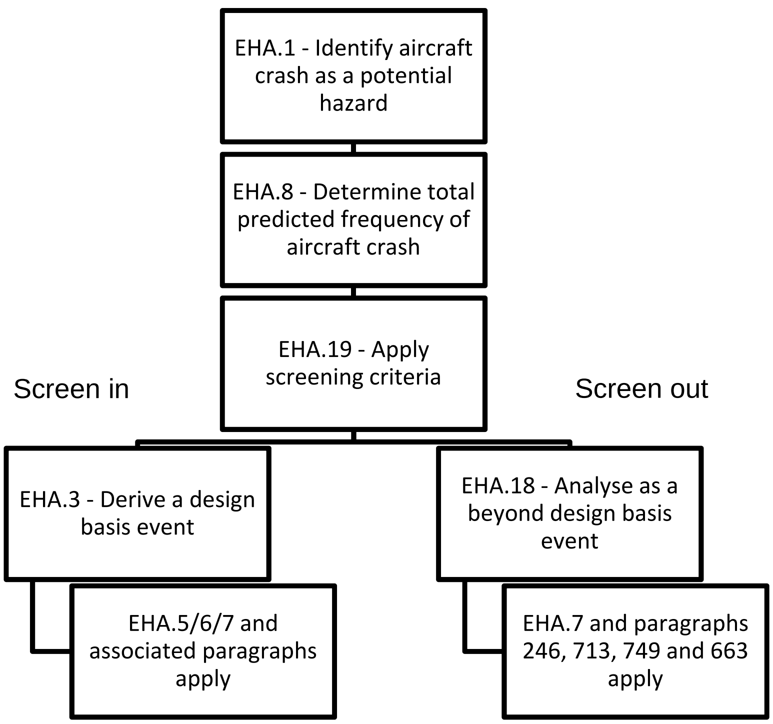

Figure 1 – Summary of a typical approach to assessing the risk posed by accidental aircraft crash at GB nuclear sites

2. The following sections set out the matters that should be taken into consideration by Office for Nuclear Regulation (ONR) inspectors undertaking assessment of dutyholders' safety documentation relating to accidental aircraft crash.

[1] The term aircraft includes aeroplanes, helicopters, remotely piloted aircraft systems and any other airborne vehicle.

1 HAZARD INFORMATION

1.1 Aircraft Categorisation

3. For the purpose of aircraft crash risk assessment, aircraft are normally categorised to take account of the different flying characteristics and reliabilities of the aircraft as well as the impact characteristics, defined generally by mass and velocity. The following 5 categories of aircraft are typical of how a dutyholder may choose to make an assessment of individual and overall aircraft crash risk.

- **Light civilian aircraft (Category 1)** – Fixed wing aircraft generally falling into the Civil Aviation Authority (CAA) classification of less than 2.3 te maximum take-off weight authorised (MTWA)
- **Helicopters (Category 2)** – All civilian and military helicopters
- **Small transport (Category 3)** – Fixed wing aircraft covering the mass range 2.3 - 20.0 te MTWA, including civilian and military transport aircraft
- **Large transport (Category 4)** – Any other fixed wing aircraft, civilian or military, not covered in the light aircraft, small transport or military combat and jet trainer categories
- **Military combat and jet trainers (Category 5)** – All military fixed-wing aircraft with MTWA up to 50 te used for, or capable of, aerobatic style flying.

4. The principal difference between the above categorisation and those used in other studies eg Slater [6], is in the separation of civilian fixed-wing aircraft into two categories. It is sometimes the case that the light aircraft category is replaced by a general aviation category of MTWA 5.7 te or less, and a single commercial aircraft category is used for all aircraft with MTWA greater than 5.7 te. The CAA's annual publication "Accidents to aircraft on the British Register" (now no longer published) used MTWA categories of <2.3 te, 2.3-5.7 te and >5.7 te for accidents to fixed-wing aircraft not engaged in public transport. Accidents to aircraft engaged in public transport were split into different MTWA categories. A different method of categorising aircraft, which has been used in airport third party risk studies, such as [7], is to group civil fixed-wing aircraft according to seat capacity.

5. There can be difficulties in placing some aircraft into the above categories, for example, with military aircraft such as the Tucano. This is a single turboprop military training aircraft used by the RAF as a replacement for the Jet Provost. The Tucano is therefore not a jet aircraft, but is too large to be classified as a light aircraft. For background crash rate studies, the Tucano should be placed into Category 5 for a conservative approach.

1.2 Crash Rates

6. In July 2012, the then Chief Nuclear Inspector took a decision to convene a Technical Advisory Panel (TAP) on the topic of accidental aircraft crash. He considered that whilst there was confidence in existing methodologies, there would be value in exploring potential improvements to the methods for calculating accidental aircraft crash frequency. The TAP was convened in order for its members to provide independent, objective, authoritative, professional scientific and technical advice to the Chief Nuclear Inspector in the area of accidental aircraft crash hazard assessment.

7. A survey of 18 models for assessing accidental aircraft crash risk was conducted. All were found to have individual strengths and weaknesses with no one model standing out as having more favourable characteristics than the others. The Byrne model, which is the most commonly used methodology in the UK nuclear industry, was found to be at least as strong as any other in its ability to quantify accidental aircraft crash risk.

8. There was consensus amongst the panel that the Byrne methodology is fit for purpose but that it could be enhanced by learning from other available models, and the other factors identified by the TAP during the course of its deliberations [8]. For this reason,

the Byrne model is referred to frequently throughout this TAG but this should not be taken to mean that other models should not be considered to be equally valid so long as they are applied within their individual limits and constraints.

9. Licensees should make an assessment of ground impact rates for the different aircraft categories. After assigning a background crash rate to the site of interest based on the most recent crash rate data, and assessing the effects of aerial features such as airfields and controlled airspace, a crash rate in terms of crashes per square kilometre per year should be obtained. The effective target area should then be calculated and multiplied by the crash rate to obtain the aircraft impact frequency measured as the number of crashes per year onto the facility being assessed. This is the value required for the safety case.

10. When calculating the target area for facilities licensees should include all facilities which provide a safety function or could be the source of a radiological release requiring consideration in the safety case. Where a site has multiple facilities it is the total target area which is relevant, the licensees should not provide a facility by facility target area without summing the target area for the site. This is relevant even when sites provide separate safety cases for each facility. Target areas may take into account the available angles of approach and mutual shielding by structures.

11. For most UK facilities, this figure will usually provide assurance that the risk is acceptably low. However, in some situations it may be necessary to demonstrate that, given a crash, the consequences are acceptable. In these cases, aircraft impact effects, including structural damage and damage to safety systems, should be assessed.

1.3 Aircraft Impact

12. When a structure is subject to impact by an aircraft, the global damage is evaluated in terms of excessive deformation (ie, displacement, or collapse of the structure). For a global response evaluation, the target's deformation due to aircraft impact depends on the characteristics of the aircraft and the target. The important parameters for the aircraft are mass, stiffness, strength, size, and velocity. The important parameters for the target are geometry, support conditions, stiffness, and strength.

1.4 Fuel Fires

13. The main type of fuel used for both civilian and military aircraft is Jet A1. This is a low volatility fuel which is more difficult to ignite than JP-4, Jet B or aviation gasoline (AVGAS). The use of AVGAS is becoming confined to light aircraft and modern light aircraft engines are increasingly running on normal road vehicle unleaded gasoline. Jet B is hardly used in the UK. Tests have shown that Jet A1 takes longer to ignite than JP-4 / Jet B, produces smaller fireballs and a smaller proportion of the fuel is burnt. However, tests on fuel mists for low and high volatility fuels have shown similar rates of flame propagation and ignition limits. Fuel quantities carried by aircraft vary widely. Large transport aircraft can carry quantities up to 200,000 litres; for military combat aircraft (MCA) the quantities carried vary from about 3,500 litres for training aircraft up to 20,000 litres for fighter / bomber aircraft. Light aircraft carry much smaller fuel loads, generally ~100 litres.

1.5 Debris

14. There are typically 40 reported incidents per year of debris falling from airborne aircraft. Approximately 20 incidents of falling ice per year are reported in the UK. Other incidents are likely to occur but are not reported because they do not affect the general public. The quantities of ice involved vary widely, ranging from lumps the size of a cricket ball to several cubic feet. The most severe damage reported is damage to buildings such as holes in roofs.

15. There have also been about 20 reports per year of aircraft parts or other objects falling from aircraft. Most of the objects are small such as locking pins, oil fill access panels and light covers. There are a few large objects such as panels or landing gear doors. The majority of incidents occur during the flight phase with a further 10% in each of climb and approach phases. Most of the incidents (about 75%) involved large transport aircraft.

16. Ref. [9] gives guidance on the frequency of aircraft sourced debris incidents.

1.6 In-flight Breakup

17. The potential problem of in-flight break-up of aircraft was highlighted by the Lockerbie incident of December 1988. Following the explosion of a terrorist bomb at altitude a Boeing 747 disintegrated immediately and wreckage was spread over a wide area, with the largest pieces falling on the town of Lockerbie[2]. The devastation caused gave an indication of the potential for serious consequences should such an incident occur over an industrial installation.

18. Ref. [10] provides useful guidance on the characteristics of parts falling from an aircraft that has broken up during flight and the frequency of in-flight break-up.

[2] Although the Lockerbie incident was strictly a malicious act, it is, by convention, included in statistics on accidental aircraft crash.

2 SAFETY ANALYSIS

2.1 Crash Rates

19. In accordance with EHA.2 and paragraph 249, the calculation of crash frequencies should include the most recent crash statistics, flight paths and flight movements for all types of aircraft, and take account of foreseeable changes in these factors if they affect risk. Furthermore, details of any local aerodromes (including flight paths), operating regimes and volumes of flights as well as any military flight activity in the area should also be taken into account. Inspectors should assure themselves that the data selected by a dutyholder to support its analysis is geographically relevant and statistically sufficient.

20. A wide range of methodologies have been developed for the estimation of aircraft crash risk, each of which has its own strengths and weaknesses. The predominant approach adopted by the UK nuclear industry is the so-called Byrne methodology [11], which is considered by ONR to be relevant good practice. However, there are limitations to this approach principal amongst which is the small volume of data from which the model has been developed. Another major limitation is the implicit assumption that flight paths into and out of airports are linear tracks. Where flight paths close to airports are nonlinear, the uncertainties associated with the methodology should be captured in the analysis.

21. Whichever methodology is applied by the dutyholder, inspectors should assure themselves that it takes account of the known uncertainties and weaknesses of the specific approach. The TAP on Accidental Aircraft Crash Hazard Assessment initiated by the Chief Nuclear Inspector in 2012 commissioned a review of the various methodologies that were in use at that time [12] and provides a useful reference to support judgements in this regard.

22. Crash rate data is collated and categorised into background, airfield related and airways related, as detailed below.

2.1.1 Background crash rate

23. Background crash rates will change with time for several reasons and should be reviewed by dutyholders on a regular basis. Aircraft activity varies with time both in terms of the types of aircraft in use and the level of activity. These changes happen generally and at individual airfields. Aircraft reliability will also likely change with time and affect crash rates.

24. For the UK, the most significant factor affecting changing background crash rates is changes in defence policy in Western Europe which has led to a decline in military aircraft activity in the UK. This can be measured both in terms of the number of low level sorties annually and the rundown of US Air Force activity in the UK.

25. Military Combat Aircraft (MCA) probably pose the greatest potential risk to GB nuclear sites because of their relatively high masses and velocities and the nature of low-level sorties. It is particularly important therefore that Licensees monitor changes in MCA activity and assess any observed changes in activity.

26. The last review of aircraft crash rates in the UK for the nuclear industry was in 2008 [3]. The CAA maintain and publishes lists of safety incidents such as birdstrikes and "mandatory occurrences", which includes crashes, at [13]; it also publishes numerous analysis reports based on this data eg [14].

2.1.2 Airfield related crashes

27. Most airfield-related crashes occur within about 10km of the runway threshold. In most crash rate assessments a conservative approach is taken and airfields within about 20km are identified. There are over 400 airfields in the UK ranging from profit-making

licensed airfields to non-profit making licensed airfields and non-licensed airfields such as farm strips. There are also many unused airfields. A full listing of UK licensed airfields is compiled and kept up to date by NATS [15] and all licensed and unlicensed airfields known to NATS are reflected on aeronautical maps published by NATS. Details of the airfields listed by NATS are contained in the UK Integrated Aeronautical Information Package [16].

28. Most aircraft accidents occur during the take-off and landing stages of flight rather than in-flight stages. The take-off phases account for about 25% of accidents, the initial climb and cruise phases account for about 20% of accidents whilst the landing phases account for a little over 50% of accidents.

29. The estimation of the crash rate attributable to airfields should be calculated taking account of:

- the number of movements per year on the runway, taking care to account for each runway direction separately;
- the probability per movement of a landing or take-off accident, and;
- the probability of a unit ground area at a specific location suffering an impact given that an accident has occurred, usually expressed as a function of the distance from the end of the runway and the angle between the extended runway centreline and the site being assessed, measured at the end of the runway.

30. Estimates of aircraft reliabilities ie the probability of an accident on landing or take-off, in the UK can be found in [12]. Methods for calculating impact probability distributions can be found in [1].

2.1.3 Crashes below airways

31. Calculation of crashes below airways is usually unnecessary for a number of reasons. The calculation of background crash rates (Section 2.1.1) specifically excludes accidents in the airport-related phases of flight, and must therefore be made up of accidents that have mostly occurred in the en-route phase of flight. Adding an airway related crash rate to the background is effectively double counting and is considered to be an overly conservative approach.

32. A potential grey area is for accidents in which the aircraft is more than 5 miles from the airfield, for example in a holding pattern prior to landing, and may therefore not be classed as an airfield-related incident.

33. It has generally been found in previous site-specific assessments for sites in the UK that airways make only a small contribution to the overall crash rate. In most cases the background crash rate is the dominant influence on the crash rate. Airways are designed to route commercial air traffic and only pilots licensed to fly under Instrument Flight Rules (IFR) are qualified to transit along them. Since very few private pilots are qualified to fly IFR, this effectively means that almost no light aircraft movements take place within airways. Airways terminate close to major airports where they give way to other forms of controlled airspace that do allow for non-IFR traffic.

34. It can usually be shown that unusually high levels of activity on airways situated close to a site would be required for the airway crash rate to be significant compared to current background levels (of the order 10^6 movements per year). The inspector should seek assurance that if a Licensee has not accounted for airway-related crashes that this is appropriate. There are some sites in the South of England for example where major airways from Southern Europe and Africa cross with major airways from North America. Airways related-crash rates may be significant in these cases.

35. A cautionary note should be struck however. If calculated levels of background crash rates fall and airway related activity continues to increase, it may be necessary to calculate values for the latter. A further consideration is that for some sites the crash rate may be strongly influenced by airfield activity, or the site's proximity to areas of high MCA activity. For these sites in particular, the question of airway activity is usually low priority.

2.1.4 Total crash rate and screening

36. Having determined the background crash rate, any relevant airfield contribution and where appropriate an airways contribution for each category of aircraft, the individual components should be summed to arrive at a total crash rate.

37. In accordance with EHA.19, hazards whose associated faults make no significant contribution to overall risks from the facility should be excluded from the fault analysis. Screening criteria should be defined in terms of frequency of occurrence and potential consequences. Accidental aircraft crash hazard may be excluded if it has no significant identified consequential effect on the safety of the facility, or if it has a total initiating frequency that is demonstrably below one in ten million years.

2.2 Aircraft Impact Parameters

38. As has already been stated, accidental aircraft crash hazard is not easily amenable to the derivation of a DBE based on frequency. Consequently, a surrogate maximum credible event (MCE) supported by scientific evidence should be defined (see SAPs paragraph 242). The severity of the MCE should be compatible with the principles of FA.5.

39. For accidental aircraft crash hazard, structural demand depends on the mass, rigidity, velocity and engine location in the aircraft as well as any assumption on whether the aircraft impacts directly or skids into the structure and the associated angle of impact. For these reasons, aircraft are usually categorised into a small number of groups as described in Section 1.1. For a DBE, the type(s) of aircraft and the associated load-time function(s) should be specified, or a bounding load-time function should be specified [17].

40. Analysis of the accidental aircraft crash DBE should apply an appropriate combination of engineering, deterministic and probabilistic methods in order to understand the behaviour of the facility in response to the hazard and to confirm the high confidence in the adequacy of the design basis definition and the associated fault tolerance of the facility.

2.2.1 Angle of descent

41. From studies of accident reports for all fixed-wing aircraft descent angle distributions have been derived by [18] which take account of pilot avoidance. MCA accidents are separated into those initiated above and below 2000 feet as below this level most accidents are associated with low level flying activities. Ref. [11] (Table 11) shows the descent angle distribution evaluated for helicopters, which is not based on accident studies but on a theoretical study.

2.2.2 Effective target area

42. In order to assess the probability of impact, a dutyholder may derive an effective 'target area' for the site, taking account of the plan area and height of safety related buildings, a representative range of impact angles etc, which can then be combined with the aircraft crash frequency. For an unshielded cuboid subject to isotropically distributed aircraft approach directions, the effective target area when subject to aircraft crash is given by:

$$A_E = lw + \frac{2}{\pi} h(w + l) \sum_{i=1}^{i=n} f_i \cot \theta$$

in which h, l and w are the cuboidal dimensions and f_i is the proportion of crashing aircraft having descent angle θ_i.

43. If the cuboid is partially shielded from impacts by other structures then this expression will give a conservative estimate. Expression for effective target areas that take account of shielding can be found in [11] but in most cases the above expression will suffice.

44. Applying the descent angle distributions from Section 2.2.1, the above expression can be simplified for each aircraft category.

45. The target area should be calculated and reported for the site, rather than for a single facility. The site target area will be the sum of the facility target areas even when a site provides individual facility safety cases.

2.2.3 Impact mass distribution

46. Impact mass probability distributions have been derived for the types of aircraft in use in the UK [19]. Most light aircraft (about 80%) are in the <1te range. This implies that the potential for significant damage from light aircraft, particularly for reinforced concrete structures, is low.

47. Separate distributions are given for civil and military helicopters as well as a combined distribution as military helicopters are generally heavier and will be more prevalent in some parts of the UK. The civil helicopter mass distribution shows a large number of aircraft with relatively low masses; as with light aircraft these would be unlikely to pose a significant hazard to most GB nuclear facilities. It should be noted that both the civil and military mass distributions are skewed by the inclusion of the Chinook, which at 21te, is at least twice as heavy as any other helicopter included in the distribution.

48. The large transport aircraft mass distribution is a combined distribution including both turboprop and jet aircraft. Turboprops account for less than 10% of large transport movements in the UK.

49. Over 50% of MCA have impact masses of less than 15te. There are fewer heavy aircraft in this category than in previous years as aircraft such as the F-111E are no longer flown by the US Air Force from the UK.

2.2.4 Impact velocity distribution

50. Aircraft impact velocity distributions can be found in Refs. [18] [20]. For helicopters, the distribution is based on a theoretical study of the probable velocities at impact following an in-flight failure. For all other aircraft categories the distributions are based on accident reports.

2.3 Consequences

2.3.1 Impact

51. The impact of an aircraft with a rigid structure is usually considered to be either a ‘soft’ missile or a ‘hard’ missile. The former can be thought of as the impact of deformable components such as the fuselage, the latter involves the impact of either non-deformable components such as the engine and undercarriage or the crushed remainder of the aircraft if multiple perforation occurs.

52. In a soft missile impact with a rigid structure some of the impact energy is expended in crushing the missile. For both soft and hard missile impact, failure of reinforced concrete

slabs is by a local ‘punching’ mode typically leading to spalling on that back face and even penetration, but global deformation of the structure is also possible. The initial mass of the missile is usually taken as that of the intact aircraft. If perforation occurs the aircraft can be considered to be deformed to a hard missile having the same mass as the initial soft missile. This is a conservative assumption as in practice some of the lighter components would be stripped from the aircraft during the initial impact.

53. Consideration of impact by the engines alone may be under conservative as the engines can be a relatively small proportion of the overall mass of the aircraft. The mass of an aircraft engine varies widely between different aircraft categories, but as an illustration, the mass of a Phantom engine was about 1.6te and the maximum take-off mass of the aircraft was about 28te.

54. There are three widely accepted analytically based methods that can be used to evaluate global damage: (i) energy balance method, (ii) force-time history analysis method, and (iii) missile target interaction analysis method.

55. The methodology most commonly adopted in the UK nuclear industry is the force-time history analysis typically associated with Riera [17]. The Riera method uses the aircraft’s mass-distribution and strength properties, and its velocity to determine the impact force time history. The Riera method assumes that the target is rigid and that the impact orientation is normal to the target so the aircraft fuselage will progressively crush / buckle axially. The impact orientation assumption results in the highest missile stiffness making the Riera method conservative. Thus, the damage potential of a crashing aircraft depends on the combination of the mass of the aircraft (or any hard components, such as engine or landing gear) and the speed of the impact.

2.3.2 Fire and explosion

56. Consequence analysis should include fire and explosion hazards deriving from aircraft crashes including fires caused by aircraft fuel, fireball and pool fire combinations and other consequential fires due to the aircraft crash. This will be more significant for the heavier classes of aircraft due to the high fuel load being carried.

57. The consequences of an aircraft fuel fire or explosion on major installations such as nuclear facilities are difficult to predict and there is no systematic methodology for dealing with the problem. The TNT equivalence method offers the most suitable means of dealing with explosions, although the blast characteristics of an aircraft fuel vapour / air mixture and TNT are similar only at longer ranges.

58. The peak temperatures reached in an aircraft fuel fire and the duration of the fire can be calculated from the fuel type and quantity. This may be an over-simplification as the aircraft itself, any cargo carried and combustibles in the impact zone should also be taken into account. A fire is therefore possible of longer duration and reaching greater temperatures than from aircraft fuel alone.

59. For military aircraft accidents the frequency of aircraft fuel fire is estimated to be about one in every three crashes. For civil aircraft accidents estimates vary, but a figure of one crash in every two accidents leading to an aircraft fuel fire would be appropriate.

60. About 80% of MCA accidents which result in post-crash fires happen in the landing and take-off phases of flight[3]. This suggests that the probability of a MCA crash which results in an aircraft fuel fire on a nuclear site will only be significant if the site is located close to an airfield.

61. Further information can be found in [21].

[3] A consideration is that in the take-off phase aircraft are obviously more heavily loaded with fuel, however any effect this has is automatically captured by the crash statistics and it is generally not considered necessary to make any distinction for the purposes of crash analysis.

2.4 Adequacy of Analysis

62. In judging whether or not a dutyholder has undertaken sufficient analysis, the inspector should identify how external factors have been taken into account. For example, whether or not the dutyholder has considered the type and nature of instrument landing system employed at the aerodrome, local use of the facility as a navigational aid, local navigational turn points, potential changes in flight paths and patterns, operational feedback of aircraft approaches to the facility and possible expansion of the airport and runways. The initiation frequency will be determined by an effective estimation of target areas, see Section 2.2.2.

63. The analysis should also identify the potential impact of accidental aircraft crash on the facility's systems, structures and components, and in particular safety systems. It should also determine the need for segregation, diversity and redundancy of the plant and equipment. However, the potential for an accidental aircraft crash to affect safety should also take account of the potentially widespread effects the event may have in challenging multiple safety systems in multiple locations simultaneously. In this instance, safety based on segregation, diversity and redundancy may be significantly challenged.

64. Other factors which may support an inspector's judgement on the adequacy of analysis undertaken by a dutyholder includes consideration of the assumptions relating to various aircraft impact models, skidding models including derivation of skidding friction factors, and projectile bounce.

65. Analysis undertaken by dutyholders should include a measure of confidence. A conservative design basis should align with the advice in [4] Section 5.5.1 and a best estimate value is appropriate for beyond design basis events.

2.5 Other Aerial Features

66. There are a large number of civil and military flying areas where flight is restricted to certain types of aircraft or for certain types of flying; those most relevant to nuclear safety are considered below. All these areas are represented on aeronautical Visual Flight Rules (VFR) charts [22] and a good guide to the definition and rules applying to each type is available in [23].

67. A dutyholder may seek to support its deterministic and / or probabilistic methods by taking account of flying restrictions in the local area, including those protecting the site itself. However, the inspector should be satisfied that this is justified given that it is relatively common for the CAA to issue exemptions to these restrictions for some aircraft without necessary recourse to either the dutyholder or ONR eg for power line inspections. It will be difficult for dutyholders to justify arguments that take account of the restricted airspace unless it can be demonstrated that they have direct control over the CAA's exemptions process.

68. The CAA is the UK's aviation regulator. ONR has no vires in relation to airspace over or around nuclear licensed sites. Any issues identified in relation to infringement of restricted airspace over a licensed site should be reported by the dutyholder to the CAA and via the INF1 process to ONR.

69. **Provost Marshal Prohibition** (PMP) zones are in place around most GB nuclear licensed sites. They are cylinders of airspace typically two nautical miles in radius extending to 2000 feet above the surface. All military flying is banned at all times within the PMP zones. However, it is not recommended that the MCA crash rate within the PMP zones should be reduced for two reasons. Firstly, infringements of PMP zones do occur and secondly, accidents could be initiated outside the PMP zone but still affect the site.

70. **Restricted Areas** are in place around many types of hazardous facilities including all GB nuclear licensed sites that have a requirement for an off-site emergency plan. Generally, all civilian and military aircraft are excluded from these areas, however, they may be entered under certain conditions, usually provided prior agreement is obtained from the CAA (see paragraph 68). The arguments for reducing crash rates in restricted areas is the same as for PMPs. The boundaries of restricted airspace around GB nuclear facilities are given in [16].

71. **Areas of Intense Aerial Activity (AIAAs), Military Training Areas** and **Military Temporary Reserved Airspaces** are used by military aircraft for training purposes and sometimes by civilian aircraft involved in unusual manoeuvres. Their locations in relation to nuclear facilities can be found on aeronautical charts [22]. The effect of these areas is usually to increase military activity. Licensees should therefore consider increasing the military crash rate in these areas.

72. **Danger Areas** are generally used for military purposes and cover areas in which activities take place that may be dangerous to the flight of aircraft, such as activities taking place at weapons testing and practice ranges. The areas are generally quite small and many are located offshore. A reduced civilian aircraft crash rate is therefore likely within these areas. However, these areas are unlikely to affect many GB nuclear sites, with the exception of Barrow. Note that many Danger Areas are not permanently active and the dates and time when they are is published by the CAA and National Air Traffic Service (NATS).

73. **Military Avoidance Areas** are areas covering major built up regions in the UK. Low-flying military aircraft are excluded from these areas, other than for landing at specific airfields or for landing during an emergency and a reduction in the MCA crash rate is to be expected. The location of military avoidance areas is published by the Ministry of Defence.

74. **Terminal Manoeuvring Areas (TMAs), Control Areas (CTAs) and Control Zones (CTRs)** are areas defined around major airports or airport clusters in which enhanced levels of flying activity are to be found. Whilst it may seem appropriate to increase the crash rate in these areas to allow for the enhanced activity, it is not recommended for the following reasons. Firstly, the treatment of airfields described in Section 2.1.2 should mean that any site within 5 miles of an airfield (or further for busier airfields) will have a crash rate that takes account of the airfield activity. Secondly, although it may be expected that the concentration of activity in TMAs, CTAs and CTRs would tend to increase the crash rate, there is no evidence to support this, probably due to the enhanced level of procedural and air traffic control.

75. **Military Aerodrome Traffic Zones (MATZs)** are areas established at various military airfields and provide a volume of airspace, generally up to 3000' above aerodrome level, within which increased protection may be given to aircraft in the circuit, approach and climb-out phases of flight, and to all aircraft transiting the zone. As with TMAs, CTAs and CTRs it is not recommended that special treatment be given to these areas.

76. Local Flying Areas are defined in many areas of the UK and are mostly used by light aircraft for leisure flying or training. They generally allow flying within a certain area, up to an altitude of about 3000 feet and under certain weather / visibility conditions. It is generally not necessary to increase the light aircraft crash rate to allow for local flying areas, since the background crash rate will include crashes attributable to this type of activity. However, it may be appropriate and conservative to increase the light aircraft crash rate for sites within the local flying area if they are known to be busy.

2.6 Air Navigation

77. The pilot is responsible for safe navigation of his / her aircraft at all times as Pilot in Command. However, pilots are encouraged to maintain two-way radio contact with a

local or regional Air Traffic Service (ATS) at all times, and must do so when entering or transiting airspace controlled by an ATS, such as around commercial airports (TMAs, CTAs, CTRs) and MATZs, or for commercial traffic flying along airways. ATSs are able to provide navigational advice and instructions to aircraft they are in communication with, based on primary and secondary surveillance radar coverage of their local area. Secondary surveillance radar provides the ATS controller with the geographical location (and often the height) of known aircraft and assists in collision avoidance.

78. Vertical navigation is based on altitude (elevation above mean sea level) and height (elevation above the surface), which in the UK are measured in imperial feet, generally in units of 1000'. For the en-route phase of flight, aircraft fly at known altitude calibrated to a regional mean sea level datum; this ensures that all aircraft altimeters are calibrated to the same datum and promotes safe flight. For approach and landing phases of flight, vertical navigation is generally undertaken in terms of height above runway threshold.

79. Light aircraft generally fly up to 3000' altitude. Above this level, vertical navigation is procedurally controlled in terms of flight levels – FL35 = 3500' altitude, FL50 = 5000' altitude, etc. FLs are established at intervals of 500' or 1000' to maintain adequate separation.

80. Military training is generally restricted to AIAAs. The main fast jet RAF training is undertaken in the AIAA established over Anglesey and Cardigan Bay. In addition, low level training is undertaken down to 250' (fixed wing) and 100' (helicopters), generally in rugged terrain areas that are suitable for such sorties. Such activities are subject to the restrictions imposed by PMP and Military Aviation Authority areas as described above.

3 EMERGENCY PLANNING & ARRANGEMENTS

81. The effects of aircraft crash hazards should be explicitly accounted for in the site's emergency arrangements under LC11. If the response to these hazards is fully accounted for by the arrangements in place to cover other fault conditions, then this should be stated. If special arrangements are required, then these should be identified.

82. A consideration with aviation hazards (and major consequential hazards) is that they provide a common cause effect across the site, ie several independent fault conditions may be created on the site simultaneously. The site's emergency arrangements should recognise this and be able to respond in a pragmatic way to this possibility.

83. Crash rate data for the UK was fist comprehensively compiled in for nuclear safety use in 1997 [21] and there have been two subsequent updates [3], [2]. NATS may be able to provide site-specific aerial activity data for use in aircraft crash rate calculation. NATS and the CAA will be able to provide information in relation to the various types of protected airspace as set out in Section 2.5.

84. The emergency arrangements should recognise that the provision of supplies and staff from off-site may be hindered following an aircraft crash and should identify ways of mitigating the adverse effects on nuclear safety if this occurs.

85. After the Fukushima accident following the Great Japan Earthquake in 2011, ONR recommended the enhancement of existing off-site emergency equipment and the establishment of additional offsite stores [24]. The site's emergency arrangements should refer to such equipment and the type of equipment should be justified by the types of severe accidents that external hazards could generate.

86. ONR provides advice to Local Authorities on the adequacy of their Off-Site Emergency Plans. Such plans, if they consider aviation events at all, will likely concentrate on managing the infrastructure away from any nuclear licensed sites within their geographical area of responsibility. Inspectors (or relevant site inspectors) should advise Local Authorities on the significance of aviation hazards and their potential for widespread common cause effects both on and off nuclear licensed sites.

87. The inspector should seek to ensure that sufficient input data is provided by the Licensee to facilitate the development of adequate emergency plans both on-site and off-site, see [4] Section 5.9. This may include representative MCE data to be assumed for emergency planning purposes.

4 APPLICABILITY OF STANDARDS AND GOOD PRACTICE

88. In July 2012, the then Chief Nuclear Inspector convened a TAP to provide independent, objective, authoritative, professional scientific and technical advice in the area of accidental aircraft crash hazard assessment. The TAP deliberated over a period of two years and called upon relevant scientific, technical and regulatory specialists to provide further expert advice, so that it could fully explore the state of the art in the topic.

89. A survey of 18 models for assessing accidental aircraft crash risk was conducted [12]. All were found to have individual strengths and weaknesses with no one model standing out as having more favourable characteristics than the others. The Byrne model [11], which is the most commonly used methodology in the UK nuclear industry, was found to be at least as strong as any other in its ability to quantify accidental aircraft crash risk.

90. There was consensus amongst the Panel that the Byrne methodology is fit for purpose but that it could be enhanced by learning from other available models, and the other factors identified by the TAP during the course of its deliberations. However, the TAP cautioned that any proposed changes or additional work must be proportionate to the benefits gained.

91. A statistical analysis of available crash data found there is no evidence of a change in the background annual rate of crashes for any of the aircraft categories considered, or in the rate of crashes for small and large transport aircraft. However, there has been a statistically significant increase in the accident rate for light aircraft and helicopters. Crash rates for Great Britain as a whole (rather than England, Scotland and Wales separately) can be used reliably.

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