Modelled Insurance Requirement Determination Process

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Section 1: Overview of the Guidance

1.1 What is the purpose of this document?

This guidance sets out the methodology that the Regulator will use for determining the amount of insurance required under the Modelled Insurance Requirement. This will be included as a licence condition in the launch operator licence. On-going development work as to how the in-orbit phase and the re-entry phase of the launch vehicles mission and their respective insurance requirements are to be considered. The inputs to the modelling of the amount of insurance will be common to those used for the safety case.

1.1.1 Who is this guidance for?

This guidance is for analysts within the Regulator who are responsible for determining the Modelled Insurance Requirement (MIR) for approved launch activities under the Space Industry Act 2018 (SIA)[1].

1.1.2 Using this guidance

The MIR value will be determined following the assessment of the safety case, with the resulting MIR value included as a license condition at the point of granting the license. This guidance is designed to define the method for determining the MIR. The guidance has the following sections :

- Section 2 – Background: Overview of the MIR approach alongside key concepts used in its determination
- Section 3 – Approach to the Insurance Requirements: Overview of the process applied for the determination of the MIR for the major mission phases of a launch activity. Details on the specifics of the steps included in the MIR process are provided in Section 4.
- Section 4 – Modelled Insurance Requirement: Overview of the major steps in the calculation of MIR. This process is currently only applied to the launch phase of the mission. Against each of these steps suggested methodologies are included. This section should be refined as the MIR approach develops.
- Section 5 – In-orbit Insurance Requirements: Overview of the major considerations for the in-orbit phase of the mission.
- Section 6 – Orbital Re-entry Insurance Requirements: Overview of the major considerations for the orbital re-entry phase of the mission.
- Section 7 – Example Launch MIR Determination: Example implementation of the MIR and the major products from the process

1.1.3 MIR fit within the Regulatory Process

[To be updated - on-going development]

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[1] In general, we would anticipate that the launch or return operator would take out the insurance covering such activities but other approaches may also be appropriate.

1.2 Applicable Documents

Reference	Document
[AD1]	FAA-AST 14 CFR Part 420 - LICENSE TO OPERATE A LAUNCH SITE
[AD2]	Convention on International Liability for Damage Caused by Space Objects, United Nation Committee On the Peaceful Uses of Outer Space, Adopted by the General Assembly in its resolution 2777 (XXVI), 1 September 1972
[AD3]	The Space Industry Regulations 2020, Draft Statutory Instruments released for consultation, 29/07/20

1.3 Reference Documents

Reference	Document

1.4 Table of Acronyms

Acronym	Meaning
FMECA	Failure Modes Effect and Criticality Analysis
FSA	Flight Safety Analysis
FSS	Flight Safety System
GAD	Government Actuary’s Department
HVI	High Value Infrastructure
LCOLA	Launch COLlision Avoidance
LV	Launch Vehicle
MIR	Modelled Insurance Requirement
OSA	Outer Space Act
OST	Outer Space Treaty
SIA	Space Industry Act
SIR	Space Industry Regulations

1.5 Table of Definitions

Acronym	Meaning
Failure Mode	Mechanism through which a failure occurs
Financial Damage Profile	The combination of major accident scenarios likelihoods and financial consequences for a given mission presented as a cumulative distribution
High Value Infrastructure	Any infrastructure with an estimated value greater than £10 million at the time of launch and that could be damaged by the spaceflight activity.
Launch System	Accounts for the Launch Vehicle and the captive carry system such as a balloon or carrier aircraft
Major Accident	An accident arising out of or in the course of spaceflight activities or preparation for spaceflight activities that is highly likely to— (a) death or serious injury to, or (b) destroy or seriously damage the property of, third party persons who are not human occupants;
Major Accident Hazard	A hazard that could cause a major accident.
Major Accident Scenario	The series of events or process by which a major accident hazard becomes a major accident and the associated outcomes.
Response Mode	How the launch vehicle and flight safety system (FSS) responds to the failure.
Spaceflight Activity	(a) launching or procuring the launch or the return to earth of a space object or of an aircraft carrying a space object, (b) launching, procuring the launch of, operating or procuring the return to earth of— (i) a rocket or other craft that is capable of operating above the stratosphere; (ii) a balloon that is capable of reaching the stratosphere carrying crew or Passengers, (iii) an aircraft carrying such a craft, but that is not included in (a), or (b) operating a space object, or (c) any activity in outer space

2 Background

2.1 Introduction

A mission should be designed with the objective of securing public safety. However, as spaceflight and associated activities are risky in nature it is important that those suffering damage or loss as a consequence can be compensated. Under the UN Convention on International Liability for Damage Caused by Space Objects [AD2], the UK Government is ultimately liable to pay compensation for damage caused by its space objects on the surface of the Earth or to aircraft in flight, and liable for damage due to its faults in space. Therefore insurance provides an important resource to meet potential claims. As a result it is necessary to consider the probability and consequence of any failures that may arise during spaceflight activities in order to determine the level of insurance that will be required. For this, we will use the Modelled Insurance requirement (MIR) approach for launch activities to determine the level of insurance required.

The Modelled Insurance Requirement is an approach similar to the Maximum Probable Loss (MPL) methodology used for setting insurance requirements in both the US and Australia.[2]

The MIR is the amount of potential third-party liability claims that an operator could incur in a realistically possible scenario. The insurance amount is then set at a probability threshold that shows the number of launches expected before an accident occurs that cause more than a given value of financial damage. The insurance amount is therefore determined by two parameters – the probability of a particular launch failure mode which leads to a major accident and the financial values applied to that particular failure mode (here termed 'consequence').

The MIR reflects the UK approach to calculating damages arising from death, injury and property damage as applied in UK courts. The Government Actuary's Department (GAD) has been commissioned to provide information on the average level of financial compensation that may be received in the UK, in order to help the Government to determine the figures it wishes to include in the MIR.

The financial values calculated by GAD, which are used to calculate the MIR, are applied to damage arising within and outside the UK. At this point separate values have not been calculated for any damage arising outside of the UK but the UK Government believes that the GAD values should provide a good proxy for international damages arising. Therefore the actual value of compensation paid to foreign nationals may therefore be different to that calculated.

Rather than applying a fixed limit that will apply to all missions, the intention behind the MIR is to set the insurance requirement on a case by case basis. The amount would be calculated in this way for all types of launch. The insurance requirement then reflects the level of financial risk associated with the mission identified/licensed. The modelling/assessment of the MIR value will be performed by the Regulator and will be based on the inputs received as part of the license assessment. The Regulator as part of their license assessment will assess the integrity of this data set and request further information if needed. As part of this assessment process, the Regulator may perform independent analysis which will inform their assessment of the risk and the MIR analysis. The outcome of the MIR

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[2] https://ablis.business.gov.au/service/ag/maximum-probable-loss-methodology/31339

https://www.faa.gov/about/office_org/headquarters_offices/ast/licenses_permits/launch_reentry/expendable/financial/

analysis will be shared at the point of licensing. The operator will therefore not need to carry out MIR modelling.

The MIR is based on the level of loss associated with a set of reasonably foreseeable accidents associated with the proposed launch. The MIR will reflect a range of factors which account for variations in potential third-party damage that could be caused (see 'financial damage' section below).

The insurance amount will be set at the level of loss arising in 1 in 10 million (1×10^{-7}) launches. The financial values to be applied are set out in the Section 4.1.3 section below. The resulting insurance amount will be set out in a licence condition. It should be noted that the MIR methodology only currently applies to the launch phase of the mission and on-going work is being performed to consider the other mission phases (in-orbit, orbital re-entry).

The remainder of Section 2 introduces several key terms that are used or should be considered in the determination of the MIR value.

2.2 Major Accidents

The Space Industry Regulations 2020 defines a major accident as:

> *an accident arising out of or in the course of spaceflight activities or preparation for spaceflight activities that is highly likely to—*
>
> *a) cause death or serious injury to, or*
> *b) destroy or seriously damage the property of,*
>
> *persons who are not human occupants [of the launch vehicle];*

This definition can be used to determine the types of events which may result in a claim being made under the Space Industry Act 2018 against either an operator or the Government.

The SIR also defines a major accident hazard as:

> *a hazard that could cause a major accident;*

Typical hazards that could arise from spaceflight activity and lead to major accident scenarios include:

1. discarded vehicle parts and / or stages;
2. blast overpressure;
3. debris fragments;
4. thermal radiation;
5. toxic release.

2.3 Major Accident Scenarios

The process by which a major accident hazard is realised (to create a major accident) can be termed a *major accident scenario* (MAS). This term is used herein to refer to the combination of all events and conditions that lead to the accident as well as the effects of that accident

The Major Accident Scenario's should be developed by the operator as part of the license application and presented in the safety case. These scenarios will inform the MIR assessment that is performed by the Regulator. As part of the safety case assessment the Regulator will verify the validity of the scenarios and may challenge certain parameters included. The Regulator may call upon a library of example scenarios to inform their thinking. It is critical to note that the Regulator will not be expected to develop the scenarios themselves. The following section introduces the Major Accident Scenarios.

Regulation 31 of the Space Industry Regulations [AD3] describes the steps required to be performed for each major accident hazard identified by the operator in order to evaluate the risk from each major accident. There are many potential combinations of events that can lead to a major accident hazard becoming a major accident. A number of different approaches exist to assess the major accident scenarios associated with a given hazard including methods such as the Bow-tie method.

Within this approach it is essential that the conditions required for a particular scenario to be realised should also be considered e.g. how the meteorological conditions or time of failure affect the consequence of inert debris impacting the ground. As part of the license assessment the Regulator will review these inputs and challenge assumptions.

Once the MAS have been identified, the likelihood of each MAS can then be assessed and used in conjunction with the assessment of the consequences to calculate the risk associated with each scenario. An assessment of the risk may or may not be required, see Section 3.2 for details.

Additional guidance may be produced at a later date for the Regulator to provide a framework to assess the MAS and develop a library of example scenarios to inform their thinking.

For the purpose of the MIR determination of the launch phase all major accident scenarios should be considered as part of the analysis for the MIR determination. Whilst only those scenarios with a likelihood of greater than 1 in 10 million ($1x10^{-7}$) (for example 1 in 1 million – $1x10^{-6}$) would be covered by the insurance, the inclusion of all *reasonably foreseeable* major accidents should be included in the MIR determination to assess the Government's level of exposure to and the potential extent of losses/ liability.

2.4 Financial Damage

For each major accident there exists a financial consequence (which could be zero) based on the expected outcome. The extent of the financial damage is a combination of:

- the number of injuries;
- the number of deaths;
- Property damage (residential/commercial and agricultural) (including business interruption);
- damage to the environment;
- damage to high value infrastructure.

Typical factors that may affect the level of damage of a given major accident during the launch phase include the:

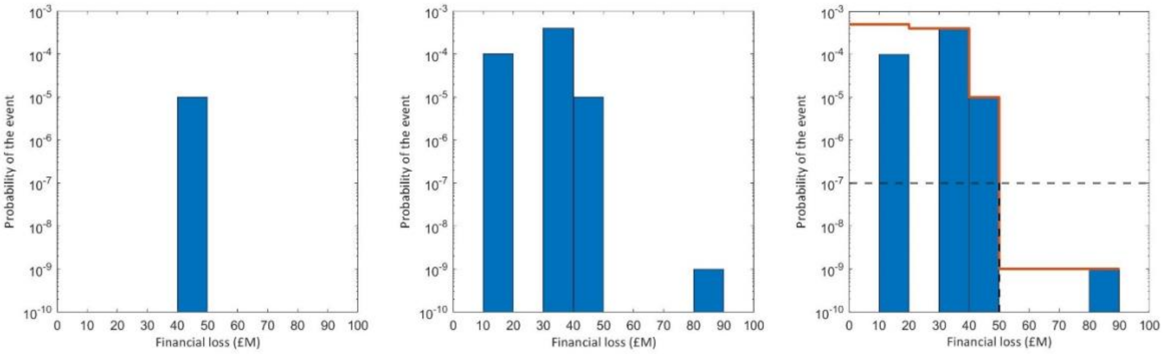
- launch vehicle - size, number of stages, propellant type etc.
- spaceport location - population affected, geography (as a mitigating or contributing factor) etc.
- mission – trajectory, staging events etc.
- time (of day and after launch) that the failure occurs;
- vehicle response mode – how the launch vehicle and flight safety system (FSS) responds to the failure.

2.5 Financial Risk and Damage Profiles

As noted above, the MIR is based on two parameters: the probability of a particular launch failure mode which leads to a major accident and the financial values applied to that particular failure mode (here termed ‘consequence’). One aspect that describes the outcome of an accident is the financial damage it would cause (consequence). An important attribute in terms of calculating the amount of insurance is how likely the accident is to occur (probability). This combination of consequence and probability enables the calculation of the financial risk.

The combinations of major accident scenarios likelihoods and consequences for a given mission can be presented as a *financial damage profile*. The creation and interpretation of such profiles is described below.

First, consider just a single accident to be added to a histogram showing the modelled financial loss and its associated probability for all accidents – as this is a histogram then the financial loss is “binned” into a suitable range, e.g. we may choose to have bins representing every £10 million between £0 and £100 million such that in Figure 1(a) below, the loss associated with the event could be anything between £40M and £50M and the probability of this event is $1x10^{-5}$, or 1 in 100,000. It should be noted that strictly speaking the bar in the histogram could represent multiple events each with a financial risk of £40M to £50M and a *total* (or combined) probability of $1x10^{-5}$.



a) Single scenario with financial loss between £40-50 million and a probability of occurring of 1×10^{-5}

b) Multiple hazard scenarios leading to different financial losses and with different chances of occurring

c) Addition of cumulative financial loss probability curve (red line), i.e. the damage profile

Figure 1: Example of a damage profile calculation

Figure 1(b) shows 3 more scenarios added to the histogram (or a number of scenarios in a total of 4 bins, i.e. there could be more than one scenario in some bins). Once all major accident scenarios have been assessed in terms of probability and consequence (financial loss) then the histogram is converted into a cumulative financial loss curve or "*financial damage profile*" (Figure 1(c)). It is important to note that the damage profile is a *cumulative* loss, e.g. the probability associated with lowest level of financial loss, represents the probability of incurring the lowest loss *or more*, i.e. it is the sum of the probabilities associated with all individual losses. Therefore, if a higher level of loss is significantly more likely, then that probability will dominate the damage profile (for all loss categories up to and including the high probability category) as can be seen in Figure 1(c).

Once constructed, the damage profile can be used to determine the insurance requirement and also the highest financial damage caused by an accident to determine the Government's level of exposure to losses above the amount of insurance and liability set out in an operator's licence.

Using the damage profile curve in Figure 1(c) as an example, and applying the 1 in 10 million criteria, we can see that the value of the curve at the 1×10^{-7} level is £50 million, i.e. on average 1 in 10 million launches are expected to result in an accident that causes more than £50 million damage. This would be the level of insurance included in an operator's licence.

In cases such as figure 1(a) where there is only one scenario, if the loss is binned at a higher probability than 1 in 10 million, the insurance level would be set at that amount. If the loss were at a probability of less than 1 in 10 million, the insurance amount would be set at £250k (relating to the environment damage value).

Finally, it should be noted that a financial damage profile is just one approach to assessing financial risk and may not be appropriate for all mission phases e.g. in-orbit and orbital re-entry. Considerations for the in-orbit and orbital re-entry phase are included later in this document.

3 Approach to the Insurance Requirements

3.1 Scope

[AD2] expands on the liability rules created in the Outer Space Treaty, (OST), and places a liability on the launching state for third party damage caused by a space object. For damage caused on the surface of the Earth this liability is absolute, while in orbit it is fault based. Section 36 of the Space Industry Act 2018 requires that a person carrying out spaceflight activities indemnifies the UK Government for claims brought against it for loss or damage. Secondly, an operator holds an unlimited liability towards third parties under section 34 of the Space Industry Act 2018. The Space Industry Act 2018 contains powers to limit, via regulations and in licence conditions, the two types of operator liability identified above.

The spaceflight activities associated with a launch vehicle can typically be divided into 3 phases (as illustrated in Figure 2:

1. Launch: this refers to the period from the moment when the launch vehicle first moves with the intention of launching until the completion of the operator's spaceflight or until the launch vehicle becomes orbital[3] or, in the case of a sub-orbital launch, all parts of the vehicle have returned to the surface of the Earth. During this time the launch vehicle presents a hazard to third parties and property on the ground.
2. In-orbit: this refers to the period of time that the launch vehicle is in orbit from the end of the launch until it re-enters the Earth's atmosphere(or enters a disposal or graveyard orbit that does not result in re-entry). During this time the launch vehicle presents a hazard to spacecraft that are in-orbit.
3. Orbital Re-entry: assuming that the mission is not interplanetary or that the vehicle is not disposed of in a graveyard orbit, the launch vehicle will finally re-enter the Earth's atmosphere (re-entry is considered to start once the perigee is below tbd km). There are two types or re-entry that are possible:
   a. via a controlled re-entry shortly after the completion of the Launch Vehicle's orbital operations or;
   b. sometime later as an uncontrolled re-entry.

   If it is not destroyed completely during re-entry, then at the end of the re-entry period the Launch Vehicle may cause an accident affecting third parties and property on the ground.

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[3] For the purposes of the insurance determination this can be interpreted to mean the time at which the perigee is greater than 150km. At this point the risk to third parties on the ground has diminished and the LV is not at sufficient altitude to affect any orbital space objects.

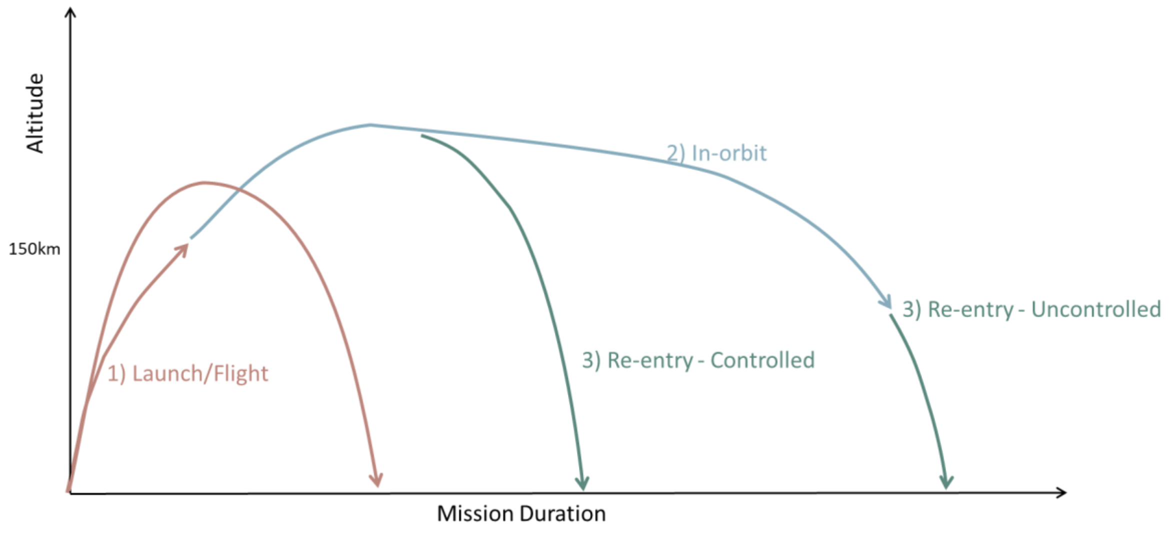

Figure 2: Typical sub-orbital and orbital[4] launch vehicle mission phases

The SIR require the operator to manage the major accident hazards arising from their spaceflight activities – this includes all mission phases. Coupled with the liabilities established under [AD2], it is necessary to give due consideration to the liabilities from all of these activities.

The risks associated with the launch phase are driven by the comparatively high probability of an accident occurring during this high-risk activity. The majority of this this document focuses on assessing the appropriate level of that risk for this phase and the approach to determining the insurance requirement for this phase (see Section 0 for details).

As stated previously, the liability of in-orbit accidents is fault based. While the probability of an accident occurring *may* be lower, the likelihood of a collision can continue to accumulate in time, which may lead to the risk eventually exceeding that seen during the transient launch phase event probability. (especially in the case of an uncontrolled re-entry). The level of risk presented by a launch vehicle component such as an upper stage while in-orbit compared to that presented during the launch phase is still being evaluated.. In-orbit liability and insurance requirements are discussed in more detail in Section 5. The policy position on upper stages and launch vehicle components left in-orbit is still under development and will be updated following the consultation .

The risk re-entry from orbit depends on factors such as the characteristics of the upper stage e.g. mass, material etc, orbital inclination and the re-entry profile. These factors determine the likelihood of any debris reaching the surface of the Earth and the population exposed to such a hazard. The policy position on insurance requirements for re-entry from orbit will be updated following the consultation.

Given the extent of activities from which liability arises, it may be appropriate to set a number of insurance requirements (i.e. individual insurance conditions for the various mission phases). The applicability of insurance for the in-orbit and orbital re-entry phase of a launch vehicle’s mission and the appropriate approach to determining the different insurance requirements for these mission

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[4] The figure relates to typical LEO missions. For, MEO, GEO and interplanetary the in-orbit phase may be considered separately.

phases are still under consideration. This guidance focuses on the implementation of the MIR methodology for the launch phase.

3.2 Process Overview

In order to set the minimum amount of insurance required and/or operator liability limit for a given phase, it is necessary to be able to calculate the probability and consequence (in terms of financial loss) of each reasonably foreseeable accident. This guidance sets out the approach by which such determinations should be made or policies that may be applied.

A top-level view of the steps taken to determine the insurance requirements is shown in Figure 3. The process is divided into three stages:

1) a **major accident scenario analysis:** this stage is concerned with assessing the consequence and likelihood of all major accident scenarios associated with all hazards of a mission phase, e.g. inert debris, explosive debris, toxic propellants etc. Separate consequence models should be applied to determine the amount of damage these major accident scenarios could cause to people, property, and the environment. The Regulator will the use information supplied in the safety case for this stage.
2) the **mission phase financial risk assessment**: this stage takes the output of the major accident scenario analysis to combine the accident damages for the mission phase to assess the associated financial risk.
3) The **Insurance Requirement Determination:** finally, the risks from all phases of the mission are considered to determine Modelled Insurance Requirement (MIR) for each phase and the associated liability and insurance requirements.

To note : For version 1 of this guidance and the MIR approach only the launch phase is considered as part of the MIR assessment. An evolution of the approach (and this guidance) may develop an approach to consider the in-orbit and orbital re-entry phase as part of the overall MIR calculation.

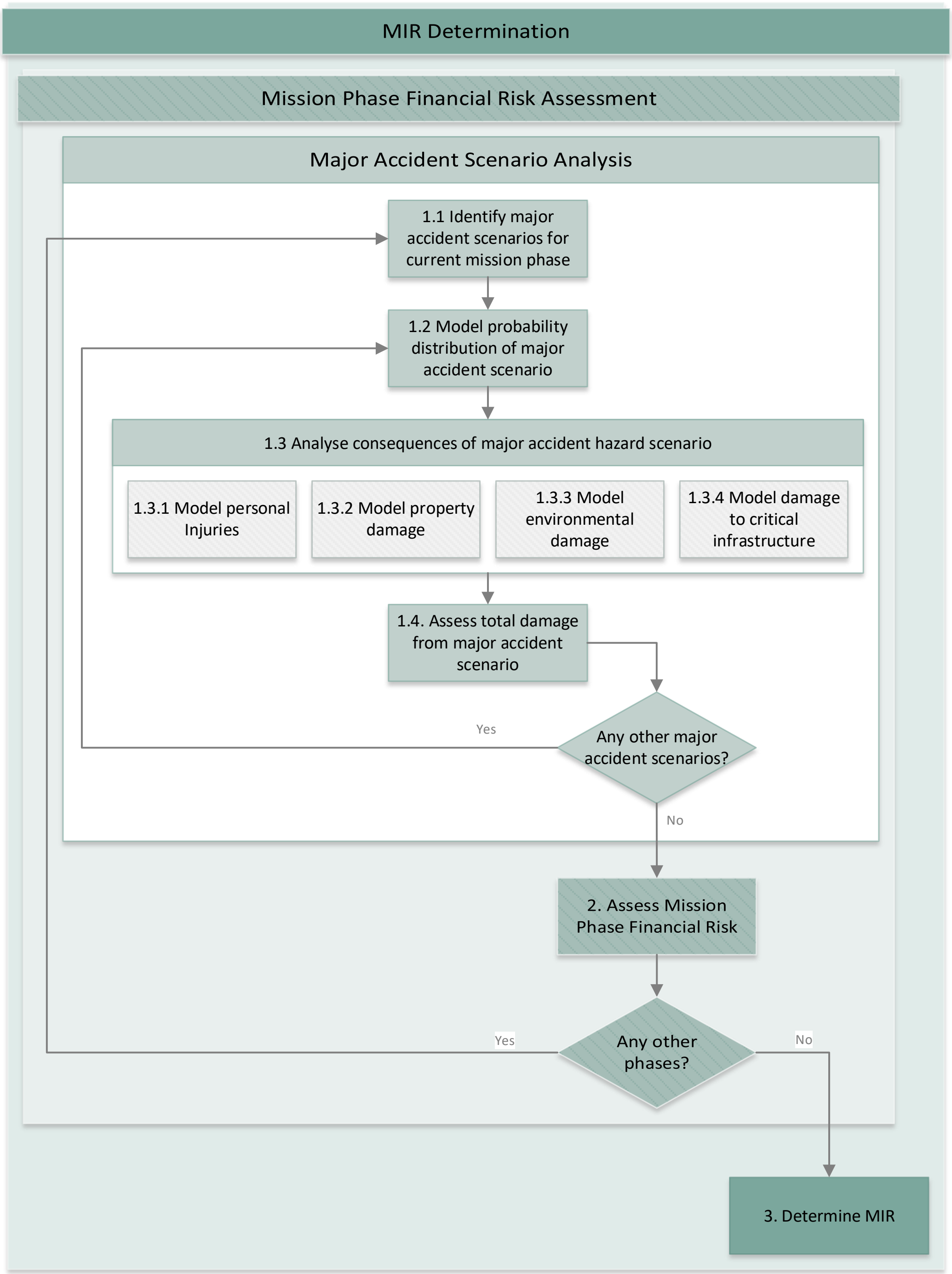

Figure 3: Summary of MIR determination process

The following sections provide details of the analysis performed during each step in the above process.

4 Modelled Insurance Requirement

The following section provides insight into how to calculate the Modelled Insurance Requirement (MIR) for a launch. The MIR in its present form has been developed to primarily account for the launch phase of the mission. Initial consideration for the in-orbit and orbital re-entry phase is given in this guidance but their integration into the MIR approach is still under development.

Additionally, it is intended that the majority of the Major Accident Scenario Analysis (steps 1.1 – 1.4) will be performed by the operator as part of their safety case and associated flight safety analysis. This information will then be used as an input into the MIR process. The Regulator's assessment will focus on ensuring that the operators activities provide an acceptable level of safety to people and property. This information gathered during this assessment will be used to perform the MIR assessment and determine the financial consequences of the activity. The exact inputs required from the license assessment is still under development. Consequently, section 4 works through the development of the MIR value without specifically identifying which information is expected to be available or in which form it will take. This section serves to highlight the key considerations in the assessment of the inputs and provides initial methodologies and approaches to applied to the various steps of the process. It should be noted that the methodologies/approaches will be refined and improved during the implementation of the MIR approach and this guidance should be updated accordingly.

4.1 Step 1: Major Accident Scenario Analysis

As part of their license application Regulation 29 of [AD3] requires operators to identify all major accident hazards. The major accident hazards must be assessed in accordance with Regulation 31 of [AD3]. This information is equally relevant to the MIR determination as it is the same accidents that must be assessed for financial consequence.

Regulation 29(1) of [AD3] and the first two steps required to be performed for each hazard (Regulation 31 of [AD3]) are to identify the major accident hazards that the system poses and to determine the conditions and (contributory) causes that could lead to the hazard causing an accident. This is synonymous with the first step of the MIR determination and therefore the major accident scenarios identified in the safety case that is based on the Flight Safety Analysis (FSA) performed. The inputs associated with the FSA should provide the bulk of evidence required in this step.

Typical hazards that could lead to major accident scenarios include:

- blast overpressure;
- inert debris fragments;
- thermal radiation;
- toxic release.

Each major accident hazard should be analysed independently before the overall range of accidents for each mission phase is assessed in terms of financial risk (as shown in Figure 3).

4.1.1 Step 1.1 Identify Major Accident Scenarios

A major accident scenario is the series of events or process by which a major accident hazard becomes a major accident and the associated outcomes. It is the intention that these Major Accident Scenarios will be identified by the operator in the license application.

The first step in assessing each major accident hazard is to identify the scenarios by which the hazard can lead to an accident.

Hazards can be realised through both nominal and malfunction conditions. During nominal operations the most obvious hazards are any discarded part of the launch vehicle and any object or substance released or separated from the launch vehicle, e.g. boost stages, fairings, sub-orbital vehicles. These will pose a risk to third parties on the ground such as downrange populations or shipping and aircraft traffic.

Failures or uncontrolled events must also be analysed as these are all likely to create a hazard. Where applicable, this should extend to failures of any part of the system such as the carrier aircraft or balloon, i.e. any hazard presented by the launch system during the spaceflight activity (e.g. while in transit to the launch point or returning to land after an aborted launch attempt).

Factors to consider when analysing major accident scenarios include:

- Vehicle failure and response modes, these may be identified through fault tree analysis and/or FMECA or comparable analysis.
- Any debris produced in response to the failure.
- Impact of atmospheric and meteorological conditions on the outcome of the failure and debris characteristics.
- External events such as range incursions.

All of the above should also be considered within the FSA which can therefore be used as a convenient input to the MIR determination.

An additional consideration that may not be included in the FSA is how the hazards could affect *high value infrastructure*. Typically this can be modelled in a similar fashion to property damage but considering specific structures and is discussed further in Section 4.1.3.1.4. As such, any additional work required in this step is likely to be minimal.

4.1.2 Step 1.2: Accident Probability

In order to determine the likelihood of a given accident it is necessary to consider:

- the probability of the major accident scenario occurring;
- how likely the accident is to affect different location i.e. the probability distribution.

Therefore, it is necessary to produce a probability distribution for each major accident hazard by combining the probability of each accident occurring with the probability of it affecting a given area.

Factors that may affect the probability of an accident occurring include:

- Launch vehicle maturity (either whether the vehicle is new or is a derived vehicle)
- Launch vehicle flight history
- Launch vehicle design
- Experience of the launch vehicle operator or developer.

Where appropriate, high fidelity modelling should be applied to launch vehicle failures and include explicit consideration of the vehicle failure mode and the likelihood of instantaneous or subsequent breakup. In most cases it would be expected that structural or aerothermodynamic loads will result in vehicle breakup prior to impact. The time of breakup will affect the location and distribution of pieces of debris on the ground not just due to the time/position that the vent occurs but due to the effect of the atmosphere on smaller, lighter pieces of debris compared with a single large, heavy one.

4.1.2.1 Probability Distribution

Each major accident will have an associated probability indicating how likely it is to affect different areas or populations. As the financial risk assessment is to be used to set the insurance requirements for a single launch[5], then the probability distribution should be expressed in terms of probability per launch (as opposed to per annum or any other time period). This implies LV failure modes should be expressed in terms of their likelihood as opposed to frequency.

Factors that contribute to the probability distribution of a given accident include:

- the size of the launch vehicle;
- the time of failure (after launch);
- the magnitude of any malfunction turn;
- the imparted velocity following an explosive failure (where applicable)
- the debris produced after an explosive failure (where applicable);
- the atmospheric conditions (primarily wind).

It should be noted that different accidents may have different probability distributions. As a minimum there should be a probability distribution associated with each combination of hazard and consequence, e.g. death and injury from over-pressure.

For orbital stages it should be expected that the probability distribution is “narrower” than of boost stages due to the lower mass, high downrange velocity component and hence the increased probability of debris burning up during re-entry. These effects compound each other as it is the larger heavier pieces of debris that are likely to survive, and less likely to be affected by imparted velocities or atmospheric winds.

Figure 4 shows typical first and second stage debris probability of impact distributions used in the proposed model.

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[5] To note that this value may be applied to subsequent launches or may need to be amended to reflect changes in mission parameters.

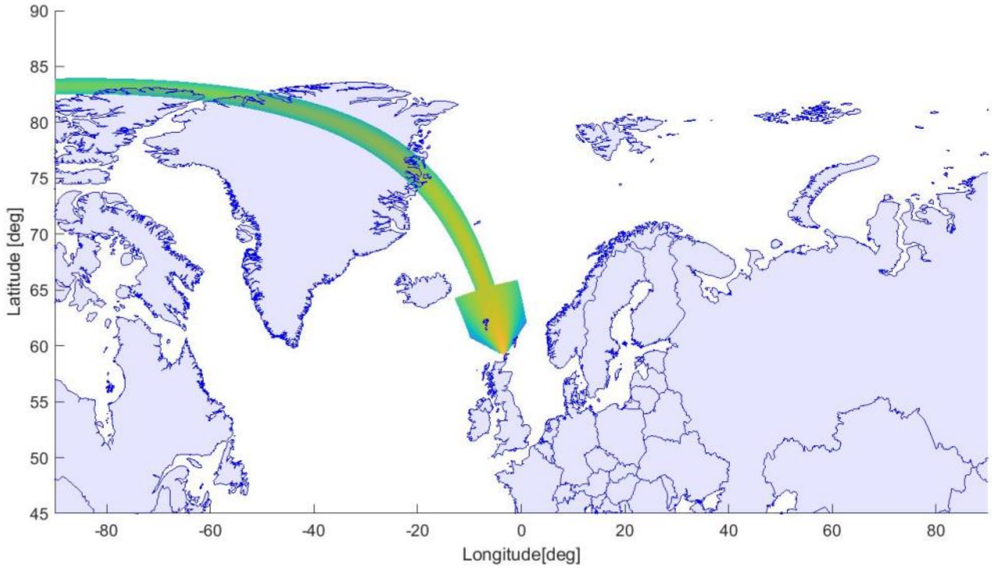

Figure 4 - Example of probability of impact distribution for first and second stages of a launch from the UK illustrating the different distributions applied to each stage

4.1.2.2 Grid

The grid used to record the probability directly affects the probability distribution. Consider ten pieces of debris that have impacted a single grid cell. If you divide that cell up into a smaller 10x10 grid then clearly most cells will have zero probability while some may have one or two tenths of the original value.

In order to ensure consistency in the approach used, the Gridded Population of the World (GPW) 2016 model[6] may be used in the first instance as a small scale global population database. The GPW dataset uses a fixed 0.5 arcminute grid which at northern Scottish latitudes corresponds to approximately a 320m x 930m quadrilateral (with an area of nearly 0.3km^2). It is noted that due to the fixed grid definition, the grid resolution varies as a function of latitude. As the majority of the risk is driven by the first stage which occurs over a relatively small latitude band, this variation is deemed to be acceptable. However, it would be preferable to adopt a grid with a fixed cell area. If such a grid is applied then the grid area should be set to 0.3km^2.

Figure 5 shows the GPW population data for the North of Scotland, Faroe Islands and part of Iceland with possible probability of impact contours (log$_{10}$ of the probability of impact) overlaid.

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[6] https://sedac.ciesin.columbia.edu/data/collection/gpw-v4

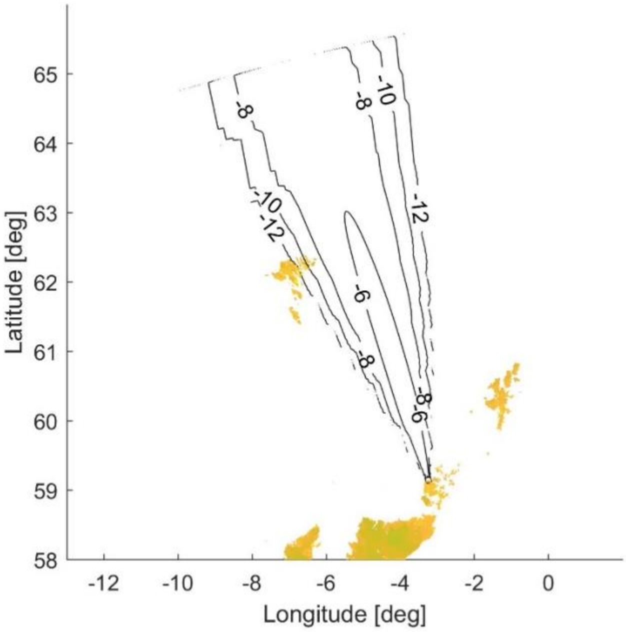

Figure 5: Probability contours (logarithmic) overlaid on GPW population layer, showing the (base 10) logarithm of the number of people within each (0.5 arcminute) grid cell

4.1.2.3 High Value Infrastructure

For the purpose of defining operator liability limits any infrastructure with an estimated value greater than £10 million at the time of launch and that could be damaged by the spaceflight activity is termed high value infrastructure. This value has been selected on the basis of the expected launch insurance requirements and the type of accident that could drive the MIR.

Given the significant value associated with them, it is important that the likelihood of damaging each piece of High Value Infrastructure (HVI) is explicitly determined (rather than just the probability of hitting the appropriate grid cell). This results in a discrete probability for each asset (rather than a distribution) and thus HVI accidents should be considered unique Major Accident Scenarios.

Furthermore, depending on the consequences, it may be necessary to distinguish between consequences, e.g. destruction of the infrastructure compared with damage to it, and corresponding distributions produced.

4.1.3 Step 1.3: Accident Consequence

Having established how likely an accident is to affect a population or place, the next step is to assess what the consequences will be and how much damage may be caused. The SIA states that an operator should consider damage caused to "persons or property on land or water…or to aircraft in flight over any such land, water or sea, or to persons or property on board any such aircraft". Therefore, as a minimum it is required to assess the potential damage to:

- People
- Property
- Ships
- Aircraft

Additionally it is considered that:

- the cost to clean-up of environmental damage is a set value;
- HVI should be assessed explicitly.

Therefore, these damages must also be assessed.

The MIR reflects the UK approach to calculating damages arising from death, injury and property damage as applied in UK courts. The Government Actuary's Department (GAD) has been commissioned to provide information on the average level of compensation that may be received in the UK, in order to help the Government to determine the figures it wishes to include in the MIR.

It is proposed to use the following financial values (levels of consequence) as the basis for determining the MIR, in line with the overall risk approach taken to setting the insurance requirement. These figures will be subject to a further review before implementation of the policy to reflect the latest statistical updates and any inflationary impacts as these figures were produced in 2018.

Table 1: Table of recommended accident consequence values provided by the Government Acturies Department

Category	Value		Symbol
Death	£244k per death modelled		D_f
	Commercial /	£1739 / m^2	D_r
	£250k (set value per launch)		

It is the intention of the Regulator to update these figures every five years, in line with the general review proposed for insurance requirements and spaceflight legislation requirements more widely. The figures will be reviewed annually to assess whether there has been a material change in the figures which requires a change in the financial values prior to the five-year review (for example due to the effects of inflation; if the Personal Injury Discount Rate changes; if there is a change in the wider methodology for calculating compensation in UK courts; or if there is a significant economic event, such as an economic downturn). In this way the Regulator would look to provide an appropriate level of assurance that changes in market conditions do not lead to over or under insurance.

The following sub-sections describe how these values should be used to determine accident financial damage values and how to account for environmental damage and damage to HVI. However, it is noted that ultimately a court would decide the appropriate compensation to be paid so actual payments could be significantly different, although this will not impact on the insurance amount contained in the operator's licence (or the limit of liability).

4.1.3.1.1 Step 1.3.1: Personal Injuries

4.1.3.1.1.1 Expected deaths

First it is necessary to determine how many deaths a specific major accident scenario is expected to cause. This determination could be done using many different injury models but for simplicity (and consistency with other launching states) the criteria are used below. Development on-going to identify an appropriated recommended relationship to determine the injury level that corresponds with death.

Table 2: Example criteria of consequence levels of common major accident hazards capable of causing a fatality

Hazard	Criteria	Fatality Level
Blastwaves	Over-pressure (kPa)	24
Inert debris	Kinetic Energy (J)	75
Toxic	tbd	tbd
Thermal radiation	tbd	tbd

Given a consequence level that equates to death then the area affected by each major accident scenario can be determined using an appropriate consequence model. The effect of sheltering should be considered where possible or conservative assumptions made if not, e.g. everyone in the open / no sheltering.

Unless more detailed information is available it is reasonable to assume that the population is distributed uniformly throughout the grid cell and that the proportion of casualties is therefore:

$$N_{f(i,j,S_n,h)} = \begin{cases} N_{(i,j)} \dfrac{A_{f(S_n,h)}}{A_{(i,j)}} & \forall\, A_{f(S_n,h)} < A_{(i,j)}, \\ N_{(i,j)} & otherwise \end{cases} \tag{1}$$

where $N_{f(i,j)}$ is the number of fatalities in grid cell (i,j) from the hazard h in major accident scenario S_n, $N_{(i,j)}$ is the population in grid cell (i,j)l, $A_{(i,j)}$ is the area of the grid cell, and A_f is the fatality area of hazard h in major accident scenario S_n. In the event that the fatality area is greater than the cell area then the number of deaths is equal to the population of the cell.

The number of deaths can be converted in to a financial value (expected damage attributed to fatalities, E_{d_f}) by multiplying the number of fatalities by the appropriate value in Table 2:

$$E_{d\,f(i,j,S_n,h)} = D_f N_{f(i,j,S_n,h)} \tag{2}$$

4.1.3.1.1.2 Expected Injuries

In principle the same approach as used for deaths can be applied but using different injury levels on each hazard criteria and accounting for the fact that people within the fatality area should not be included in the casualty area as well. Suggested hazard criteria to be used in conjunction with an appropriate model to determine the casualty area are given in Table 3.

Table 3: Example criteria of consequence levels of common major accident hazards capable of causing a casualty

Hazard	Criteria	Injury Level
Blastwaves	Over-pressure (kPa)	8
Inert debris	Kinetic Energy (J)	15
Toxic	tbd	tbd
Thermal radiation	tbd	tbd

The expression to find the number of casualties is similar to (1) but modified to reduce the area as discussed previously:

$$N_{c(i,j,S_n,h)} = \begin{cases} N_{(i,j)} \dfrac{A_{c(S_n,h)} - A_{f(S_n,h)}}{A_{(i,j)}} & \forall\, A_{c(S_n,h)} < A_{(i,j)}, \\ N_{(i,j)} & otherwise \end{cases} \tag{3}$$

A single value for all injuries is to be applied. The financial value (expected damage attributed to casualties, E_{d_c}) can therefore be found by multiplying the number of casualties by the injury value (£192k) in Table 2:

$$E_{d\,c(i,j,S_n,h)} = D_c N_{f(i,j,S_n,h)} \tag{4}$$

4.1.3.1.2 Step 1.3.2 Property Damage

There is clearly a different financial consequence associated with damaging a built up area compared to agricultural land and this is reflected in the values to be applied in the MIR (Table 1). Therefore, it is necessary to determine the type of property that should be associated with a given grid cell.

In the absence of more accurate data, one approach is to consider the number of people occupying the grid cell. Given that there are very disperse populations in regions around the proposed launch sites it is suggested that setting a very low threshold on the population is appropriate to ensure adequate cover is determined for local populations (where the probability is likely to be highest).

Figure 6 highlights regions where the population per grid cell is greater than or equal to five. This can be seen to correspond quite accurately with major population centres as well as identifying a number of smaller settlements so is suggested as an appropriate threshold to distinguish residential / commercial areas. All other land areas are consdiered as agricultural (although in practice this will not affect the MIR as other accidents will drive the MIR value).

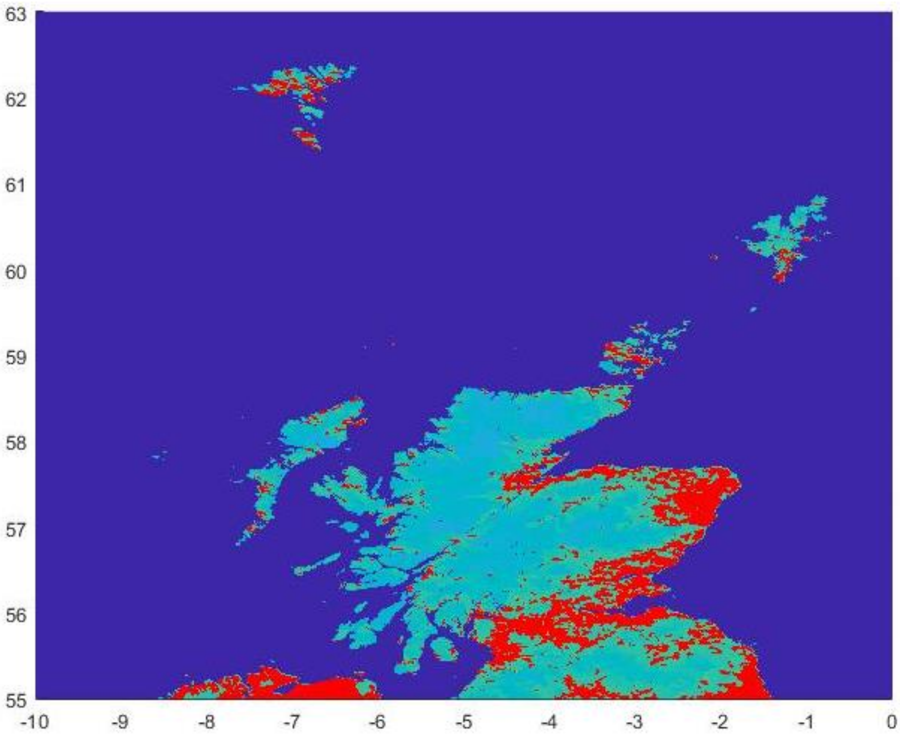

Figure 6: GPW Population totals for regions in and to the North of the UK, highlighting areas (in red) with a population of more than 5 people per grid cell

4.1.3.1.2.1 Agricultural

If known the damaged area could be assessed for each major accident scenario. However, given the low cost associated (even for large areas) it is suggested that simply applying the cost per m^2 to the entire grid cell would be a conservative assumption that is unlikely to drive the MIR value, i.e.:

$$E_{d_{a(i,j,S_n,h)}} = D_a A_{(i,j)} \tag{5}$$

4.1.3.1.2.2 Residential and Commercial

Residential and commercial property are slightly more complicated. A consequence model should be established to determine the property which would be significantly damaged, $A_{p(S_n,h)}$. Given that only a single value for residential / commercial property damage (including business interruption costs) is given, then there is no need to try to estimate the level of damage caused to buildings. In the absence of a more refined model, the thresholds for fatalities caused by each hazard (Table 2) can be applied resulting in $A_{p(S_n,h)} = A_{f(S_n,h)}$. Note this is the area within which property would be damaged and should be less than or equal to the grid cell area $A_{(i,j)}$.

The challenge with property damage is estimating the number and size of affected properties. If no other data source is available population may be used as a proxy for property distribution. If population is to be used to determine the property distribution, assumptions must be made to translate population to property area. The safety case will need to include a description of the environment around the launch site to identify what could be impacted by a major accident. Initial approaches implemented by the Regulator have used the following assumptions:

- All properties are residential: given that the same value is applied to both types of property and lacking further information this is a pragmatic necessity.

- The area of an average property is (A_r) 300m^2: may be considered as a conservative value (it will increase the damage associated with property).
- Three people inhabit a typical property (ρ_r)

The financial value of property that suffers damage can then be given directly by:

$$E_{d_{r(i,j,S_n,h)}} = \frac{N_{(i,j)}}{\rho_r} A_r D_r \tag{6}$$

4.1.3.1.3 Step 1.3.3: Environmental Damage

The financial damage from any hazard shall be assessed as $E_{d_{e(i,j,S_n,h)}} = £250{,}000$ for any grid cell affected by an accident. This is unlikely to drive any MIR except in the case of very small, and low risk, sub-orbital launches.

Additionally, environmental damage caused by damaging HVI shall be assessed within the HVI determination, if considered appropriate.

4.1.3.1.4 Step 1.3.4: High Value Infrastructure

The cost associated with damaging HVI should be determined through an engineering assessment. Different levels of damage should be established corresponding with the probability distributions produced (Section 4.1.2.3). As a minimum it is suggested that the consequence of damaging and destroying the asset should be considered separately.

When making the engineering assessment, all costs associated with each major accident scenario should be included, i.e. casualties, fatalities, property damage and environmental clean-up. This is necessary as impacting a HVI is considered a major accident scenario on its own accord and independent of all other consequences.

As an alternative, in the absence of an engineering assessment, the insured cost of the Piper Alpha disaster adjusted for inflation can be used as a worst-case cost for damage and / or destruction. At the time of writing this value is approximately £4.5 billion (tbc) and further work is on-going to refine this figure.

4.1.4 Step 1.4: Assess Total Damage of Major Accident Scenarios

Ultimately what we require is the likelihood and damage associated with each major accident scenario, $E_{d_{S_n}}$. For each major accident scenario, this is simply found by summing all consequences across all hazards and all grid cells:

$$E_{d_{S_n}} = \sum_{i \in f_c} \sum_{j \in f_c} \sum_{h \in MAH} \left(E_{d_{f(i,j,S_n,h)}} + E_{d_{c(i,j,S_n,h)}} + E_{d_{a(i,j,S_n,h)}} + E_{d_{r(i,j,S_n,h)}} + E_{d_{e(i,j,S_n,h)}} \right) \tag{7}$$

where all symbols have their previous meanings and f_c represents the flight corridor which is defined as the region of the Earth for which there is a non-zero probability of the spaceflight activity affecting, and MAH, represents the set of identified major accident hazards for the LV. Note that for a given major accident scenario, the expected cost in most grid cells (for any hazard) will be zero.

4.2 Step 2: Assess Mission Phase Financial Risk

Having evaluated the probability and consequence of each Major Accident Scenario all that remains is to use this information to provide some insight into the financial risk of the proposed spaceflight activity.

4.2.1 Any other phase?

At this point in the MIR process consideration is paid to the in-orbit and orbital re-entry phase of the mission. The current MIR approach does not consider the in-orbit or orbital re-entry phases as such the process would move to step 3.

As the MIR methodology evolves it may be the intent to repeat the Major Accident Scenario Analysis and Assess Mission Phase Financial Risk for the in-orbit phase and then separately for the orbital re-entry phase and then either :

- Establish separate Financial Risk and Damage Profiles for these phases. An alternative probability threshold could be selected to reflect the fault based liability regime in-orbit or international precedents for the collision probability with space objects (as shown in SFGL3Sasfety: Launch Vehicle Space Debris Mitigation Technical Measures (tbc));
- Integrate the Mission Phase Financial Risk for the together for the various phases to develop and overall Financial Risk and Damage Profile for the mission

On-going consideration of how to accurately consider the financial consequences of the in-orbit and orbital re-entry phase.

4.3 Step 3: Determine Insurance Requirements

Once the financial risk from the relevant phases have been analysed, the insurance requirements can be determined. For mission phases where a damage profile has been constructed and a probability threshold specified then the insurance requirement can be determined directly from the damage profile.

The launch phase requires the assessment of financial risk using a damage profile and a $1x10^{-7}$ probability threshold. Figure 7 shows an example financial damage profile from a launch phase and indicates the required probability threshold, reading the level of damage at the point the $1x10^{-7}$ probability on the curve gives a MIR of £20M

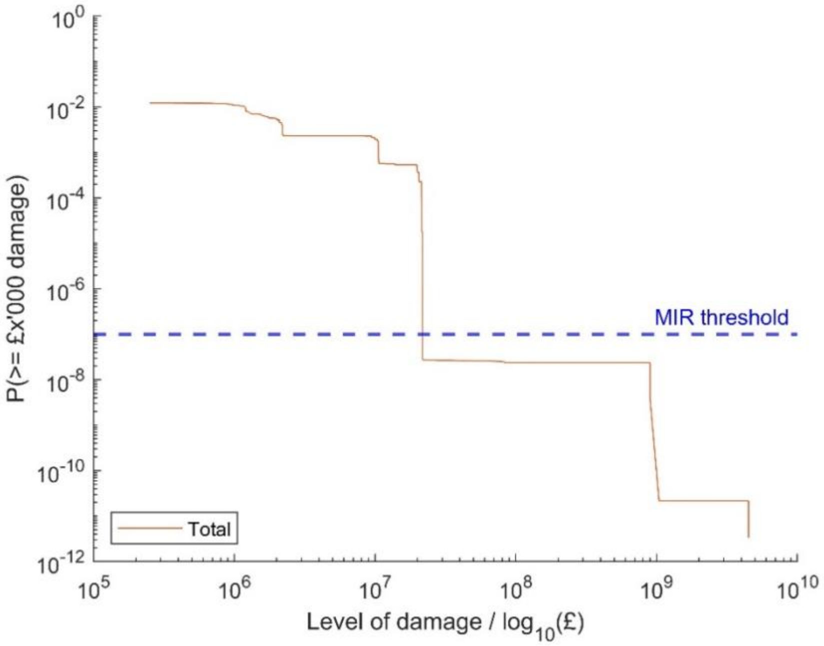

Figure 7 - Example launch phase damage profile

The final outcome of the financial risk modelling at this stage is a single value for the launch phase of the mission. Given that the in-orbit and re-entry phase are not presently integrated into the MIR requirement, further consideration of their insurance requirement is required.

5 In-orbit Insurance Requirement

Figure 2 identifies the principle mission phases for typical launch activity from the UK. This section of the document considers the risk associated with the in-orbit phase of an orbital mission or any portion of a sub-orbital trajectory above 150km. Looking at the in-orbit phase in more detail there are broadly 4 different sub-phases:

1. sub-orbital: where a sub-orbital launch attains an altitude greater than 150km consideration should be given as to whether it poses a hazard to any orbital space objects. This hazard may be controlled by performing a Launch COLlision Avoidance (LCOLA) screening. If such an analysis is performed according to best practice (as defined in SFGL3Sasfety: Launch Vehicle Space Debris Mitigation Technical Measures (tbc)) then these risks may be expected to be below the MIR threshold in which case they could be considered *not* reasonably foreseeable, i.e. there is no insurance requirement associated with them. Further work is on-going on this.
2. Launch and Early Operations (LEOP): for orbital launches there is an initial period where the uncertainty on the location of the space object and its lack of being added to the catalogue prohibits accurate conjunction analysis and hence collision avoidance manoeuvres. During this period the Launch Vehicle poses an elevated hazard to space objects. This risk may be controlled using LCOLA analysis, particularly identifying a suitable screening approach as described above for sub-orbital missions.
3. In-orbit (active): if the LV operations continue long enough for accurate orbit determination then it will continue to pose a hazard to space objects. The level of risk associated with the activity will depend on the orbit and duration of the phase and this will determine whether

this phase shall be considered under the MIR approach or the in-orbit approach. The phase can be considered to end when the LV is passivated or actively de-orbited. During this phase it is conceivable that the risk could be controlled by performing any required Collision Avoidance Manoeuvres (CAM) but this would be part of the operational approach of the upper stage.

4. In-orbit (passive): for the time between passivation and re-entry the LV will continue to be a hazard to space objects, but it will no longer be possible to perform a CAM. Additionally, in many instances this period will be the longest part of the LV's mission, possibly extending up to 25 years (while still complying with international best practice) thus increasing the exposure time and hence risk.

The initial results indicate the level of risk is different from the launch to the in-orbit phase. Therefore, different approaches need to be applied for the identification of insurance requirements for the launch versus the in-orbit phase. It is recognised that the requirement for third party insurance is likely to be dependent on the mission profile of the upper stage and its potential interaction with high-value assets such as the ISS.

[To be updated - on-going development with initial considerations included in the consultation document]

6 Orbital Re-entry Insurance Requirement

Figure 2 identifies the principle mission phases for typical launch activity from the UK. This section of the document briefly describes the hazards posed by an orbital re-entry phase. Note that the re-entry of sub-orbital missions, regardless of apogee, are considered within the launch phase.

During an orbital re-entry a Launch Vehicle may pose a hazard to third parties and property on the ground depending on the orbit, Launch Vehicle construction and demiseability.

The hazards from the orbital re-entry phase are similar to many of those from the launch phase, i.e. debris spread over a large area, but in the case of an uncontrolled re-entry, the hazards could potentially affect a much larger region of the Earth (due to high uncertainty of the location of the re-entry point, irrespective of the size of the debris footprint). The other obvious difference compared to the launch phase is that the aerothermal environment is likely to be much more severe leading to significantly more of the debris demising- during orbital re-entry. In some instances, there may be a residual risk of financial damage. The level of this risk and the feasibility of insuring it (noting that it could occur many years after launch) should be investigated further with an appropriate level of modelling to understand the level of financial risk / impact.

[To be updated - on-going development with initial considerations included in the consultation document]

7 Annex A: Example Launch MIR Determination

7.1 Case study

This section discusses an example of the MIR determination process, assuming the launch of a two-stage vertical launcher from a fictional spaceport on Orkney, Scotland. The MIR determination included is for the launch phase of the mission. This location has been specifically chosen for this example as it is not a proposed spaceport, and so it can be used to showcase the approach to determining insurance requirements.

7.2 Step 1: Major Accident Hazards

7.2.1 Step 1.1: Identify Major Accident Scenarios

A single type of major accident hazard is considered here for simplicity, but an actual MIR determination requires the full range of hazards to be accounted for. This will typically rely on information provided in a license applicant's safety case. In this case, it is assumed that a single accident hazard - blast overpressure from an intact vehicle impacting the surface is representative of the worst case and therefore provides a conservative estimate of the financial risk.

7.2.2 Step 1.2: Accident Probability

The second step is to calculate the probability of an accident impacting a point on the Earth. This is usually a combination of a series of probabilities; including the failure probability of vehicle, the probability-weighted time of failure and the characteristics of the failure itself.

For this example, an approximate probability of impact distribution is formulated based on the flight corridor approach of FAA part 420. This defines a "flight corridor" associated with a launch and the expected number of casualties per launch associated with that corridor. The flight corridor represents the area on the surface of the Earth within which it is considered possible for debris to fall based on some assumptions regarding factors such as:

- the size of the launch vehicle;
- the magnitude of any malfunction turn;
- the imparted velocity following an explosive failure (where applicable)
- the debris produced after an explosive failure (where applicable);
- the atmospheric conditions (primarily wind).

Within the expected casualty method there is a calculation to determine the probability of debris hitting an area (population) within the flight corridor. However, the method in APPENDIX B of [AD1] has a singularity at the launch point of the trajectory and is poorly defined until the vehicle has significant downrange velocity (it is typically only applied when the vehicle is above 50,000ft). To address this, the probability of impact directly downrange of the launch site to a distance of 5 km is mapped uniformly around the launch point. This is considered to be a conservative assumption.

The probability of failure of the first stage is assumed to be 0.3, which results in the probability of impact distribution shown in Figure 8.

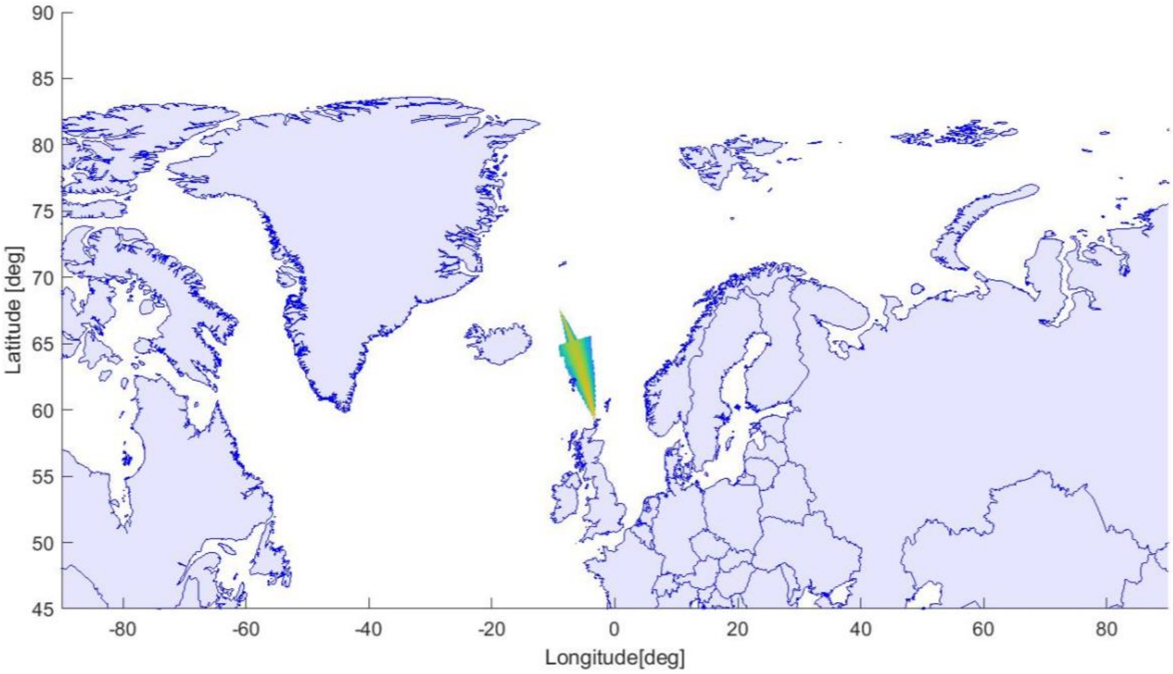

Figure 8 - Probability of impact distribution SSO

7.2.3 Step 1.3: Accident Consequences

The damage is calculated based on the area blast overpressure from the rocket impacting the ground. This is used in conjunction with the associated models in section 4.1.3 to estimate the consequences in terms of cost of:

- fatalities;
- casualties;
- property damage;
- environmental damage; and
- damage to high value infrastructure;

for each major accident scenario. The approach to modelling the financial consequence to each of the

7.2.4 Step 1.4: Assess Total Damage of Major Accident Scenarios

These financial damages are summed in each grid cell to provide the overall damage of each major accident scenario. If we were considered more types of hazard, we would also sum across these to provide the overall damage in each grid cell.

7.3 Step 2: Assess Mission Phase Financial Risk

The financial consequence can be plotted against the probability of this level of damage or higher from occurring to produce the damage profile, as in Figure 9. A few interesting features can be identified from this damage profile. The first is that this damage profile is driven by two populations; the population on the Orkneys close to the launch site (as discussed in step 1.2, a 5km probability of impact zone is assumed in this simplified analysis) is the driver of the level of damage above the MIR threshold. The second population, that of the Faroe Islands, drives the increase in damage below the

MIR threshold. The increase in damage from 10^9 to 10^{10} is due to damage to high value infrastructure (e.g. rare events with high levels of consequences).

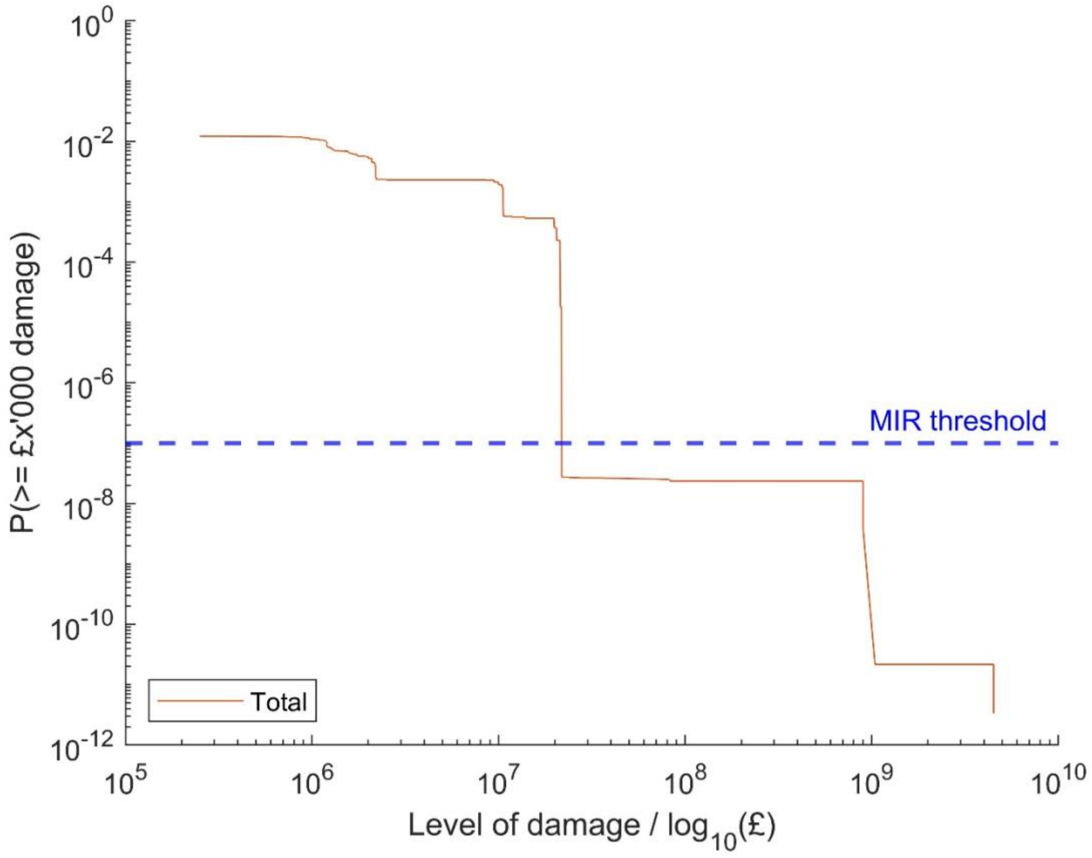

Figure 9 - Example Damage Profile

7.4 Step 3: Determine Insurance Requirements

Also shown Figure 9 is the horizontal line corresponding to the MIR threshold, set to 1×10^{-7}. The intersection with the "Mission Total" damage profile with this likelihood is "reasonably foreseeable" level of damage, and in this case is £21.8 million. However, it is important to note how close the increase in damage from 10^7 to 10^9 is to the MIR probability threshold. This indicates how potentially sensitive the insurance requirement will be to the risk of the operations of a launch operator (and especially the risk controls and mitigations they will have in place).