Andøya Spaceport

# Safety summary
# Reference Document for the use by Norconsult

Final Ver 1.0

ASP: 2018

12.12.2018

| Rev. | by | Changes | Date |
|---|---|---|---|
| 0.1 | Rob Dines and Cato Wistnes | Draft for internal review | 25.09.2018 |
| 1.0 | Cato Wistnes | Final Version | 12.12.2018 |

| **Authorised by** | **Role** | **Date** |
|---|---|---|
| Ingun Berget | Project Manager ASP | 12.12.2018 |

# Contents



# Figures



# Tables

# 1 Introduction/Scope

This Safety Summary is based mainly on excerpts from work undertaken in the Feasibility Report from work package 2 (WP2) of the Andøya Space Port (ASP) feasibility study project, conducted jointly between Andøya Space Center and the Norwegian Space Agency. It has also elements from the studies and calculations done in connection with the mentioned feasibility report from WP 2.

The purpose ios to supply NorConsult with a reference document describing the safety aspects, that is not company confidential or contain sensitive information regarding ASP's ConOps and strategy.

# 2 Definition of terms (From Feasibility Report WP2)

As there is some inconsistency in the use of terms used to discuss orbital launch operations from the perspectives of the launch site, launch vehicle and satellite operator, this section defines the terminology used in this document. They are grouped under four general headings: system, operations, facilities and safety.

| **The system** | |
|---|---|
| **Launch vehicle (LV)** | A vehicle that is capable of carrying a payload that is intended to reach outer space. Includes rocket motors, payload housing and any payload adaptors/separation systems. |
| **Launch Vehicle types** | LV type A: All rocket motors of the LV use solid fuel |
| | LV type B: All rocket motors of the LV use liquid fuel. Assume RP-1 + LOX. (LOX + polypropylene, etc are also possible) |
| | LV type C: Solid + liquid fuel. Typically, the first stage motor(s) are solid fuel; one or more subsequent stages is liquid fuelled. |
| | LV type D: Hybrid fuel. The first stage (at least) uses a hybrid (fuel + oxidant) motor. |
| **Payload** | All of the satellites, probes or equipment to be launched into outer space by the LV, encapsulated in payload fairing for integration with the LV |
| **Satellite** | One or more satellites may be contained within the payload housing, to be delivered into orbit by the LV, to operate independently in outer space |
| **Launch System (LS)** | The integrated LV + Payload |
| **Operations** | |
| **Mission control** | In this document the scope of the *mission control* function includes all activities in the process of preparing a launch system for launch through to delivery of the |

| | |
|---|---|
| | payload into orbit. It comprises all the systems on the range, including the *launch system control* and *launch safety control* functions. |
| **Launch system control** | The *launch system control* function includes all activities directly associated with launch system preparation and launch, including vehicle integration and test, preparation on the pad, fuelling and arming and delivery of the mission to the satellite manufacturer or service provider customers. |
| **Launch safety control** | The scope of responsibility of the launch safety control function includes the safety of all operations associated with the mission, from preparation of the launch system at the launch site through to delivery of the payload into orbit. The pre- and post-launch responsibilities are generally considered separately as *ground safety* and *flight safety*. |
| **Launch preparation** | All activities conducted from the start of LS integration on-site to completion of final pre-launch tests of the erected LS on the launch pad. Includes any launch pad fuelling activities. |
| **Payload preparation** | Preparation, test and fuelling of satellites before integration into a payload & encapsulation in the payload housing |
| **Launch** | All activities from ignition onwards, to insertion of the payload into orbit and including return to earth of all non-orbital LV components. |
| **Facilities** | |
| **Launch system integration facility** | A facility used for horizontal integration of a Launch System from the delivered components of the launch vehicle and payload, and the tests conducted before deployment of the LS to the launch pad. |
| **Transporter / erector vehicle** | A vehicle used to transport the LS from the integration facility to the launch pad and erect it to vertical for launch |
| **Launch table** | A launch pad interface for the launch system, typically metallic structure raised 4 metres above the pad and |

| | |
|---|---|
| | above a conical flame deflector, to deflect rocket exhaust away from the vehicle and pad. |
| **Launch pad facility** | A launch pad and the associated systems & infrastructure required to conduct all activities in the launch pad area, including LV liquid fuelling (if applicable), final checks, launch and post-launch clean-up. |
| **Safety** | |
| **Hazardous activity** | In this context, an activity undertaken specifically associated with spaceport operations that may expose individuals to unacceptable risk unless suitable mitigation measures are taken. (Hazards associated with general support operations are not considered here, as mitigations are within the scope of general health, safety and environmental regulations.) |
| **Launch pad hazard area** | The area within which there is an unacceptable risk of injury from the blast, debris or fire hazards of a launch accident on the pad before lift-off. A launch pad hazard area is defined for each launch pad. |
| **Flight hazard area** | An area below the launch trajectory of a vehicle within which the risk of fatality from debris impact exceeds the applicable criteria for acceptable risk[1]. It is determined by applying the methods defined in FAA part 417 Appendix A 417.23(c). |
| **Impact Limit Lines (ILLs)** | Lines on the surface of the earth defining the maximum permitted divergence of the IIP from the planned launch system trajectory. |
| **Instantaneous Impact Point (IIP)** | At any point on the launch system trajectory the IIP is the point at which the launch system or debris from it would impact the earth if thrust was terminated and the launch system followed a ballistic trajectory. |
| **Safety clear zone** | The area around a launch pad within which there is an unacceptable risk of injury from the blast or fragmentation of an accidental explosion of a fuelled launcher on the pad. Defined by the greater of the blast |

[1] The applicable Norwegian regulatory criteria for acceptable risk during launch of an orbital launch system is at present unknown. Until such criteria are defined by the Norwegian government, existing ASC criteria will be used.

| | |
|---|---|
| | and fragmentation radii of the total mass of propellant in a full launch vehicle (FAA guide 437.53A) |
| **Blast radius** | The area within which a LV explosion may generate a blast overpressure > 6.9kPa (=1psi), calculated as the radial distance $R = 23.2 \times W_t^{1/3}$ (metres), where Wt is the TNT equivalent mass of LV fuel (in kg.) |
| **Fragmentation radius** | The distance from the point of explosion to the point at which the density of hazardous fragments (those having an impact energy of 79 joules or greater) has decreased to less than 1 hazardous fragment per $56m^2$ |
| **Explosive hazard area** | An area around any storage facility for hazardous materials in category 1 of the UN classification of dangerous goods within which there is an unacceptable risk of blast or fragmentation injury in accordance with the Direktoratet for Samfunnssikkerhet og Beredskap (DSB) regulations for safe separation distances from public buildings, workplaces, etc. |
| **Public access point** | Any point outside the spaceport security boundary that is accessible to the public. Includes open spaces, roads, houses, local community buildings, etc. |

## 2.1 Basis of assumptions (From Feasibility Report WP2)

This section summarises the fundamental assumptions on which the spaceport capability requirements are based. They concern:

- the general characteristics of the vehicles launched;
- the launch concept of operation adopted by vehicle operators;
- the scope of launch services to be provided by the spaceport;
- the external constraints to which spaceport design and operation are subjected, mainly related to the safety and security of operations.

### 2.1.1 Generic launch vehicle

The spaceport capability requirements are based on delivery of launch services for a generic launch vehicle that is representative of commercial vehicles in the <1.5t payload class. The key parameters of the vehicle affecting spaceport requirements are summarised in Table 2-1. As solid and liquid-fuelled vehicles in this class impose unique requirements on the launch site, both types of vehicle are considered.

Support for hybrid vehicles is not specifically considered. It is assumed that by defining the requirements for solid and liquid vehicles, the spaceport will have the capability to meet the less demanding requirements of hybrid (and mixed fuel) vehicles.

| Launch vehicle | 2/3 stage solid | 2/3 stage liquid |
|---|---|---|
| Launch system size | 30m x 2.5m | |
| Launch mass | <60t | |
| Payload | <1.5t | |
| Propellant | <55t LOX + RP-1 | <55t solid fuel |
| Orbit | Polar and SSO, 700km | |

*Table 2-1 Generic launch vehicle characteristics*

# 3 Definition of hazard areas (From Feasibility Report WP2)

## *3.1 Hazard area requirements – general*

Safety regulatory authorities generally differentiate between:

- **Ground safety** and the ground hazard area associated with launch preparation activities, and:
- **Flight safety** and the launch hazard area that applies from vehicle ignition onwards.

Ground safety is primarily concerned with handling hazardous materials and in particular, large quantities of propellants with some explosive potential. Flight safety is concerned with the risk that the vehicle departs from its planned trajectory and/or breaks up in flight, causing debris to fall outside planned impact areas. The spaceport site must be located, and the site infrastructure planned, such that the ground and flight hazard areas required for the class of launch vehicles proposed may be accommodated within an unpopulated area around the launch site. The following sections determine the dimensions of those areas, to define site planning constraints.

## *3.2 Ground hazard areas*

Regulations defined by the Norwegian Direktoratet for Samfunnssikkerhet og Beredskap (DSB) and by the US Federal Aviation Administration (FAA) are applicable to different aspects of ground safety:

### 3.2.1 DSB regulations

DSB safety regulations include those relating to the storage and handling of hazardous materials in accordance with the UN categorisation 1-9 of Dangerous Goods. The regulations for explosive material categories 1.1 and 1.3 are relevant here (Table 3-1). Propellants of both solid and liquid fuelled versions of the generic launch vehicle are classified as category 1.3 explosives. A solid fuelled vehicle with cat 1.1 igniters installed must be categorised as 1.1.

The DSB regulations specify the safe separation distances required between explosive stores and between explosive stores and public places. The regulations apply to all spaceport stores of potentially explosive material. A fuelled launch vehicle is regarded as an ‘explosive store’ in this context.

Separation distances are calculated using

$$D = K(W_t)^n$$

Where D = Safety distance in meters

K = Constant which depends on the acceptable safety limits for an exposed object regarding pressure/blast, debris, etc

$W_t$ = net explosive weight in kg = actual weight x TNT equivalent factor

n = 1/3 (unless blast protection walls are used, see Table 3-3)

The K factor applicable to different explosive categories and the objects exposed to the hazard (house, school, road, etc) are defined in Table 3-2 and Table 3-3.

| Category | Definition |
|---|---|
| 1.1 | Substances and articles which have a mass explosion hazard (a mass explosion is one which affects almost the entire load virtually instantaneously |
| 1.2 | Substances and articles which have a projection hazard but not a mass explosion hazard |
| 1.3 | Substances and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard.<br>This division comprises substances and articles:<br>(i) which give rise to considerable radiant heat; or<br>(ii) which burn one after another, producing minor blast or projection effects or both; |
| 1.4 | Substances and articles which present no significant hazard<br>This division comprises substances and articles which present only a small hazard in the event of ignition or initiation during transport. The effects are largely confined to the package and no projection of fragments of appreciable size or range is to be expected. An external fire shall not cause virtually instantaneous explosion of almost the entire contents of the package |
| 1.5 | Very insensitive substances which have a mass explosion hazard<br>This division comprises substances which have a mass explosion hazard but are so insensitive that there is very little probability of initiation or of transition from burning to detonation under normal conditions of transport |
| 1.6 | Extremely insensitive articles which do not have a mass explosion hazard<br>This division comprises articles which predominantly contain extremely insensitive substances and which demonstrate a negligible probability of accidental initiation or propagation. |

*Table 3-1 UN categories of explosive material - from DSB regulations*

| Distance in meters to: Hospital, school, nursery, shelter and meeting rooms | Distance in meters to house | Distance in meters to: Public road, quayside, railway and the like. | Distance in meters between magazines with barricade | Distance in meters between magazines without barricade |
|---|---|---|---|---|
| K = 44,4<br>n = 1/3<br>Dmin = 800 | K = 22,2<br>n = 1/3<br>Dmin = 400 | K = 14,8<br>n = 1/3<br>Dmin = 180 | K = 2,4<br>n = 1/3<br>Dmin = 8 | K = 22,2<br>n = 1/3<br>Dmin = 180 |

*Table 3-2 Hazard groups 1.1 and 1.5*

| Distance in meters to: Hospital, school, nursery, shelter and meeting rooms | Distance in meters to house | Distance in meters to: Public road, quayside, railway and the like. | Distance in meters between magazines with / without barricade |
|---|---|---|---|
| K = 12,8<br>n = 1/3<br>Dmin = 240 | K = 6,4<br>n = 1/3<br>Dmin = 60 | K = 6,4<br>n = 1/3<br>Dmin = 60 | K = 0,22<br>n = 1/2<br>Dmin = 25 |

*Table 3-3 Hazard group 1.3*[2]

### 3.2.2 FAA regulations applicable to ground operations

In the case of a US launch vehicle, FAA regulations apply from the point of ignition. However, the FAA definitions of the blast and fragmentation hazards of a vehicle explosion on the launch pad are applied here to define the pre-launch ground hazard area. The FAA defines a ***safety clear zone*** around the launch pad as the larger of the blast and fragmentation hazard areas:

#### Blast hazard

FAA part 417 appendix A417.23(d) requires the launch vehicle operator to define a near-launch-point blast hazard area as a circle extending from the launch point with a radius equal to the 1.0 psi overpressure distance

[2] Safety distances for explosives in hazard group 1.4 are 25 meters to the nearest neighbour for quantities up to 10 tonnes and 50 meters for quantities exceeding 10 tonnes.

produced by the equivalent TNT weight of the explosive capability of the vehicle. The circle has radius

$$R_{op} = 45 \times (W_e \times C)^{1/3} \quad \text{(lbs, feet)}$$

where $W_e$ is the total weight of launch vehicle explosive material (in lbs)

C is the factor used to convert to a TNT equivalent weight

$R_{op}$ is the 1psi overpressure radius.

Converting to metric measures:

$$R_{op} = 23.2(W_e \times C)^{1/3} \text{(kg, metres)}$$

A417.23(d) defines C factors for standard liquid propellants. LOX/RP-1 has a C factor of 0.2. C factors for solid propellants are not defined in FAA regulations.

Anyone within the 1psi (6.9kPa) radius must be treated as a casualty, whether they are inside a building or outside (see §417.107.c.2).

#### Fragmentation hazard

The fragmentation hazard associated with a launch pad explosion of a liquid fuelled vehicle may be determined using the FAA guide 437.53-1. The calculation of based on the TNT equivalent weight of the fuel $W_t = (W_e \times C)$.

The fragmentation hazard is defined as the Hazardous fragment distance (HFD). This is the distance measured from the point of explosion to the point at which the density of hazardous fragments generated by the explosion has decreased to where people in the open are not expected to be seriously injured. The HFD is calculated as:

$$HFD = (389 \times \text{Ln}(W_t)) - 1134 \quad \text{(feet, lbs)}$$

or $$HFD = (389 \times \text{Ln}(W_t \times 2.2) - 1134) 0.3048 \quad \text{(metres, kg)}$$

$$= (119 \times \text{Ln}(W_t \times 2.2) - 346$$

The HFD is always larger than the 6.9kPa blast radius; for vehicles in the small class, it may be more than 2x the blast radius.

### 3.2.3 Applying FAA and DSB regulations to define ground hazard areas

Table 3-4 summarises the separation distances applicable to spaceport fuel storage areas. For a liquid fuelled vehicle launch, the total mass of fuel on the pad may be up to 2.5x the capacity of one vehicle. Up to five solid fuelled vehicles may be in storage on site at any one time (see **Error! Reference source not found.**).

The distances applicable to the generic solid and liquid fuelled vehicles are highlighted in red:

- Safety clear zone radii of 949m / 960m are applicable to the solid / liquid fuelled launch vehicles on the pad;
- Any launch system integration area containing a solid fuelled vehicle with igniters installed (cat 1.1) must be 670m from the nearest house and 447m from a public road.
- A store of five solid fuelled vehicles with no igniters (cat 1.3) must be 374m from a public road.

Storage hazard radii may be significantly reduced if blast & fragmentation barriers are installed.

| Fuel (kg) | | | FAA: Launch site safety clear zone (metres) | | DSB: Hazardous stoarge area separation distances (metres) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cat 1.3 (e.g fuel) | | Cat 1.1 (or fuel with igniter) | | | |
| Equivalent solid fuel mass | Equivalent liquid fuel mass | TNT equivalent Wt | Hazardous fragment distance | Radius for 6.9kPa overpressure | Distance to school, meeting room | Distance to public road / house | Distance to school, meeting room | Distance to house | Distance to public road | Distance between magazines with a barricade |
| 20000 | 50000 | 10000 | 840 | 384 | 276 | 138 | 957 | 478 | 319 | 52 |
| 30000 | 75000 | 15000 | 888 | 440 | 316 | 158 | 1095 | 547 | 365 | 59 |
| 40000 | 100000 | 20000 | 922 | 484 | 347 | 174 | 1205 | 603 | 402 | 65 |
| 50000 | 125000 | 25000 | 949 | 522 | 374 | 187 | 1298 | 649 | 433 | 70 |
| 55000 | 137500 | 27500 | 960 | 538 | 386 | 193 | 1340 | 670 | 447 | 72 |
| 60000 | 150000 | 30000 | 970 | 554 | 398 | 199 | 1380 | 690 | 460 | 75 |
| 70000 | 175000 | 35000 | 988 | 584 | 419 | 209 | 1452 | 726 | 484 | 79 |
| 80000 | 200000 | 40000 | 1004 | 610 | 438 | 219 | 1518 | 759 | 506 | 82 |
| 90000 | 225000 | 45000 | 1018 | 635 | 455 | 228 | 1579 | 790 | 526 | 85 |
| 100000 | 250000 | 50000 | 1031 | 657 | 472 | 236 | 1636 | 818 | 545 | 88 |
| 110000 | 275000 | 55000 | 1042 | 678 | 487 | 243 | 1689 | 844 | 563 | 91 |
| 120000 | 300000 | 60000 | 1052 | 698 | 501 | 251 | 1738 | 869 | 579 | 94 |
| 130000 | 325000 | 65000 | 1062 | 717 | 515 | 257 | 1785 | 893 | 595 | 96 |
| 140000 | 350000 | 70000 | 1071 | 735 | 528 | 264 | 1830 | 915 | 610 | 99 |
| 150000 | 375000 | 75000 | 1079 | 752 | 540 | 270 | 1872 | 936 | 624 | 101 |
| 160000 | 400000 | 80000 | 1086 | 769 | 552 | 276 | 1913 | 957 | 638 | 103 |
| 170000 | 425000 | 85000 | 1094 | 784 | 563 | 281 | 1952 | 976 | 651 | 106 |
| 180000 | 450000 | 90000 | 1100 | 799 | 574 | 287 | 1990 | 995 | 663 | 108 |
| 190000 | 475000 | 95000 | 1107 | 814 | 584 | 292 | 2026 | 1013 | 675 | 110 |
| 200000 | 500000 | 100000 | 1113 | 828 | 594 | 297 | 2061 | 1030 | 687 | 111 |
| 210000 | 525000 | 105000 | 1119 | 842 | 604 | 302 | 2095 | 1047 | 698 | 113 |
| 220000 | 550000 | 110000 | 1124 | 855 | 613 | 307 | 2127 | 1064 | 709 | 115 |
| 230000 | 575000 | 115000 | 1129 | 867 | 622 | 311 | 2159 | 1080 | 720 | 117 |
| 240000 | 600000 | 120000 | 1135 | 880 | 631 | 316 | 2190 | 1095 | 730 | 118 |
| 250000 | 625000 | 125000 | 1139 | 892 | 640 | 320 | 2220 | 1110 | 740 | 120 |
| 260000 | 650000 | 130000 | 1144 | 904 | 648 | 324 | 2249 | 1125 | 750 | 122 |

*Table 3-4 Minimum separation distances*

## 3.3 Launch hazard area (From Feasibility Report WP 2)

For launch site planning purposes, it is necessary to estimate the size of unpopulated area around the launch site required to accommodate the *flight hazard area* of any vehicle expected to launch from the site. This defines the maximum available *launch hazard area* at the launch site.

Before any launch mission is conducted, extensive analyses of hazard, trajectory and risk analyses must be undertaken to characterise the flight hazard area for the launch. (The requirements to undertake these analyses in e.g. FAA part 417, are detailed and proscriptive). The flight hazard area is specific to the vehicle and mission. It is determined by the vehicle's flight characteristics, the planned (*nominal*) trajectory, the possible failure modes, the flight termination regime, and the post-termination behaviour of the vehicle. The launch hazard area for a site cannot therefore be based on the flight hazard area of a specific launch vehicle and mission. (Unless only all missions undertaken from that site are similar and involve the same launch vehicle.)

To define such an area, the FAA part 420 for launch sites provide useful guidance[3], as it specifies the dimensions of an 'overflight exclusion zone' that it is necessary to establish around the launch point to accommodate different sizes of vehicle. This overflight exclusion zone is adopted to define a launch hazard related to the characteristics of the generic launch vehicles (solid and liquid variants).

Table 3-5 defines the overflight exclusion zone dimensions for four classes of vehicle, defined by payload mass (not by gross vehicle mass or fuel) launched vertically into 100km orbit.

| | | **Vehicle class** | | | |
|---|---|---|---|---|---|
| | | **Small** | **Medium** | **M-Large** | **Large** |
| | Max payload (kg) | 1497 | 3810 | 6804 | >6804 |
| Debris dispersion radius(km) | Dmax | 2.23 | 2.83 | 3.23 | 3.96 |
| Downrange Distance (km) | Doez | 6.11 | 6.43 | 7.88 | 23.82 |

*Table 3-5 FAA overflight exclusion zone parameters*

[3] FAA part 420 defines regulations applicable to a US launch site; these regulations are not applicable to launches from Norway. Part 420 is adopted here as valuable guidance based on good practice in the US.

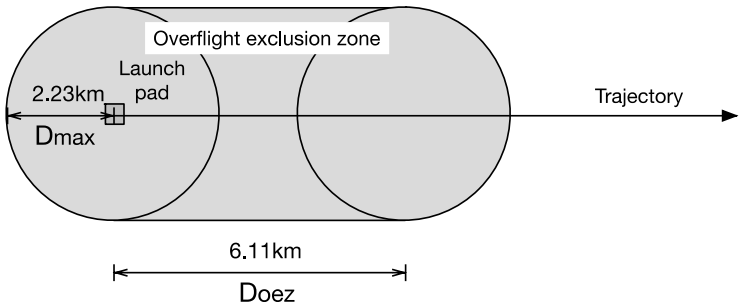


*Figure 3-1 Overflight exclusion zone for small launch vehicle class*

Figure 3-1 describes the overflight exclusion zone for a vehicle in the small class (<1.5t payload) corresponding to the generic launch vehicle.

## 3.4 Hazard area requirements for launch site planning

Figure 3-2 uses the FAA definitions of the safety clear zone and the overflight exclusion zone to dimension the hazard area to be accommodated when planning the layout of buildings and infrastructure. The figure also illustrates the need to maintain DSB-defined separation distances between storage areas for fuel and other potentially explosive materials.

(It should be noted that this figure is simply an *illustration* of the hazard area constraints applicable to any launch site on a shore with access to SSO and polar trajectories. It does not describe the geography of a real location or scaled dimensions of a vehicle flight hazard area).

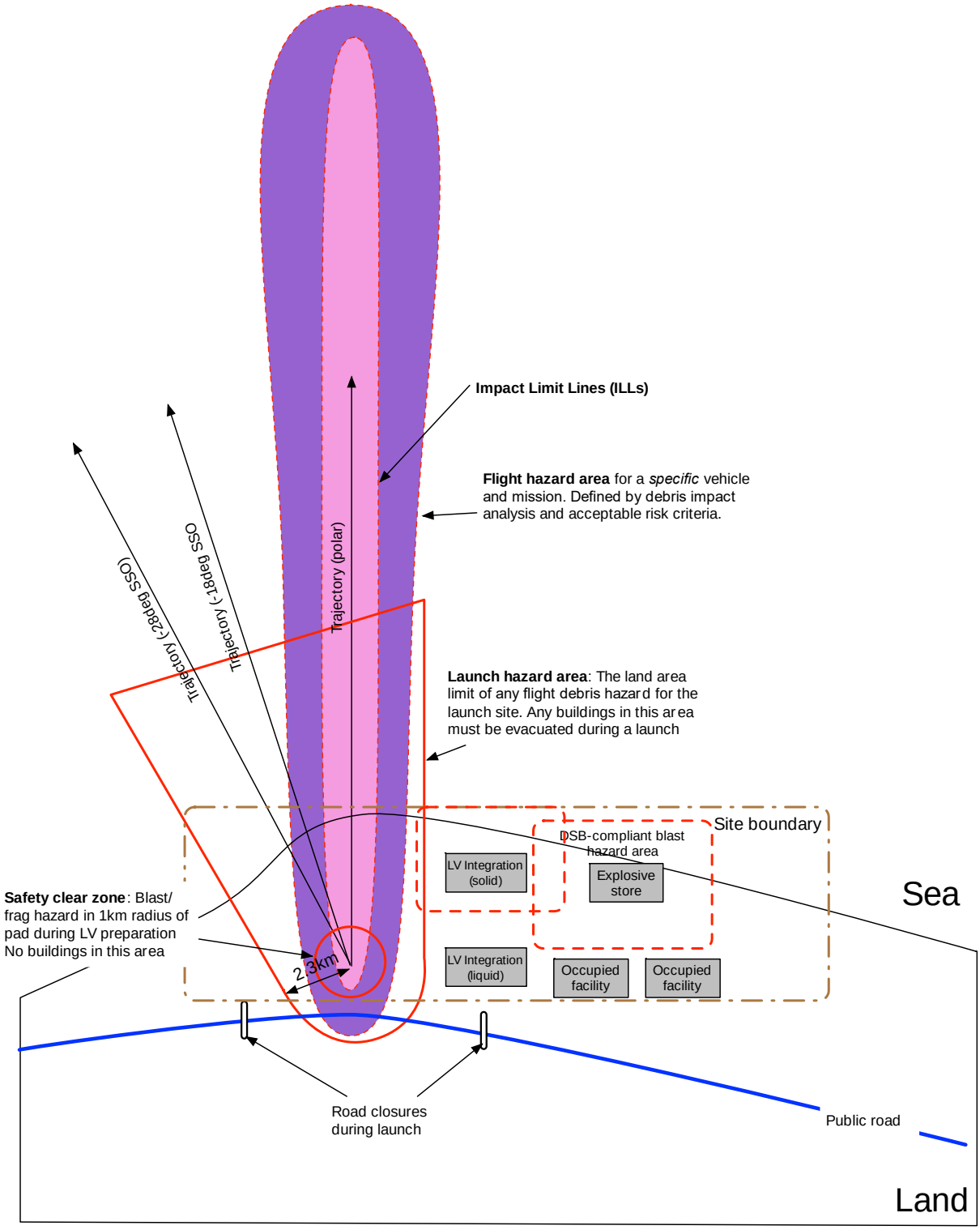


*Figure 3-2 Hazard areas – illustration*

The figure illustrates the following site planning constraints:

- The ***safety clear zone*** is active at any time a fuelled vehicle is on a launch pad. It is a circle of 1km radius centred on each launch pad.
- The ***launch hazard area*** is described by a 2.3km circle around each pad and tangential lines extending out in the direction of the most extreme launch trajectories as shown. It is active from the point of

launch until the vehicle debris hazard has cleared the area. No occupiable buildings may be constructed within this area. The tangential arms of the launch hazard area may be ignored where they extend out to sea; the flight hazard area for the specific mission will define sea area clearance requirements.

- Storage and assembly areas for solid fuel vehicles must be separated from all other working areas and points of public access by DSB-defined separation distances (Table 3-4).
- A site boundary and a public road are shown in the figure to illustrate the potential impact of hazard area activation on public access to the local area. In this illustration, the public road is outside the site boundary, but must be closed before launch. As it is outside the safety clear zone of the launch pad, it may remain open during launch preparation.
- The purple ***flight hazard area*** illustrates that trajectory analyses of any launch mission must verify that any debris resulting from in-flight failures will fall within the available hazard area.

It is recognised that defining a 2.3km launch hazard area does not guarantee that any vehicle with <1.5t payload may be launched from the site. The 2.3km is an allocation of unpopulated area intended to accommodate the flight hazard areas of vehicles in this size category. It is possible that trajectory analysis for a specific vehicle in this category cannot be accommodated.

## 3.5 Use of the hazard areas in site planning

Figure 3-3 shows the launch and explosive storage hazard areas superimposed on the proposed launch site to the SW of Nordmela. The launch pad is located in shallow water ~1km from the main shore line, connected by stone breakwater.

This figure illustrates how hazard areas constrain site planning options. It does not describe a detailed site plan for the spaceport to be developed in WP7. The locations of buildings and facilities are therefore indicative.

The planning constraints are:

a. Any building within the launch hazard area (2.3km radius) must be normally unoccupied (e.g. a storage area) or must be evacuated during launch. As it would be commercially unacceptable for a launch by one operator to interrupt the activities of a second operator, all occupy-able buildings must be located outside the launch hazard area.

b. The green rectangle labelled ‘spaceport operations’ is used here to represent all non-hazardous operations buildings, e.g. mission control, launch control and offices, workshops, administration buildings, etc associated with the spaceport.

c. An integration facility for a solid fuelled vehicle is represented outside the launch hazard area but within its own category 1.1 explosion hazard area. The 570m separation distance (represented as a 570m radius circle) may be reduced if suitable barriers are used. The integration facility for liquid fuelled vehicles does not required a large hazard area for the main propellant explosion risk, however other hazards may apply associated with e.g. smaller quantities of satellite propellant.

d. The storage and integration facility for a liquid fuelled vehicle is shown as non-hazardous; it is possible that integration will involve small quantities of hazardous material, e.g. for satellite fuelling within the facility.

e. As the solid fuelled vehicle store will not be occupied during launch operations, it may be located within the launch hazard area, as shown in the figure.

f. The main road (shown as the yellow line) passes through the launch hazard area but is outside the pre-launch blast hazard area (radius 1km). The road may therefore remain open during launch preparation but must be closed during launch. The white line indicates the internal road system needed for example to transport launch vehicles between integration facilities and the launch pad area.

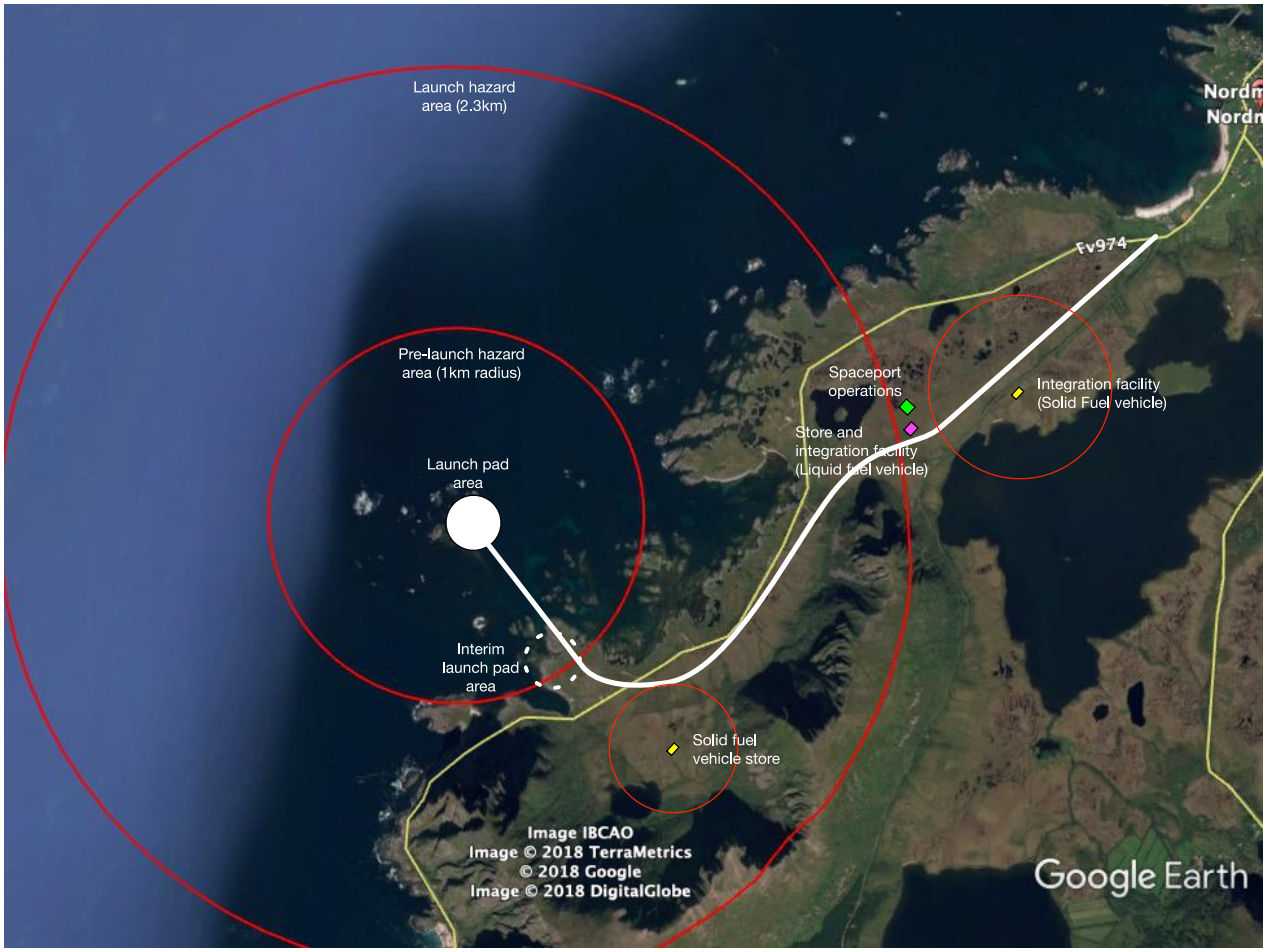


*Figure 3-3 Launch hazard areas – Nordmela*

## 3.6 Launch safety (From Feasibility Report WP 2)

The launch safety team implements the measures defined in a mission safety plan (typically structured as a ground safety plan and a flight safety plan). Their primary responsibilities are to:

a. Perform Mission Analysis based on LV provider's launch trajectory

b. Verify the analysis of conditions for safe flight defined in the mission safety plan;

c. Define the flight termination regime (rule set) and configure the mission control system to implement it[4];

d. Manage access to the pad area during launch vehicle preparation;

e. Prepare the Range system and verify readiness for launch;

[4] Points (c) and (k) are only applicable if a conventional ground-based flight termination system is used.

f. Define launch readiness criteria and chair the launch readiness review;

g. Verify that the flight hazard area is clear before launch;

h. Manage the launch countdown;

i. Authorise launch when safety criteria defined in the mission safety plan are met;

j. Track the trajectory of the launch system and the initial trajectories of any separating stages;

k. Calculate and track in real time the Instantaneous Impact Point (IIP) and terminate the flight if the IIP exceeds an Impact Limit Line (ILL) defined in the flight safety plan[4];

l. Acquire and store telemetry and tracking data;

m. Coordinate any debris recovery and/or emergency response measures.

### 3.6.1 Ground safety

In the period leading up to a launch, the primary responsibilities of ground safety are to:

- Limit access to the safety clear zone to persons essential to pre-launch pad operations;
- Ensure that all persons are clear of the launch hazard area before launch. This includes closing the public road through the site.

(The safety clear zone and the launch hazard area correspond to the Pre-Launch Danger Area (PLDA) and Launch Danger Area (LDA) defined in ASC safety regulations.)

### 3.6.2 Flight safety

The ILLs for the mission will be defined in the flight safety assessment presented to the regulatory authority. Figure 3-4 illustrates the FAA definition of ILLs in relation to flight hazard areas, but applying ASC criteria for acceptable public risk of:

- Pc <1E-7
- Ec < 3.0E-5
- Risk of multiple fatalities is within the acceptable region defined by the F-N graph of Figure 3-5.

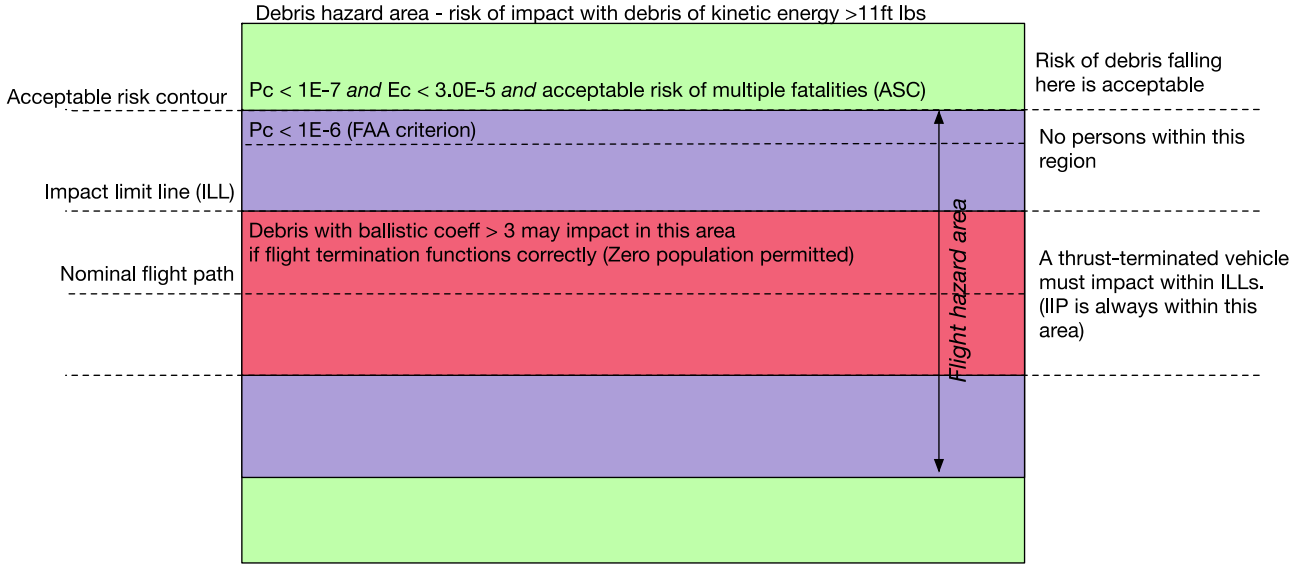


*Figure 3-4 Flight hazard area and ILLs*

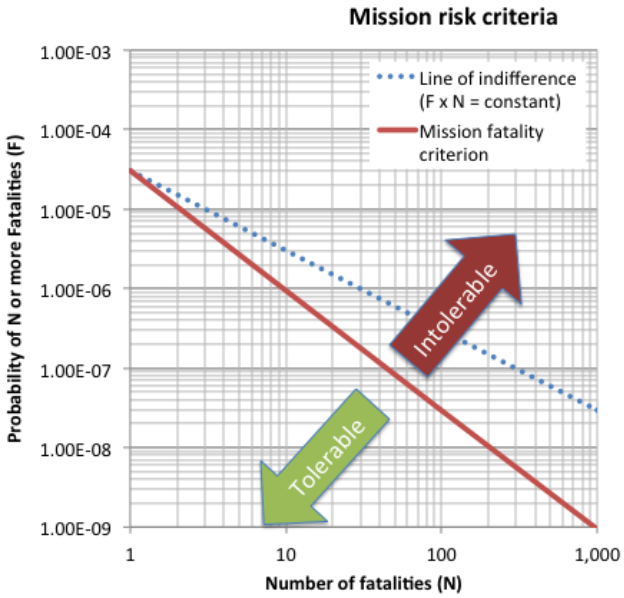


*Figure 3-5 ASC criterion for acceptable risk of multiple fatalities*

The flight termination system and operating procedure must implement precisely the rule set presented to the regulatory authority in the launch license application. FAA part 417.113 provides an example of requirements for rule set definition. To accommodate the flight within the defined hazard area, the termination rule set may be complex and FTS operation time critical. The flight termination system will therefore be designed to operate without human intervention (i.e. no person-in-the-loop). Two options are possible:

### 3.6.3 Autonomous flight termination

The launch safety function may be simplified if the launch vehicle employs an Autonomous Flight Termination System (AFTS), in which case the

functionality 3.6(k) is embedded in the vehicle. Launch safety may track the launch system and have the capability to over-ride the on-board AFTS, or a safety argument may be made that no ground-based flight termination capability is necessary.

An FAA-approved AFTS device is now available in the US. It is expected that the system will increasingly be adopted by small launch vehicle operators to reduce launch costs and achieve higher launch cadences.

### 3.6.4 Automatic flight termination

The term automatic flight termination is used here to describe the possibility of a ground-based system used to monitor the vehicle trajectory and automatically initiate a terminate command if pre-defined safety criteria are exceeded. This system is currently used at ASC in a time-critical missile test application, eliminating the person-in-the-loop and ensuring a deterministic outcome.

## 4 Reference Documents

- DSB's veiledning til kap 5 i «Forskrift av 15. juni 2017 nr. 844 om sivil håndtering av eksplosjonsfarlige stoffer (eksplosivforskriften):
  Hele dokumentet med vekt på pkt 4. Veiledning til §37 KRAV til plassering av rom, bygning eller innretning. Alle underpunkter samt Tab 1 & Tab 3.
- Federal Aviation Administration (FAA) Code of Federal Regulation 14 part 417, Appendix A, parax A417.23(d) Blast Hazard
- Calculating of Safety Clear Zones according to Federal Aviation Administration (FAA) Guide 437.53A
- Blast overpressure (1 PSI) K-factor according to Department of Defence Publication 6055.9 CH2 Subsection C.11
- United Nations International Ammunition Technical Guideline (IATG) 01.80
- Department of Defense Manual 6055.09 Vol 1-3