NORTH ATLANTIC TREATY ORGANIZATION
ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD

MILITARY AGENCY FOR STANDARDIZATION (MAS)
BUREAU MILITAIRE DE STANDARDISATION (BMS)
1110 BRUSSELS

Tel : 707.55.84
Fax : 707.57.18
masarmy@hq.nato.int

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STANAG 2921 NRS (EDITION 2) - WEAPON DANGER ZONES FOR LAND LAUNCHED GUIDED MISSILES FOR USE BY NATO FORCES OPERATING IN A GROUND ENVIRONMENT
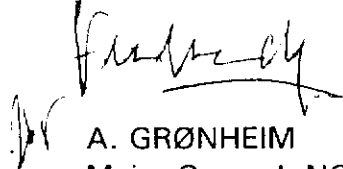
References:
a.   MAS(ARMY)012-NRS/2921 dated 22 May 1996 (Edition 2) (1st Draft)
b.   MAS(ARMY)301-MIS/2921 dated 27 October 1994 (Edition 1)

1.   The enclosed NATO Standardization Agreement, which has been ratified by nations as reflected in page iii is promulgated herewith.

2.   The references listed above are to be destroyed in accordance with local document destruction procedures.

3.   AAP-4 should be amended to reflect the latest status of the STANAG (and AP if applicable).

ACTION BY NATIONAL STAFFS

4.   National staffs are requested to examine page iii of the STANAG and, if they have not already done so, advise Army Board, MAS, through their national delegation as appropriate of their intention regarding its ratification and implementation.
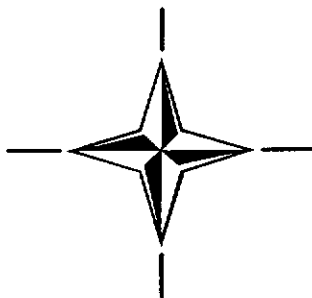
A. GRØNHEIM
Major General, NOAF
Chairman MAS

Enclosure:
STANAG 2921 (Edition 2)

STANAG No. 2921
(Edition 2)

NORTH ATLANTIC TREATY ORGANIZATION
(NATO)

MILITARY AGENCY FOR STANDARDIZATION
(MAS)

STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: WEAPON DANGER ZONES FOR LAND LAUNCHED GUIDED
MISSILES FOR USE BY NATO FORCES OPERATING IN A
GROUND ENVIRONMENT

Promulgated on 10 July 1997

A. GRØNHEIM
Major General, NOAF
Chairman MAS

RECORD OF AMENDMENTS

No.	Reference/date of amendment	Date entered	Signature

EXPLANATORY NOTES

AGREEMENT

1.   This NATO Standardization Agreement (STANAG) is promulgated by the Chairman MAS under the authority vested in him by the NATO Military Committee.

2.   No departure may be made from the agreement without consultation with the tasking authority. Nations may propose changes at any time to the tasking authority where they will be processed in the same manner as the original agreement.

3.   Ratifying nations have agreed that national orders, manuals and instructions implementing this STANAG will include a reference to the STANAG number for purposes of identification.

DEFINITIONS

4.   Ratification is "The declaration by which a nation formally accepts the content of this Standardization Agreement".

5.   Implementation is "The fulfilment by a nation of its obligations under this Standardization Agreement".

6.   Reservation is "The stated qualification by a nation which describes that part of this Standardization Agreement which it cannot implement or can implement only with limitations".

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

7.   Page iii gives the details of ratification and implementation of this agreement. If no details are shown it signifies that the nation has not yet notified the tasking authority of its intentions. Page iv (and subsequent) gives details of reservations and proprietary rights that have been stated.

Agreed English/French Texts

STANAG 2921
(Edition 2)

NAVY/ARMY/AIR

NATO STANDARDIZATION AGREEMENT
(STANAG)

WEAPON DANGER ZONES FOR LAND LAUNCHED GUIDED MISSILES FOR USE BY NATO FORCES OPERATING IN A GROUND ENVIRONMENT

Annex : A. Derivation of In-Flight Guided Weapon Danger Areas and Risk Assessment

Related Documents:

STANAG 2402 NRS - Danger Areas for Land Launched Unmanned Aerial Vehicles for Use by NATO Forces Operating in a Ground Environment

STANAG 3606 NRS - Evaluation and Control of Laser Hazards on Military Ranges

AIM

1. The aim of this agreement is to standardize the method by which danger areas/zones for land launched guided missiles are derived and the associated risks are assessed.

AGREEMENT

2. Participating nations agree:

 a. That the armed forces consider this STANAG as a basis for continuing a working relationship on the preparation of danger areas/zones for individual weapon systems.

 b. The danger areas/zones for all ranges intended for use by NATO forces shall be based on the principles outlined in the Annex to this agreement and that the data used to determine the dimensions of each danger area/zone shall be available on request to the armed forces of the other NATO countries.

 c. That the terminology defined in this agreement and the allowances recommended for the various hazards shall, where possible, be used in the preparation of national danger areas/zones which establish user requirements.

SCOPE

3.   This agreement is concerned primarily with:

a.   Assessing the various hazards associated with firing, flight, and impact of land launched guided weapons.

b.   Assessing the risk to personnel operating on military ranges and the general public.

c.   Discussing the factors for which allowance should be made when determining the extent of the danger area/zone.

4.   It is intended to give guidance on some methods that have been used in the past and to give an indication of the detail and quality of information required.

5.   Figures regarding required reliability and tolerable risk are not given as it is considered that the responsibility for setting them lies with the country in which the guided weapon system is to be fired.

6.   Detailed safety advice applicable to specific guided missile systems in service use will be published later in AOPs.   The application of weapon danger areas in order to define range danger areas is the responsibility of the appropriate service authority.

TERMS AND DEFINITIONS

7.   The following terms are defined for the purpose of this STANAG only.   Other technical terms are defined in the NRS WP Glossary of Terms.   No formal agreement exists for their employment in any other context.

a.   Buffer zone is the 3 dimensional area between a weapon danger boundary and a range danger boundary designed to increase the margin for error in weapon danger area calculations.

b.   Debris zone is the 3 dimensional area between the flight termination boundary and the weapon danger boundary.

c.   Launch danger area is the space around a guided weapon launcher in which personnel are at risk from system launch hazards and therefore the presence and protection of personnel is closely controlled.

d.   Range safety equipment is the materiel used by the range authorities to control the live firing of guided weapons.

e.   Visual flight safety officer is a nominated person who is responsible for the termination of missile flight if

the missile is observed to cross a flight termination
boundary.

<u>IMPLEMENTATION OF THE AGREEMENT</u>

8.   This STANAG is implemented when the necessary orders/
instructions putting the principles and procedures detailed in the
agreement into effect have been issued to the forces concerned.

ANNEX A TO
STANAG 2921
(Edition 2)

DERIVATION OF IN-FLIGHT GUIDED WEAPON DANGER AREAS AND RISK ASSESSMENT

Appendices:
1. Failure Mode List
2. Failure Mode LOG Sheet
3. Example Failure Mode Impact Area Trace
4. Example of Failure Mode Impact Area Trace
5. Example Showing Areas of Low and High Risk within a WDA as a Result of Impact Analysis
6. WDA Generated by Using Monte Carlo Techniques
7. Example of Event Tree Showing Probabilities
8. Example of WDA Showing Areas of Low, Medium and High Risk with Assigned Probabilities
9. The Application of an "Omni-Directional" Wind Correction

GENERAL

1. **Introduction**. Guided weapons (GW) systems are fired for practice on designated military land and sea ranges with defined boundaries or on the high seas. A GW system includes the missile, firing platform, guidance and control equipment. Outside the range boundaries the general public have freedom of access. Where a range utilises sea danger areas, shipping of any nationality may freely enter these designated danger areas. Similarly civil and military aircraft may fly over ranges where GW are being fired. The hazards to personnel operating the weapons, those working within range areas and the general public must be assessed to ensure that the risk of them being injured by missiles fired on those ranges is reduced to a level which is As Low As Reasonably Practicable (ALARP). A key element in this process is the identification of the Weapon Danger Areas (WDA) associated with each type of GW being fired. A WDA contains 2 groups of hazards which need to be evaluated: launch hazards and in-flight hazards.

2. **WDA**. There are 2 types of WDA associated with GW systems:

   a. **Total Energy WDA**. These WDA are applicable to GW which are not fitted with a Flight Termination System (FTS) and are designed usually to contain all the missiles and their associated debris during firing. Such WDA are used for those missiles with a short range. The WDA will differ depending on whether the missile has an inert, telemetry or operational payload.

   b. **WDA derived for GW Systems with a FTS Fitted**. For longer range and more agile GW it may be impossible to contain the total energy WDA within designated range danger area. Consequently, FTS are used to allow a reduced WDA.

3.   Outline of Activity.   To derive a WDA some or all of the following activity is required:

   a.   Development of a GW system performance model.

   b.   Analysis of the guided missile flight failure modes and the resultant hazards.

   c.   Derivation of the Air Danger Height (ADH).

   d.   Derivation of the Total Energy WDA.

   e.   Derivation of the Launch Danger Area.

   f.   Identification of the flight termination/destruct boundaries.

   g.   Derivation of the WDA when a FTS is fitted.

   h.   Assessment of the reliability of the FTS (where applicable).

   i.   Conducting a risk assessment.

   j.   Considering the method of wind correction if applicable.

GW SYSTEM PERFORMANCE MODELS

4.   General.   When developing modern GW systems, use is made of performance models allowing data to be processed by computer. These are usually 6 degrees-of-freedom (DOF) models whose outputs are in the X, Y and Z positional axis and the yaw, pitch and roll rotational axis set.   These models are essential tools in calculating the trajectories of correctly functioning and "rogue" missiles (a "rogue" missile is defined as one which when in flight, goes out of control and flies an unintended trajectory). Where appropriate these models will be supplemented with others that represent warhead effects (e.g. point mass models).   If a 3 DOF model (i.e. X, Y and angular positional axis set only) is used, it should be validated against a 6 DOF model.   The safety criticality/safety significance of the model, if used to examine potential hazards, should be established.   Since some models may be safety critical/safety significant it therefore follows that they should be written using high integrity software and be subjected to independent validation and verification in accordance with appropriate national/international standards.

5.   Model Inputs.   The inputs to models can be divided into 7 groups, with sub-paragraphs a. to f. used to obtain the total energy WDA, and data under sub-paragraph g. included where a FTS is fitted:

   a.   Launch variables.

   b.   Missile in-flight characteristics.

    c.   Missile in-flight failure modes.

    d.   Engagement geometry.

    e.   Range and environmental factors.

    f.   Payload effects.

    g.   Additional factors introduced as a result of the introduction of a FTS.

6.   Launch Variables. Some of the variables that can be introduced at launch and which should be considered are:

    a.   Launch platform altitude and position.

    b.   Launch platform velocity.

    c.   Launch platform heading.

    d.   Launch platform quadrant elevation (QE) or pitch attitude in the case of aircraft.

    e.   Launch platform roll angle.

    f.   Launcher tip-off effects.

    g.   Propulsion motor charge temperature and its effect on motor performance.

    h.   Launch mass.

    i.   The relative position of missile launch points on a multiple launcher to the line of fire.

    j.   In the case of long range missiles consideration should be given to latitude, curvature of the earth and the Coriolis effect.

7.   Missile Flight Characteristics. The following are examples of missile flight characteristics that should be considered:

    a.   Propulsion motor thrust misalignment.

    b.   Asymmetric thrust resulting when one or more launch motors, fired as a cluster, fail to function.

    c.   Missile thrust/time profile of both the launch and flight motors (if appropriate).

    d.   Charge mass and burn-out time of both launch and flight motors (if appropriate).

    e.   Earliest and latest Safety and Arming Unit (SAU) Arming Unit/FTS Arming Unit times and distances.

f.   Missile centre of gravity including changes in this parameter in flight, e.g. when fuel is expended, and its effect on the static margin.

g.   Missile aerodynamics, kinematics, and coefficients.

h.   Maximum lateral acceleration (latax) which the missile can achieve.

i.   Maximum velocity.

j.   Missile trajectory; on occasions this will be the output of the programme.

k.   Fault tolerance and correction.

l.   Variations in build standard.

8.   Missile Flight Failure Modes (FM).   As a result of an analysis of the GW system, missile flight FM should be identified with their probability of occurrence and then incorporated, at set time in the missile flight, within the performance model so that their effect on the missile trajectory can be assessed.

9.   Engagement Geometry.   The relative positions of modules of the GW system and the target will affect the operation of the system and therefore need to be considered.   Examples are:

a.   Target location including consideration of moving targets.

b.   The displacement of the GW system sight from the missile launch position.

c.   Movement of the launch platform (e.g. vehicle, ship, or aircraft (including helicopters)).

10. Range and Environmental Factors.   Range and environmental factors contribute to the size of WDAs and may impose limitations on their application.   Examples are:

a.   In the application of range safety measures there is usually an element of delay such as:

(1) Reaction times of the range safety staff.

(2) Range safety equipment (RSE) functional delays.

b.   Meteorological effects (including temperature, air density, wind direction and speed).

c.   Errors in measuring missile position.

d.   The accuracy of range sensors.

e.   The physical lay-out of the range.

11. <u>Payload Effects</u>. A warhead/payload event could occur at an unplanned time in the flight of a missile, e.g. a missile warhead may detonate on arming. This will affect the shape of a WDA. Whenever possible these effects, which will be dependent on the type of warhead used e.g. blast, fragmentation or shaped charge, should be included within the model. This information should be available from component trials. If such data is not available the effect should be modelled and whenever possible the effects should be confirmed by live firing. The payload may not be explosive (e.g. it may be a chaff dispenser) nevertheless the effects of desired and premature operation, on range safety, need to be assessed and quantified.

12. <u>Additional Factors to be Considered as a Result of the Introduction of a FTS</u>. When a FTS is fitted the following additional factors may need to be considered and incorporated within the performance model:

    a. Pre-defined destruct boundaries (azimuth and elevation).

    b. Position of the Visual Flight Safety Officer (VFSO) with respect to the launcher.

    c. Position of the VFSO with respect to the nominal line of fire.

    d. FTS interfaces with the missile control systems.

    e. The VFSO's reaction times.

    f. Delays in the operation of the FTS.

    g. The reliability of the FTS.

    h. Missile and debris scatter after the FTS has been initiated.

    i. GW system and functional delays.

<u>GW SYSTEM IN-FLIGHT FAILURE MODES AND HAZARD ANALYSIS</u>

13. <u>Introduction</u>. It is first necessary to assess the probability of a GW fitted with a FTS of going "rogue". The GW may behave in a variety of ways:

    a. It may crash within the WDA, thereby should not pose a risk to personnel.

    b. In the event of FTS failure there are 3 possibilities which could present a level of risk to personnel:

        (1) It could become a ballistic projectile, continue on course but, in the event of a FTS failure, crash beyond the WDA boundary.

(2) It may turn and crash outside the left and right WDA boundary or within areas defined as low risk where the population density is controlled.

(3) Under certain failure conditions it may loop over the launcher and crash outside the WDA rear boundary.

14. General Approach. When assessing the probability of a "rogue" missile flight a whole-system approach should be taken. An analysis should be made of the GW system's FM and their effect on the missile trajectory should be identified. Additionally, when fitted and used, the RSE and the FTS are part of the system. The method used to assess the probability of a "rogue" missile flight varies with the size, complexity and cost of the weapon system. When a small, comparatively cheap missile system is being considered, a large amount of data from firing trials may be available. An assessment based upon actual results may be made, supplemented by theoretical analysis of the system. When a large, costly system is assessed, it is unlikely that sufficient missiles will have been fired to produce adequate data and a purely theoretical assessment will have to be made. However, all available firing data should be used.

15. Possible Effects of Failure. A missile failure after launch may have serious consequences for range safety if the operator/ system loses control of the missile. The length of time the missile remains airborne will depend on the nature of the failure and the nature of the missile engagement. For example: removal of all control signals by wire-break may be designed to result in a wire-guided missile flying ballistically to the ground whilst a failure of system electronics or missile control hardware which results in the control surfaces remaining in a fixed position may cause an aerodynamically stable missile to travel a considerable distance.

16. Types of Failure. The types of failure to be considered depend on the GW system used, e.g. the FM associated with a Command to Line-of-Sight (CLOS) system will be different to a fire and forget system. Examples of FMs that have been identified in the past are:

a. Autopilot failures such as gyro topple and drift.

b. Control surfaces jamming (fins, jetavators or vanes).

c. SAU/FTS arming unit failures.

d. A break in, or interference with, the command link.

17. Component Reliability. The first stage of FM analysis is to establish the failure rate for each component of the GW system including RSE. This information should be available from manufacturers or other data bases e.g. MIL HDBK 217. These figures are usually theoretical, being based on reliability data obtained during development and the ground testing of components.

Difficulty may be experienced in obtaining these figures when GW and components are purchased from foreign manufacturers. Useful tools in support of this work are reliability block diagrams, Fault Tree Analysis (FTA), Failure Modes Effects and Criticality Analysis (FMECA) and quantified hazard analysis techniques. Care should be taken to ensure that the information is relevant in the particular application being considered. Figures used should be justified and sources stated. If information is unavailable it may be necessary to rely on the qualitative assessments made by guided weapons engineers. A number of worst-case assumptions may have to be made; this will at least ensure that the resultant WDA has a high safety factor.

18. <u>FM Analysis</u>. Using reliability data it is necessary to identify each failure separately on a FM list, an outline of which is given at Appendix 1. The FM list should then be used as the basis of a FM Log, an explanation is given at Appendix 2. Each FM should be allocated a discrete number for cross reference purposes. The FM should then be described in plain English. The missile behaviour resulting from the failure should be analyzed and described. The FMs should then be simulated at any time in a missile flight to identify possible "rogue" trajectories. The method of simulation should be described in the FM Log with any conclusions to be drawn.

19. <u>Impact Analysis</u>. The approach used to conduct this analysis is dependent on the principles which form the basis of the design of the GW system. It follows that there is no prescribed method to be followed. Two possible methods are described below:

a. Using data gathered as a result of the FM analysis it is possible, using a performance model, to analyze the fall of shot for each FM. An example of a possible form of output is at Appendix 3. This should be incorporated within the FM Log (Appendix 2). A line can then be drawn around the plots thus defining an impact area associated with that specific failure. This procedure is followed for all the identified FMs and all the impact areas are then combined to produce an overall impact area, as shown at Appendix 4. Using this information it is possible to produce an impact trace based on the line of fire in which areas of high and low risk, based on impact analysis, can be identified (Appendix 5). Confidence levels and assumptions should be agreed with the appropriate national authorities.

b. Alternatively, it is possible to analyze where the majority of the missiles will land using modelling techniques such as Monte Carlo simulations. The likely impact area is divided into small squares and the impact of a large number of simulated firings (e.g. 100,000) is plotted in the squares. The distribution can then be used to create a WDA identifying areas of high and low risk. An example of the results derived from this form of analysis is given at Appendix 6. Confidence levels

and assumptions should be agreed with the appropriate national authorities.

20. <u>Frequency</u>. The relationship between the various FMs need to be established and the change of their occurring assessed so that their individual and cumulative effect may be evaluated. Using flight records and theoretical assessments it should be possible to establish the probability of a failure occurring. Care should be taken to ensure that the environment in which this data was obtained is known. This ensures that the application of this data is appropriate to future firing. It may be necessary to adjust the figures using technical judgement. This should confirm the high and low risk areas inside a WDA which were identified as a result of the impact analysis and refine the risk assessment. A possible basis for this analysis is to create an event tree (Appendix 7), assigning probabilities to each FM; an example of output from this form of quantified analysis is given at Appendix 8. In this case, the designation of areas of high, low and medium risk is dependent on the order of probabilities i.e. Pf1<Pf2<Pf3. It may be necessary to make some worst case assumptions.

21. <u>Problems Associated with Air Launched GW</u>. The exact position, velocity and heading of the aircraft is not known at the instant of launch. Therefore extra allowance has to be made when calculating the boundaries of WDAs based on the probability of a missile FM occurring. Consideration should be given to:

    a.   <u>Launch</u>. A launch box in which the missile can be fired should be defined. The pilot should not be permitted to fire when outside the box and should be constrained to fire within prescribed limits of altitude, heading, angle of attack and roll angle.

    b.   <u>Engagement</u>. A WDA should be defined when firing an air launched GW at a target such as a Unmanned Aerial Vehicle (UAV). It should contain a danger area for each target engagement because of the variations which are possible in engagement conditions, such as altitude, speed and attitude.

A WDA can then be produced including both launch and engagement areas.

<u>DERIVATION OF THE ADH</u>

22. In order to minimise the risk to aircraft flying over range areas it is necessary to calculate the maximum height which a guided missile, and its debris, may achieve. Three cases should be examined:

    a.   A complete guided missile.

    b.   A guided missile that has broken up as a result of FTS initiation.

c.   A missile that achieves its maximum height which then
     breaks up. In these circumstances the distance to which
     the warhead fragments may reach must be considered and
     added to the apogee of the missile trajectory.

DERIVATION OF THE TOTAL ENERGY WDA

23. In order to assess whether a GW system needs to be fitted
with a FTS and identify possible areas where people may be at
risk, the total energy WDA needs to be determined using a
performance model. This is the area which will contain the
missile and its debris in any eventuality. It takes into account
the maximum motor burn time and minimum missile drag and is
dependent on worst case missile launch QE and missile biases,
which will cause the missile to fly the maximum distance from the
launcher. To this is added the total energy effects of the
warhead, including re-ignition and secondary launch if the motor
can still produce thrust. The resultant shape of the total energy
WDA is dependent on the missile aerodynamic characteristics;
particular account should be taken of the maximum lateral
acceleration (latax) to which the missile can be subjected before
its structure fails. Consideration should also be given to
meteorological effects.

LAUNCH DANGER AREA

24. General. During the development of a GW, hazards with
associated areas and distances may be identified. These launch
hazard distances must be contained within the GW designated WDA.
Examples of such hazards are: blast overpressure, noise, debris,
efflux, high velocity erosive gases, motor malfunctions and
inadvertent captive firing. Consideration should also be given to
the missile going "rogue" and causing a hazard to personnel on or
near the firing point.

25. Blast Overpressure. Motor ignition generates a pressure wave
which may cause injury to human internal organs e.g. lungs.
During development, trials should be conducted using remote firing
techniques and instrumentation to establish the hazard area.

26. Noise. Noise generated at missile launch may cause damage to
the hearing of persons located in the area of the launcher. In
order to establish a hazard area trials should be conducted to
establish the noise hazard distance to the protected and
unprotected ear.

27. Debris. Missile launch may result in:

a.   Primary Debris. When the missile is launched from a
     tube or canister items such as blow out panels may be
     ejected. Normally this debris rapidly loses kinetic
     energy and would not be a hazard to personnel though it
     could cause the operator to be distracted. During
     firing trials it is recommended that the position of
     these items is identified so that areas of potential

hazard be derived so that it is contained within the WDA.

b.   Secondary Debris.   The missile efflux can disturb loose stones and gravel near the launcher.   This hazard area should be identified.

28.   Toxic Effects.   A missile efflux frequently contains toxic fumes and particles.   Trials should be conducted to measure the toxic content of the efflux and assess its effects.   Trials should be conducted to measure the effect on persons located close within or close to the launcher and a hazard area identified.

29.   High Velocity Erosive Gases.   When launched, missiles emit a plume of very hot gases which could cause injury to persons. Trials should be conducted to measure any hazard area.

30.   Motor Malfunctions.   A missile motor design should follow the appropriate published national design principles.   Range safety submissions should include details of the performance of the motor.   Consideration should also be given to a number of possible motor hazards.

a.   Hang Fire and Misfire.   A hang fire is an undesired delay in the functioning of a firing system, a misfire is the failure of the ignition system of the rocket motor of a round to function wholly or in part.   The hazards associated with a misfire or hang fire in either the 1st Stage or 2nd Stage Motor have to be assessed.

(1)   1st Stage Motor.   The hangfire/misfire waiting period should be defined and justified by the GW manufacturer.   During the safety wait period the range clearance procedures for the weapon are to remain in force and the equipment and associated range systems must be set to demand flight termination in the event of a missile being launched.   During this period, the risk to operators is reduced by the adoption of well defined safety drills.   Usually these are designed to ensure that the missile is kept at all times, during the designated waiting period, pointing in the centre line of the firing arc.   In the case of hand held weapons a suitable secure mounting is required.

(2)   2nd Stage Motor.   Unless the hang fire is of short duration it is likely that both hang fire and misfire events will result in the missile impacting with the ground.   Subsequent action will depend on the location and state of the missile.

Neither the missile nor any fragments should be approached until the waiting period associated with the missile has expired and then only after the appropriate safety rules published in National Ammunition Safety Regulations have been complied with.

b. Late Light-up of the 2nd Stage Motor. There is no direct hazard to personnel on the firing point providing the missile does not ground prior to or shortly after light-up. If the missile grounds there is the possibility that the missile will break up on impact, with the debris being projected forward. There is, however, a remote possibility that a burning motor section might ricochet or turn so that it may be projected rearwards. A protective wall should reduce the risk from this hazard. If the missile does not break up the possibility exists that the missile may resume flight, in which case the missile flight shall be terminated and the resultant debris should fall within the designated WDA. The situation could occur that the FTS is damaged and it would not be possible to terminate missile flight. This should be considered when designing the FTS and deriving the WDA.

31. Inadvertent captive firing. Some missile systems use the packaging as part of the missile launcher. On occasions an error of drill or system failure may cause the missile not to be released from the retaining packaging furniture at launch. This may result in the missile and packaging flying down range. A hazard area should be identified with this failure mode which should be included within the WDA.

IDENTIFICATION OF FLIGHT TERMINATION/DESTRUCT BOUNDARIES

32. General. When a GW system is fitted with a FTS it is necessary to consider the position of the flight termination/ destruct boundary in both plan and elevation. The following factors should be considered:

a. The user requirement.

b. The debris zone.

c. The range topography.

d. The buffer zone.

e. Meteorological effects.

33. The User Requirement. In the case of long range weapons, e.g. terrain following and sea skimming missiles, the free flight zone must be large enough to allow the user to achieve his trial/ training aims. In the past the destruct boundary has been based on the 3σ contour around the planned missile trajectory to allow

for variations in GW system performance, i.e. it is the area in which 99.7% of missiles will travel.

34. The Debris Zone. Associated with a FTS fitted GW is a debris zone, which is defined as the zone between the destruct boundary and the weapon danger boundary. It is designed to contain all the debris that results from the activation of the FTS and is based upon the conclusions of the hazard and impact analyses discussed above. As part of the computer modelling process the throw of major missile components, including the payload, after break-up (which is assumed when the missile is destroyed) may be assessed using worst case assumptions such as:

    a.   The missile is at the elevation destruct boundary altitude as used by the VFSO.

    b.   The missile crosses the azimuth destruct boundary at right angles.

    c.   The missile is travelling at the maximum velocity.

    d.   The missile body attitude is that which would produce the worst case throw conditions.

35. The Range Topography. If a GW is to be fired on a specified range it is possible to tailor the destruct boundary and hence the WDA. In this case the WDA will be designed to avoid the possibility of missile debris impacting in specific areas such as ammunition compounds, range technical facilities, maintenance and administrative areas.

36. The Buffer Zone. On occasions it may be necessary to include an extra margin for error to ensure that there is a low risk to personnel living close to but outside the range boundary. This may be dependent on the confidence levels associated with the performance model. In this case a buffer zone may be inserted between the WDA boundary and the range boundary. The following diagram below demonstrates the concept in plan view.
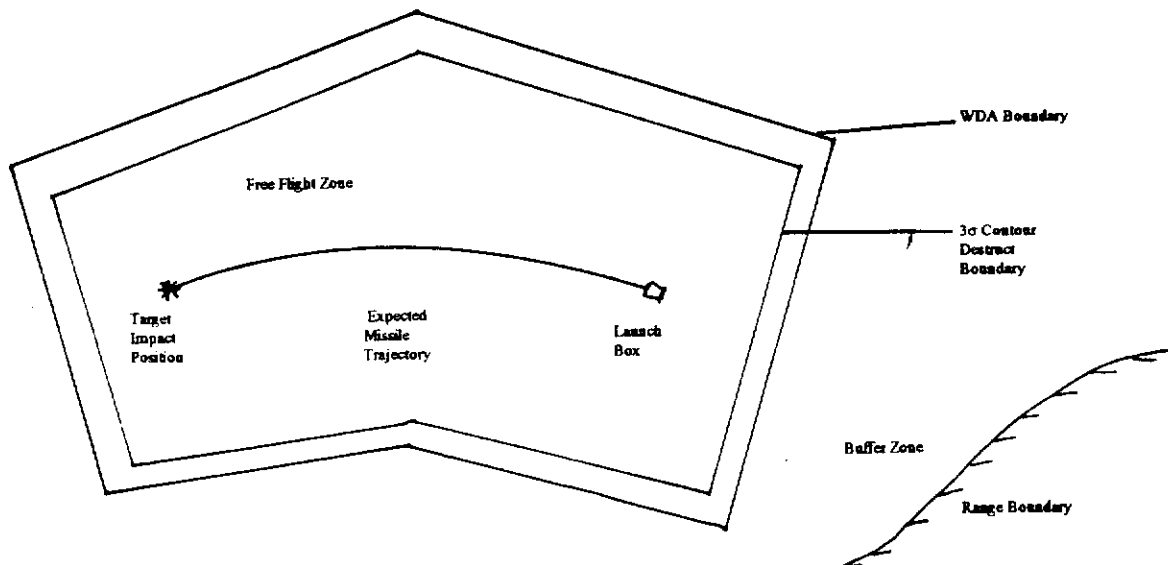

Fig 1 - FTS Based WDA

NATO UNCLASSIFIED

37. Engagement Arcs. When a FTS is used and depending on the type of GW system, precautions may need to be taken to inhibit the firing of the missile so that it cannot be launched outside clearly defined azimuth and elevation engagement arcs. If it were to be launched it would be destroyed on arming. It is therefore essential to define engagement arcs that are within the associated flight termination/destruct boundaries.

WDA WITH FTS FITTED

38. To ensure that "rogue" missiles fall within their designated WDA they are fitted with a FTS. This produces a degree of confidence that a missile will not fly outside a designated WDA. It follows that the reliability of the FTS must be assessed. The method used will depend on how frequently the system has been used in flight. If insufficient empirical data is available from trials, a theoretical assessment based on a reliability analysis (such as FMECA and FTA) of its components supported by good engineering judgement will have to be completed.

39. The probability of a dangerous "rogue" missile occurring in these circumstances may be calculated by compounding the probability of a missile failure with the probability of the FTS failing.

RISK ANALYSIS - PERSONNEL

40. General. It is possible to postulate multiple fault conditions which, if they occur, could lead to a missile or parts of a missile impacting outside the WDA. It must however be demonstrated that the probability of this occurring is reduced to a level such as to be ALARP. A risk analysis should be completed taking into account the following groups of people:

    a.   Exercise participants.

    b.   Personnel on the range who are not participating in the exercise.

    c.   The general public.

41. Risk Criteria. Risk criteria are agreed from time to time by the appropriate national authorities. The risk analysis should, if possible, be quantitative in nature and should address both individual (I_{risk}) and individual cumulative risk (C_{risk}) resulting from a person being exposed to a large number of firings.

42. Individual Risk. The risk of injury to an individual per firing within a given area is given by:

$$I_{risk} = \frac{E \cdot P}{A}$$

    where: E is the missile debris area in sq.m.
                 A is the area at risk in sq.m.

P is the probability of missile impact in Area A.

This overestimates the risk to an individual when the missile debris is a scatter of bits smaller than a person with the spacing between them larger than the person. In these conditions a more accurate method is to replace E with Ap.B.

where: Ap is the area represented by one person.
          B is the number of discrete debris bits.

Casualty expectation (C_{exp}) from a single firing is related to the I_{risk} by the formula:

$$C_{exp} = I_{risk}.n$$

where: n is the number of persons in area A.

43. <u>Individual Cumulative Risk</u>. The formula used for calculating C_{risk} is as follows:

$$C_{risk} = \frac{N.E.P}{A}$$

where: N is the number of missiles fired annually.
          E is the debris area in sq.m.
          A is the area at risk in sq.m.
          P is the probability of missile impact in area A.

44. <u>Risk to the General Public</u>. Many ranges are located close to centres of population. An analysis shall be conducted into the possibility of a missile impacting outside the WDA and the risk of injury to a member of the general public. Consideration should be given to all known FMs and should not be based upon the assumption of a single FM. A number of methods may be used to assess and present the risk levels in the area surrounding a range. Two such methods are:

a.   <u>Method 1</u>. Establish contours of constant risk based on the probability of a rogue missile crossing a line where it is assumed that a person on that line will be fatally hit. As a general rule this probability value will decrease as the radius from the missile launch point increases. The gradual decrease is due to the probability of missile fragments reaching a given distance decreasing with increasing radius. A step change in the probability figures may occur where an additional failure occurs. The probability of causing a fatality during a firing (Pf) is given by the expression:

Pf = Pr.Phk.Ap.Dpop.Pa.R.

where: PR is the probability of a rogue.
       Phk is the probability of a lethality given a hit. If this information is unavailable a value of 1 should be assumed.

AP is the area represented by 1 person, 1×10^{-6} sq km (1 M²).

Dpop is the population density per sq.km.

Pa is the probability of the missile being in an area with a (sensibly) uniform distribution of hit chance that contains the population cluster.

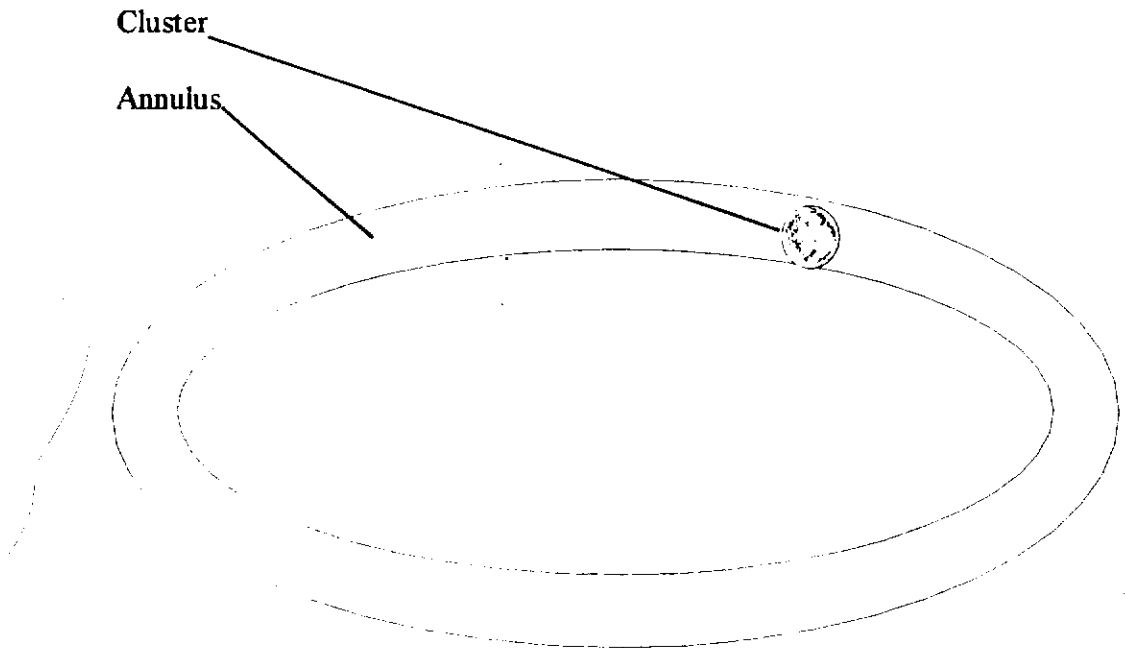R is the ratio of the area of the population cluster to the area with the probability Pa.

Cluster

Annulus

Fig 2 - Diagrammatic Representation of Method 1

b. Method 2. Conduct a detailed analysis based upon the known population densities in particular areas and calculate a discrete risk figure for that particular area. The formula used to calculate the total probability of causing 1 fatality per firing, Pf is given by:

Pf = Pr.Ap.Dpop.Pa.R

where: Pr is the probability of a rogue.

AP is the area represented by 1 person (1 m² or

10^{-6} sq.km.).

Dpop is the population density per sq.km.

Pa is the probability of the missile reaching the nearest and furthest point of the population cluster being considered.

R   is the ratio of the area cluster to the total area of an annulus with the same nearest and furthest distances.

METEOROLOGICAL CORRECTIONS

45. Missile flight is subjected to meteorological effects. Usually a guided missile's auto pilot will compensate for normal variations. A strong gusting wind, however, may cause excessive yaw or pitch and as the missile's auto pilot seeks to compensate, the gyro may topple. If the missile has a long ballistic or unguided phase of flight, wind drift may become a significant problem. After a warhead event occurs, the debris dispersion will be affected by the meteorological conditions. Therefore limitations will be placed on missiles being fired under specified meteorological extremes and/or procedures developed to compensate for them.

46. In the case of short range anti-tank missiles, an omni-directional approach might be taken (as shown at Appendix 9). Provided the missile is planned to be fired close to the ground, surface wind speed may be applied. It should be noted that a constant radial distance added for wind is only correct if the missile flight time to impact around the WDA boundary remains constant.

47. In the case of longer range weapon systems, a true meteorological correction may be applied to the down wind WDA boundary. In the case of ground to air missiles, a mean ballistic wind correction should be obtained and applied to the trace. If the missile passes through a number of risk zones at different heights (such as a diving anti-ship missile) it may be necessary to establish discrete wind corrections for each zone and apply them the individual parts of the trace.

FAILURE MODE LIST

Failure Mode Number	Item/Component	Description of Failure
G001	Control Surface	Jams hard over
etc.	etc.	etc

FAILURE MODE LOG SHEET

GENERAL

1.   The failure mode (FM) list forms the basis of the FM log.

FAILURE MODE LOG PROFORMA FOR USE IN GUIDED WEAPON FAILURE MODE ANALYSIS

2.   FM Number. A unique number cross referenced to the hazard list which is used to identify this FM throughout all the analyses.

3.   FM Description. A concise description of the FM that would result in a hazard being created. Initially a loosely worded statement may be made which can be expanded at a later date.

4.   References. References made to source documents such as FTAs and FMECAs or cross references to other FMs.

5.   FM Sequence(s). The sequence of events necessary for the FM to result in an accident. This should include a description of the missile behaviour that would result from the FM.

6.   Simulation. The method used to simulate the FM should be described.

7.   Classification of Severity. The severity of the accident will be classified i.e. catastrophe or negligible, etc.

8.   Classification of Likelihood. The probability of the specified FM occurring should be stated with an associated confidence level.
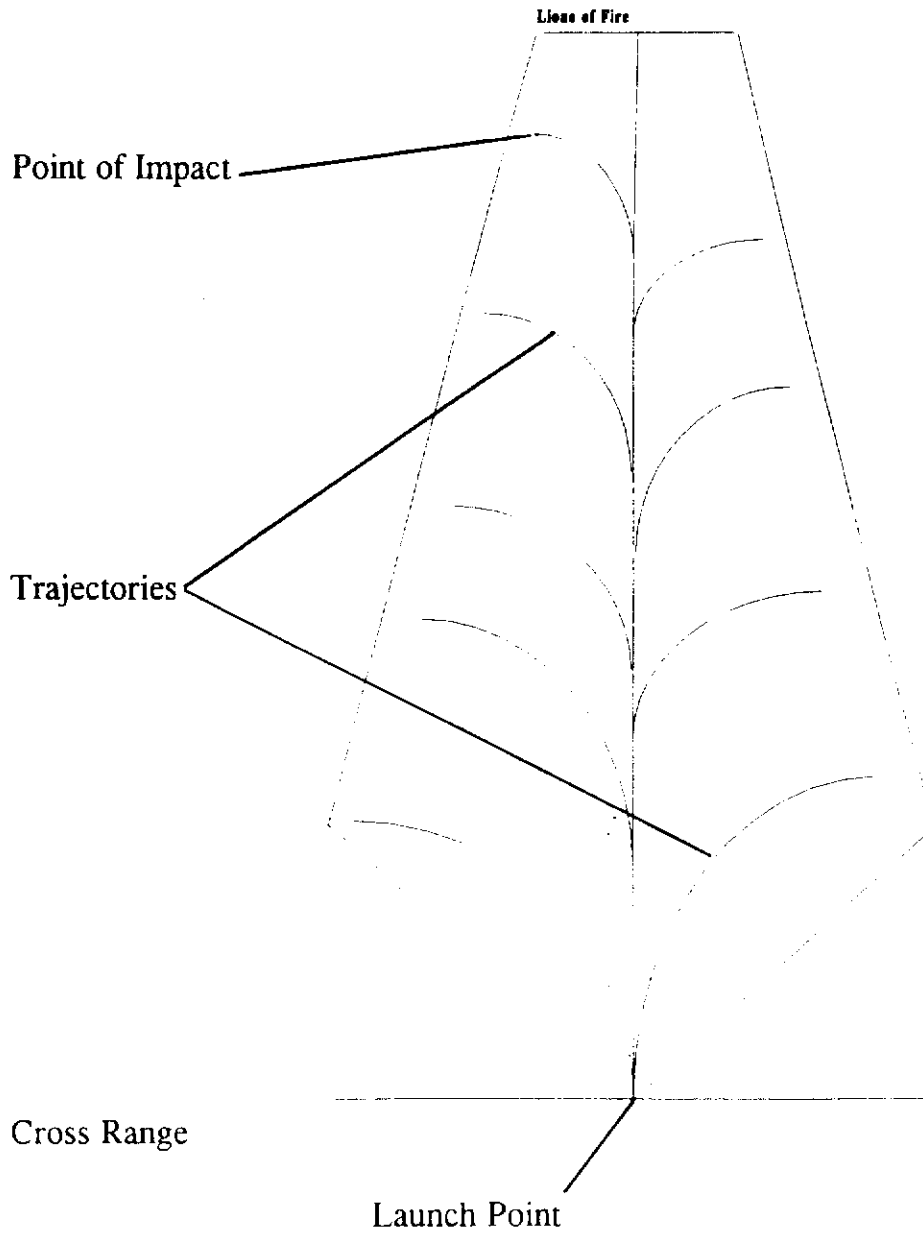
9.   Classification of Risk. Where appropriate this can follow the guidance given in appropriate national documents.
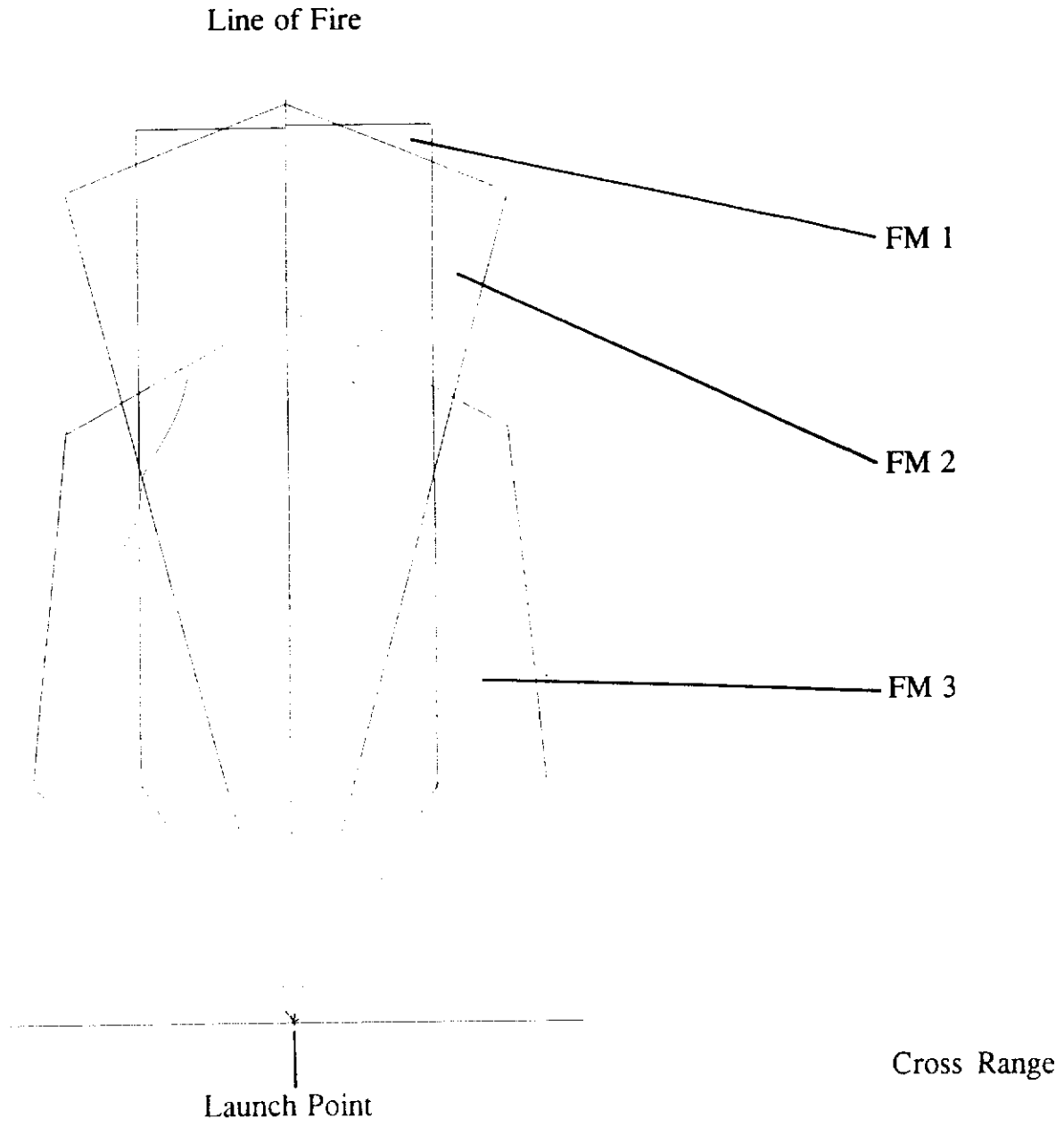
10.   Simulated missile trajectories and impact zone

Line of Fire   Line of Fire

Points
of
Impact

Trajectories

Plan   Elevation
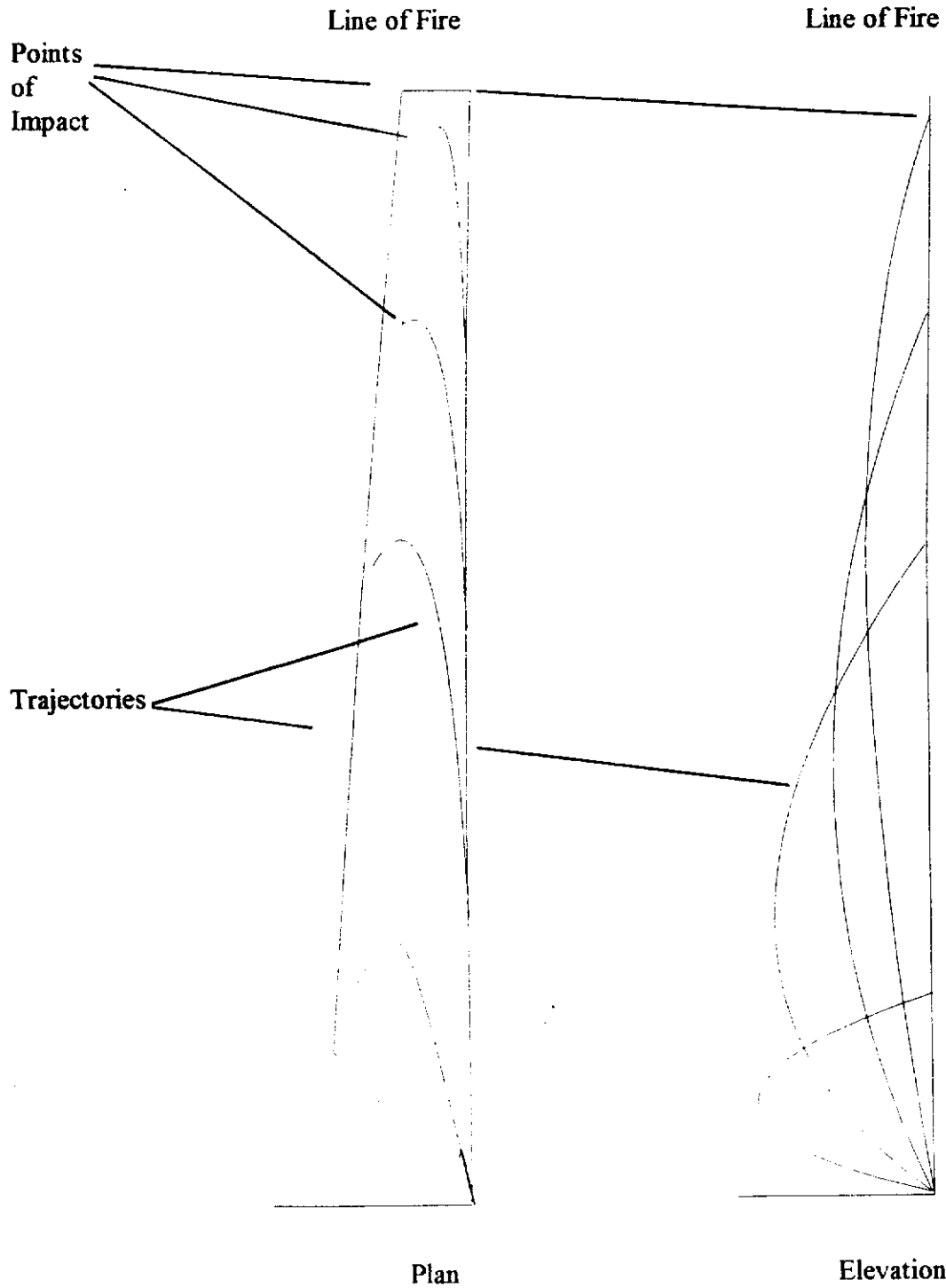
11.   Risk Reduction Measures.   Where appropriate risk reduction
measures should be identified and described.
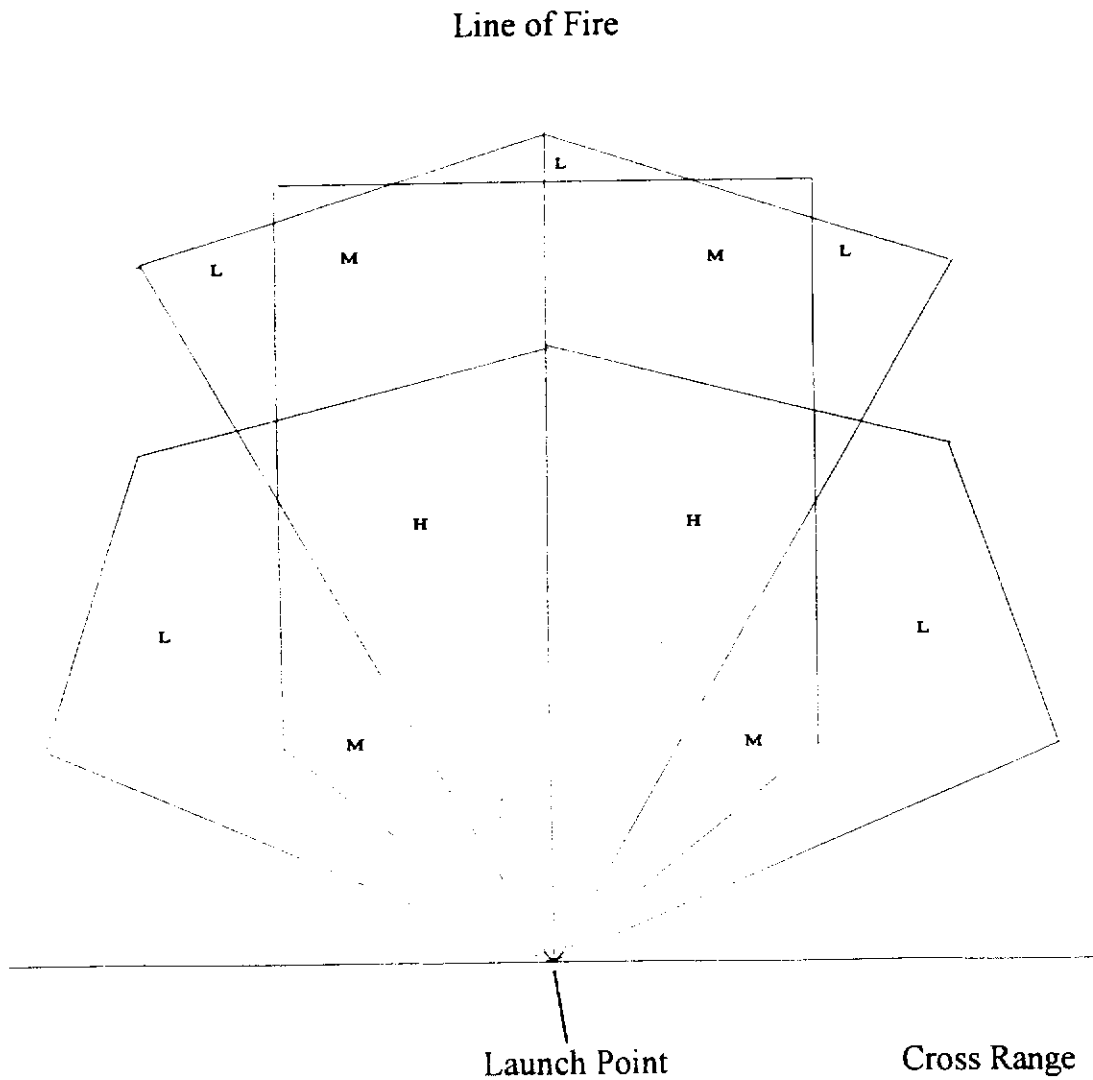
EXAMPLE FAILURE MODE IMPACT AREA TRACE

Lines of Fire

Point of Impact —

Trajectories <

Cross Range

Launch Point

EXAMPLE OF FAILURE MODE IMPACT AREA TRACE

Line of Fire

FM 1

FM 2

FM 3

Cross Range

Launch Point

EXAMPLE SHOWING AREAS OF LOW AND HIGH RISK WITHIN A WDA AS A RESULT OF IMPACT ANALYSIS

Line of Fire

Launch Point   Cross Range

L: Area of Low risk
M: Area of Medium risk
H: Area of High risk

WDA GENERATED BY USING MONTE CARLO TECHNIQUES
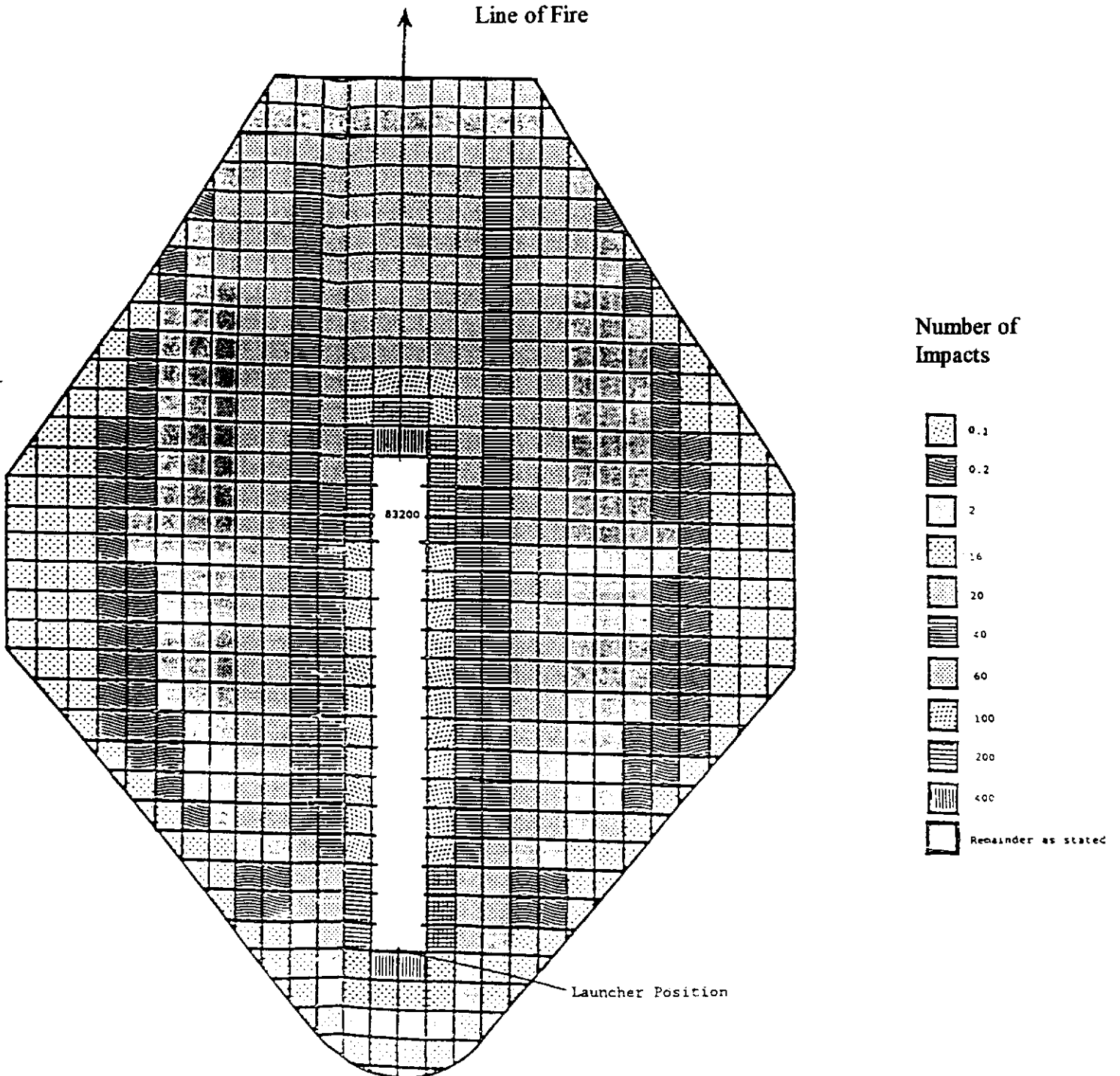
EXAMPLE OF EVENT TREE SHOWING PROBABILITIES

Initiating Event	FTS Functions	Missile Remains Within WDA	Missile Impacts Close to Personnel	Outcome	Frequency (per year)
	Yes 0.98			No Fatality	9.8×10^{-4}
Missile Guidance Failure 10^{-3}/year		Yes 0.1		No Fatality	2.0×10^{-6}
	No 0.02		No 0.9	No Fatality	1.6×10^{-5}
		No 0.9	Yes 0.1	Fatality	1.8×10^{-6}
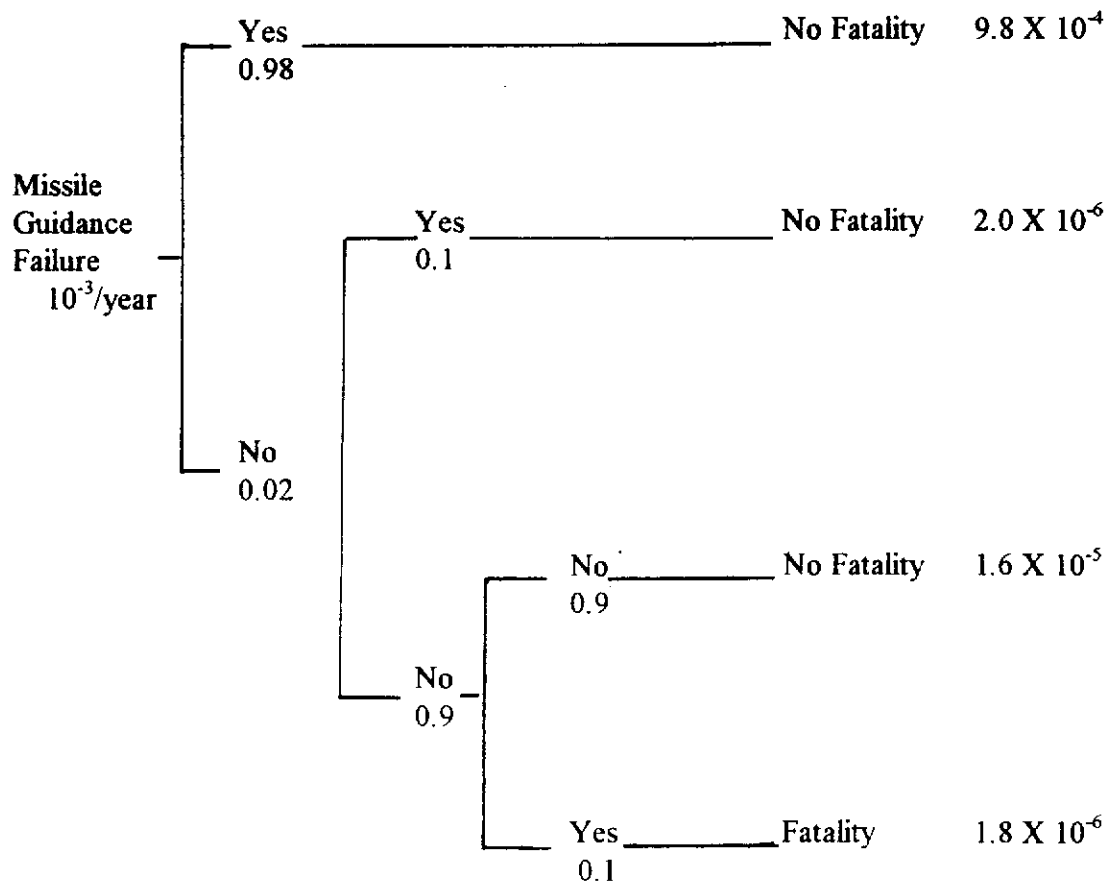
NATO UNCLASSIFIED

EXAMPLE OF WDA SHOWING AREAS OF LOW, MEDIUM AND HIGH RISK WITH ASSIGNED PROBABILITIES

Line of Fire

Pf2

Pf1   Pf1

Pf2   Pf2

Pf1 + Pf2   Pf1 + Pf2

Pf2 = Pf3   Pf2 + Pf3

Pf1 + Pf2 + Pf3   Pf1 + Pf2 + Pf3

Pf3   Pf3

Pf1 + Pf3   Pf1 + Pf3

Launch Point   Cross Range
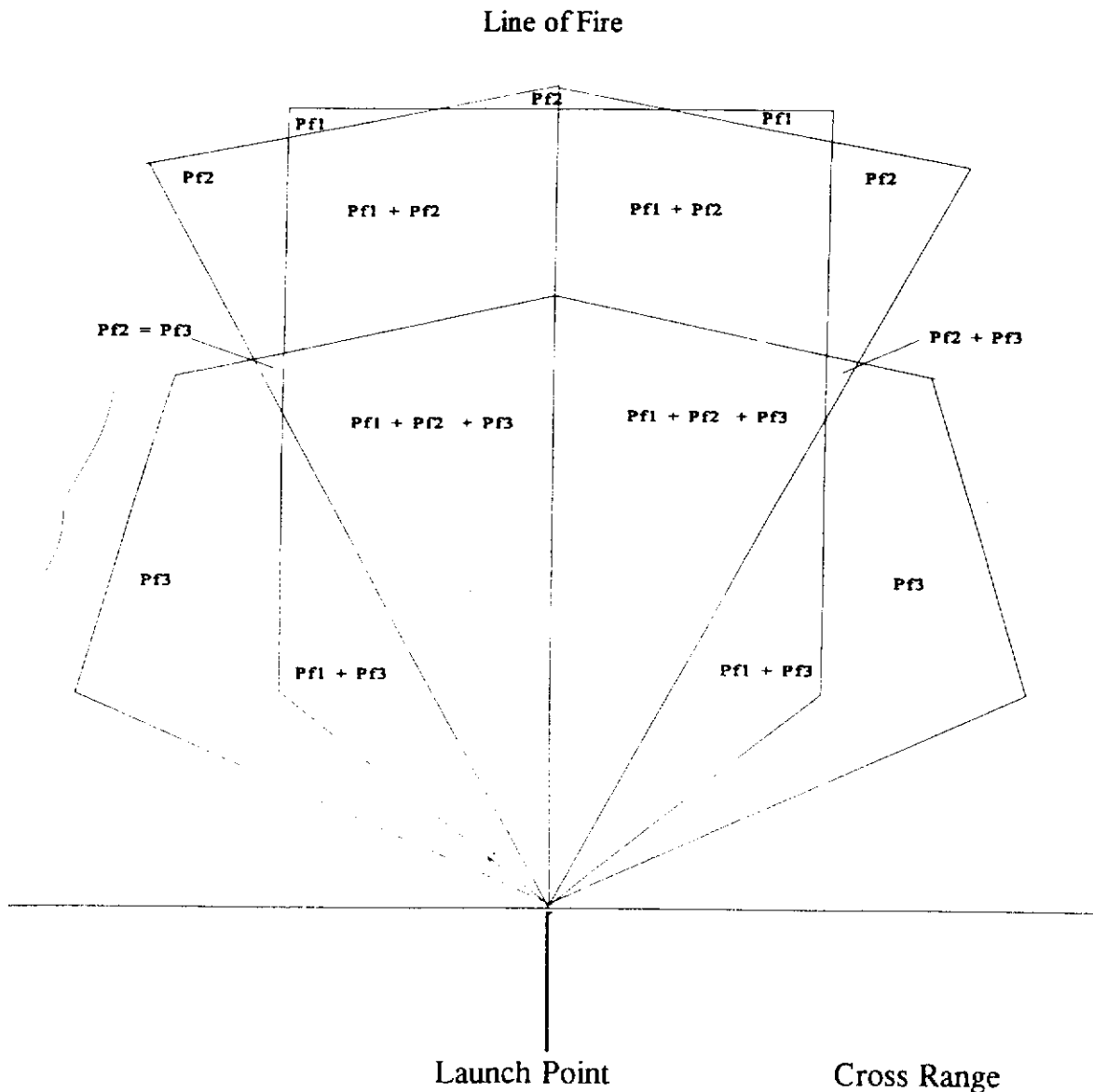
Pf1: Probability of Failure Mode (FM) 1 occurring.
Pf2: Probability of FM 2 occurring.
Pf3: Probability of FM 3 occurring.
Probabilities are summed where FM areas overlap.

THE APPLICATION OF AN "OMNI-DIRECTIONAL" WIND CORRECTION

Zone 1

Zone 1

Zone 2

Zone 2

Zone 3

Zone 3

20°   20°

Still air WDA ————

WDA accounting— — —
for 25 kt wind in
any direction

LAUNCHER

Zone 4

Scale

0	1	2	3	4	5	Miles
0	1	2	3	4	5	6	7	8	Km
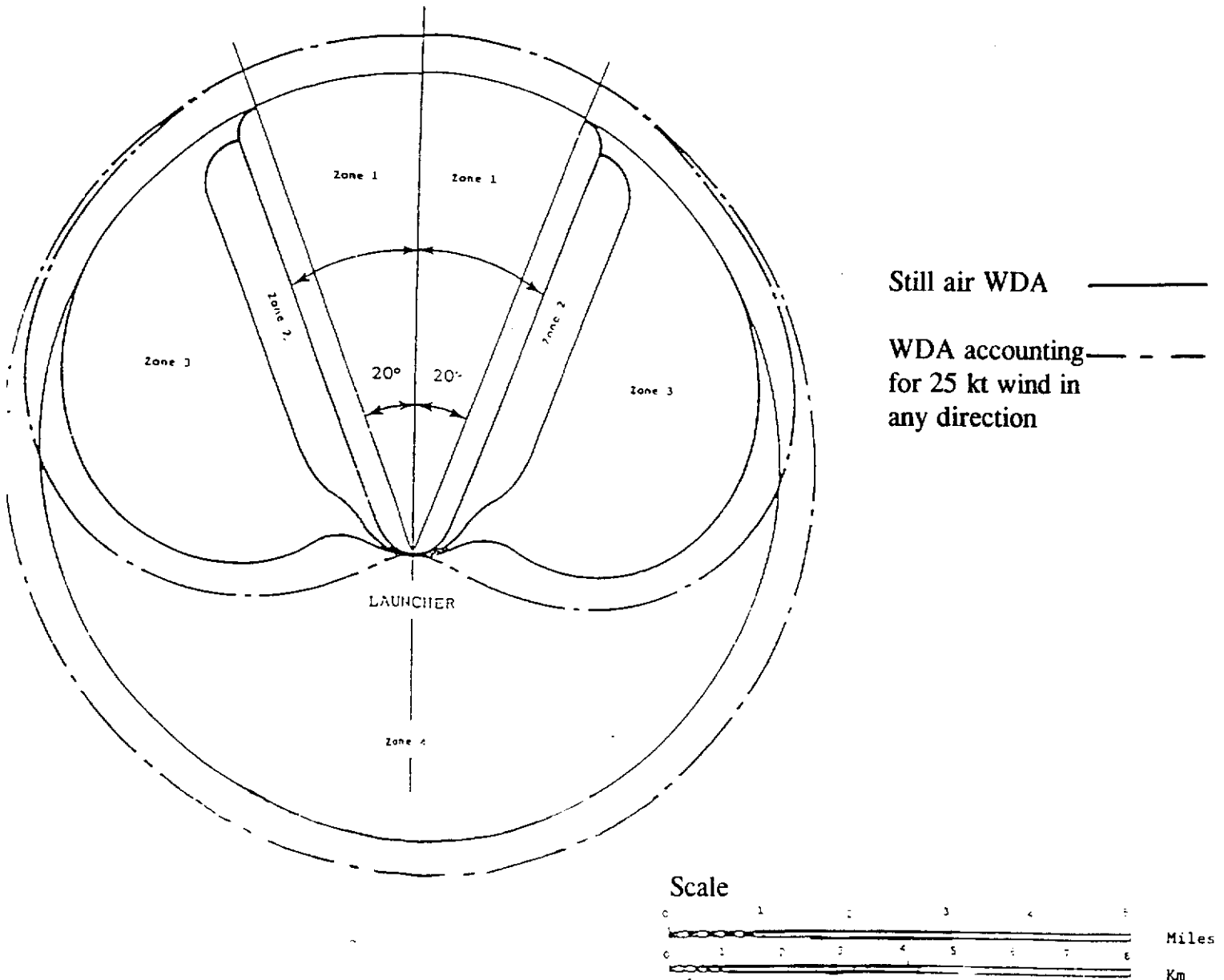
Engagement arc 20°
Zone 1: should contain no unprotected personnel.
Zone 2: should lie within the range boundary and contain limited
number of persons.
Zone 3: may contain unprotected and may cross the range boundary.
Zone 4: may contain large concentrations of population.