# Part II/Risk-Based Siting Criteria – Current Efforts in Risk Management and Siting Applications

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## Abstract

The U.S. Department of Defense Explosives Safety Board (DDESB) has established an approved quantitative risk assessment (QRA) methodology for evaluating and accepting risks associated with explosives storage and other activities. In the explosives safety community, QRA represents an alternative path for regulator acceptance to the long-established, deterministic method of quantity-distance (QD), where a singular distance as a function of explosives weight is determined acceptable. The QRA methodology is defined in DDESB Technical Paper (TP) 14 and consists of:

1. Estimate of probability of event ($P_e$) as a function of activity type, hazard division (HD) of ammunition and explosives (AE), and environmental factors,
2. Exposure modeling for various population groups,
3. Consequences in terms of potential fatalities and injuries given the occurrence of an event, and
4. Uncertainty modeling for the estimated risks.

The QRA model approved by DDESB has been recently updated, based on the latest advances in explosives field test results, accident experiences, explosion effects, and structural response, to better reflect real-world accidental explosions, but still provides conservative risk calculations.

Part II of this paper looks at the current efforts by the DDESB Risk Assessment Program Team (RAPT) associated with the risk-based siting described above. These efforts include relooking at the $P_e$, updating the uncertainty modeling, relooking at the criteria by which QRA analysis are compared to, updates to the Universal Risk Scale (URS), development of the Risk-Based Explosives Safety Siting (RBESS), updates to TP-14 and TP-23, and providing support to the updates to NATO AASTP-4. This paper also discusses the objectives, short-term goals, and long-term goals of the RAPT, and presents a way-ahead for the team.

## Introduction

The QRA methodology established by DDESB is based on the basic concept of risk. Using the basic risk concept, the risk to personnel can be defined as:

$$Risk = Probability\ of\ Event \times Consequences \times Exposure$$

DDESB's QRA methodology is designed to calculate the annual probability of fatality to any individual ($P_f$). $P_f$ is the product of three components, as shown below:

$$Risk = P_f = P_e \times P_{f|e} \times E_p$$

The $P_e$ is defined as the probability that an explosives mishap will occur at a potential explosion site (PES) in a year. The $P_{f|e}$ is defined as the probability of fatality given an explosives event and the presence of a person. The $E_p$ is defined as the exposure of one person (as a fraction of a year) to a PES on an annual basis.

DDESB's QRA methodology also calculates the risk to an entire group of people and provides the average number of fatalities per year. This is referred to as the "Group Risk" and is calculated as the summation of individual risk within the group.

The goal of the RAPT is to improve each element included in the calculation of risk within DDESB's QRA methodology. Also, the RAPT is focused on determining the best risk criteria to use in comparison with the calculated risk. This paper discusses the ongoing efforts of the RAPT.

## Current Efforts by RAPT

1. Current Objective and Goals of the Risk Assessment Program Team

### 1.1. Objective

The objective of the RAPT is to assess and improve the overall safety associated with operations involving explosives and ammunition through the implementation of risk management processes. This is to be accomplished by developing risk-based tools, procedures, and DDESB risk acceptance criteria that provide the Services with the information needed to make risk-based decisions.

### 1.2. Short-Term Goals

The RAPT has identified several short-term goals the team is actively working on. The short-term goals for the team include:

- Updating the probability of event ($P_e$) used in TP-14 methodology
- Implementing a "warning system" as the criteria for a TP-14 QRA analysis
- Updating the URS
- Updating the uncertainty methodology used in TP-14 methodology

- Removing undue conservatism in TP 14 methodology to create a more realistic model
- Creation of RBESS v1.0 for incorporation into Explosive Safety Siting (ESS)

### 1.3. Long-Term Goals

The RAPT has identified several long-term goals the team is projecting to accomplish in the future. The long-term goals for the team include:

- Implementing an "As Low as Reasonably Possible" (ALARP) methodology into the criteria used for a TP-14 QRA analysis
- Implementing an F/N process to consider catastrophic risk criteria for a TP-14 QRA analysis
- Continue to remove undue conservatism in TP-14 methodology to create a more realistic model
- Continue to support future versions of RBESS

## 2. Current Efforts

### 2.1. Relooking at Probability of Event ($P_e$)

The probability of event ($P_e$) is a critical component of a QRA analysis as $P_e$ is a term that is directly included in the risk equation described in the introduction. TP-14 defines the $P_e$ to be used in a QRA analysis by using a $P_e$ matrix. The matrix currently published in TP-14 Rev 4a can be seen Table 1. The $P_e$ is a function of the activity type and "element". An "element" is defined by the compatibility group of the explosive used in analysis. The three elements used with the current $P_e$ matrix can be seen in Figure 1. The $P_e$ determined by the activity type/element pair can then be adjusted by "environmental factors". "Environmental factors" are external factors deemed to increase the probability of event of an operation. The current list of environmental factors can be seen in TP-14 Rev 4a (Ref 1).

*Table 1: Current $P_e$ Matrix*

| Activity | Element I | Element II | Element III |
|---|---|---|---|
| Assembly / Disassembly / LAP / Maintenance / Renovation | 4.70E-03 | 4.70E-04 | 1.60E-04 |
| Burning Ground / Demil / Demolition / Disposal | 2.40E-02 | 2.40E-03 | 8.10E-04 |
| Lab / Test / Training | 4.30E-03 | 4.30E-04 | 1.40E-04 |
| Loading / Unloading | 5.70E-04 | 5.70E-05 | 1.90E-05 |
| Inspection / Painting / Packing | 8.20E-04 | 8.20E-05 | 2.70E-05 |
| Manufacturing | 1.70E-03 | 1.70E-03 | 1.70E-03 |
| Deep Storage (longer than 1 month) | 2.50E-05 | 2.50E-05 | 2.50E-06 |
| Temporary Storage (1 day - 1 month) | 1.00E-04 | 3.30E-05 | 1.10E-05 |
| In-Transit Storage (hours-few days) | 3.0E-04 | 1.0E-04 | 3.3E-05 |

| Elements | Compatibility Group |
|---|---|
| I | L, A, B, G, H, J, F |
| II | C |
| III | D, E, N |

*Notes: The elements in the matrix are comprised of Compatibility Groups. Definitions of the Compatibility Groups can be found in DoD 6055.09-M. Ref 5*

*Figure 1: $P_e$ Matrix Elements*

The RAPT recently commissioned a study on the $P_e$ used in TP-14 Rev 4a and made an effort to update the $P_e$ values where appropriate for incorporation into TP-14 Rev 5.

Attachment 10 of TP-14 Rev 4a (Ref 1) describes the process for creating the probability of event ($P_e$) matrix used in the TP-14 methodology. The data used in creating the $P_e$ matrix originally came from the DDESB mishap database and the Army Industrial Operations Command (IOC) Risk Report. The Air Force, Navy, and Marine Corps contributed mishap and PES data at a later time. A total of 241 mishaps were used to create the $P_e$ matrix. Currently, 138 mishaps, their descriptions, and activity type are listed in Attachment 10 of TP-14. The listed mishaps include Army incident data from FY1997-2002, Air Force incident data from FY1987-2002, Navy incident data from FY1987-2002, and Marine Corps incident data from FY2000-2003. The Army IOC Report includes 103 mishaps from Army incident data from FY1987-1996, but the specific incidents and their descriptions are not listed. The current $P_e$ matrix was developed with a very conservative mindset, in that when in question for applicability, mishaps were categorized as events.

The purpose of the aforementioned $P_e$ study was to conduct a scrub of each mishap listed in Attachment 10 of TP-14 Rev 4a to determine if the mishap should be used in the $P_e$ matrix calculations, and whether the right activity type was associated with the listed mishap. Following the data scrub, the $P_e$ calculations were to be compared to different values to determine the effect that the data scrub had on the values. An HD was also assigned to each mishap that included a description. The group that conducted the scrub on the mishap data included APT Research, Inc. (APT) (Jorge Flores, John Tatom, and Gabe Nickel), ACTA (Jon Chrostowski), DDESB (Dr. Jo Covino), Naval Air Warfare Center Weapons Division (Cynthia Romo), and Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) (Dr. Ming Liu and Bob Conway). Each member of the group conducted an independent scrub of the mishap data. After the independent scrubs, the group attempted to reach a consensus on the inclusion of mishaps, the activity type associated with each mishap, and hazard classification.

Following the scrub of the mishap data, a report (Ref 2) was prepared to look at the effect the data scrub would have on the $P_e$ values used in TP-14. Overall, the $P_e$ values decreased simply because the number of accidents used in the $P_e$ calculations decreased from the original 241 mishaps. Recommendations were presented to the RAPT in the report based on the analysis of the data. One major conclusion of the study was that a new $P_e$ matrix based on HDs instead of Compatibility Groups (CGs) might be more appropriate than the current $P_e$ matrix.

In February 2018, the RAPT held a meeting at APT in Huntsville, AL. One major topic of this meeting was reviewing the recent $P_e$ study and using the information gained from the study to present an updated $P_e$ matrix for inclusion into TP-14 Rev 5. The group discussed the recommendations from the $P_e$ report and came to the following agreements:

- The new $P_e$ matrix should be classified by HD as three columns: HD1.1/1.2/1.5, HD1.3, and HD1.6.
- The scrubbed mishap data, excluding the Army IOC data, should be used to develop the new matrix.
- The baseline $P_e$ values calculated from mishap data should be used for HD1.1/1.2/1.5 in the new matrix.
- The baseline values should be increased by a factor of 3.0 to determine the $P_e$ values for HD1.3.
- The $P_e$ values for HD1.6 should be two orders of magnitude less than the baseline values.
- The three storage groups in the current TP-14 matrix should be combined into one activity type.
- The lab/testing/training activity in the current matrix should be split into lab/test and training activities.
- The baseline values for burning ground/demilitarization/demolition/disposal, lab/test, and manufacturing will be used for all HDs because of the nature of these activities.

The group developed the proposed new $P_e$ matrix in Table 2 using scrubbed accident data, findings from the $P_e$ study, expert opinion, and the agreements discussed above.

*Table 2: Proposed New $P_e$ Matrix*

| Activity | HD 1.1/1.2/1.5 | HD 1.3 | HD1.6 |
|---|---|---|---|
| Assembly / Disassembly / LAP / Maintenance / Renovation | 5.37E-04 | 1.61E-03 | 5.37E-06 |
| Burning Ground / Demil / Demolition / Disposal | 7.78E-03 | | |
| Lab / Test | 9.75E-04 | | |
| Training | 9.75E-04 | 2.92E-03 | 9.75E-06 |
| Loading / Unloading | 3.15E-05 | 9.45E-05 | 3.15E-07 |
| Inspection / Painting / Packing | 2.05E-04 | 6.16E-04 | 2.05E-06 |
| Manufacturing | 1.90E-03 | | |
| Storage | 1.20E-05 | 3.59E-05 | 1.20E-07 |

The RAPT also came to several different agreements along with the proposed new $P_e$ matrix. These agreements were:

- HD 1.5 blasting agents should have a (beneficial) scaling factor of 0.01. HD 1.5 water-based explosives should have a (beneficial) scaling factor of 0.03.

- CGs L, A, B, G, H, F, J should not have any scaling factor.
- CG C should have a beneficial scaling factor of 0.3 in addition to the environmental factors.
- CGs D, E, N should have a (beneficial) scaling factor of 0.1 in addition to the environmental factors.
- The environmental factors can be beneficial (i.e., < 1.0) in TP-14 Rev 5, in addition to the detrimental environmental factors in TP-14 Rev 4a. Temporary storage and in-transit storage will be added as environmental factors.

### 2.2. Updates to Uncertainty

The need to address uncertainty in the TP-14 QRA model was identified by the Risk-Based Explosives Safety Criteria Team (RBESCT) as far back as 1998. The current published version of TP-14 (Rev 4a) includes a complex uncertainty model that has an effect on the final risk that the model outputs. A description of this model can be found in TP-14 Rev 4a (Ref 1).

Recently the RAPT commissioned a study to focus on the uncertainty model included in TP-14 Rev 4a. The purpose of this study was to investigate the use of uncertainty distributions other than lognormal (which is the current distribution used in the uncertainty model) for the elemental models used in the TP-14 methodology ($P_e$, $P_{f|e}$, exposure, etc). This study also examined the effect of setting the point estimate of the elemental models to the distribution mean instead of the current method of setting the point estimate of the models to the distribution median.

Upon completion of the study, it was concluded that the use of distributions other than lognormal for the TP-14 elemental models is possible and that the resulting risk distribution remains lognormal. It was also determined that it is possible to assign the elemental point estimates as the mean rather than the median.

The RAPT has decided that the uncertainty model incorporated in TP-14 Rev 5 will assign the elemental point estimates as the mean. However, the RAPT recently discussed using different uncertainty distributions in the TP-14 Rev 5 uncertainty model. The RAPT agreed on a path forward that included examining changing the distributions used in the uncertainty model and determining the methodology for calculating the distribution parameters to be used in the model.

Additional detail on the updates to uncertainty modeling can be found in another paper that is being presented at the 2018 International Explosives Safety Symposium & Exposition[1].

### 2.3. Relooking at Risk Acceptance Criteria

Recently, the RAPT completed a risk literature review with the purpose of gaining understanding of how different groups and countries looked at risk and determined risk criteria. The team searched multiple sources to compile as many applicable documents as possible. These sources

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[1] "Uncertainty Modeling Enhancement Concepts in Quantitative Risk Assessment Methodology" International Explosives Safety Symposium & Exposition 2018, Paper 20706; R. Baker, J. Tatom.

included: Defense Technical Information Center, Google Scholar, Researchgate, agency-specific websites, references in NATO AASTP-4 and DoD 6055.09M, etc. A summary report was also compiled that organized the findings of the literature review (Ref 3). The report organized the findings based on how risk assessment is understood and used in other countries, industries, and regulatory bodies around the world. The report also discussed the benefits and challenges of commonly used risk acceptance methods and compared the findings of the literature review to the current method used by DDESB.

The risk literature review demonstrated that there is a wide range of methods and criteria for conducting QRAs. The review found that an individual public risk criterion of 1E-06 is fairly consistent within other countries and groups. Another finding from the review is that ALARP and F/N curves (discussed below) are the most common ways of comparing group or societal risk. The group also concluded that no country or group handles group risk the way that DDESB does. The risk literature review report presented a three-phase approach to updating the criteria currently used for DDESB QRA analysis. Phase One would be a three-level risk paradigm or a "warning system". Phase Two would be implementing an ALARP approach. Phase Three would be developing and implementing an F/N process to consider catastrophic risk.

At the RAPT meeting at APT in February 2018, the team discussed a path forward for implementing new risk criteria. The team agreed on the previously mentioned three-phase approach to updating the criteria used for QRA analysis.

Currently, the DDESB criterion for QRA analysis is a simple pass/fail criterion, as shown in Table 3 and Figure 2. A QRA site plan is approved if all measures for risk fall under the specified threshold for each category.

*Table 3: Current DoD Pass/Fail Criterion*

| Personnel Category | | Current Pass/Fail Criterion |
|---|---|---|
| Related | Individual | 1E-04 |
| | Group | 1E-03 |
| Public | Individual | 1E-06 |
| | Group | 1E-05 |

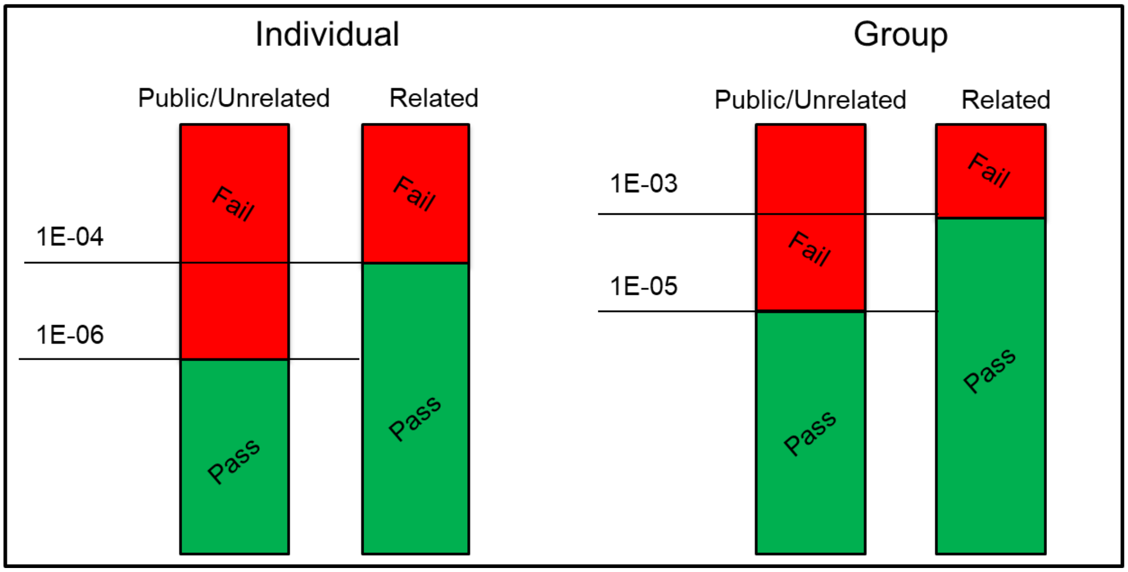


*Figure 2: Current DoD Pass/Fail Criterion*

A three-level risk paradigm, or warning system, is the proposed Phase One update to the current DDESB criteria. A three-level risk paradigm consists of three regions of risk: Unacceptable, Tolerable, and Broadly Acceptable. A description of each of these regions can be seen below:

- Unacceptable ("Red") - A site plan will be rejected because the risk is above a specified tolerable limit.
- Tolerable ("Yellow") - A site plan will be accepted, but the Service will receive a "warning" from DDESB that the site is moderately high-risk and is close to the failure criterion.
- Broadly Acceptable ("Green") - A site plan will be accepted because the risk is below a specified broadly acceptable level.

In order to implement a three-level risk paradigm, numerical thresholds were defined for the breakpoints between the "Red" and "Yellow" regions and between the "Yellow" and "Green" regions. At the aforementioned 2018 RAPT meeting, the team defined proposed values for these numerical thresholds, as shown Table 4. The three-level risk paradigm system and the current pass/fail criterion can be seen graphically in Figure 3 and Figure 4.

*Table 4: RAPT Proposed Risk Acceptance Criteria*

| **Personnel Category** | | **Current Pass/Fail Criterion** | **Proposed Warning Lower Limit** | **Proposed Warning Upper Limit** |
|---|---|---|---|---|
| Related | Individual | 1E-04 | 1E-05 | 1E-04 |
| | Group | 1E-03 | 1E-04 | 1E-03 |
| Public | Individual | 1E-06 | 1E-07 | 1E-06 |
| | Group | 1E-05 | 1E-05 | 1E-04 |

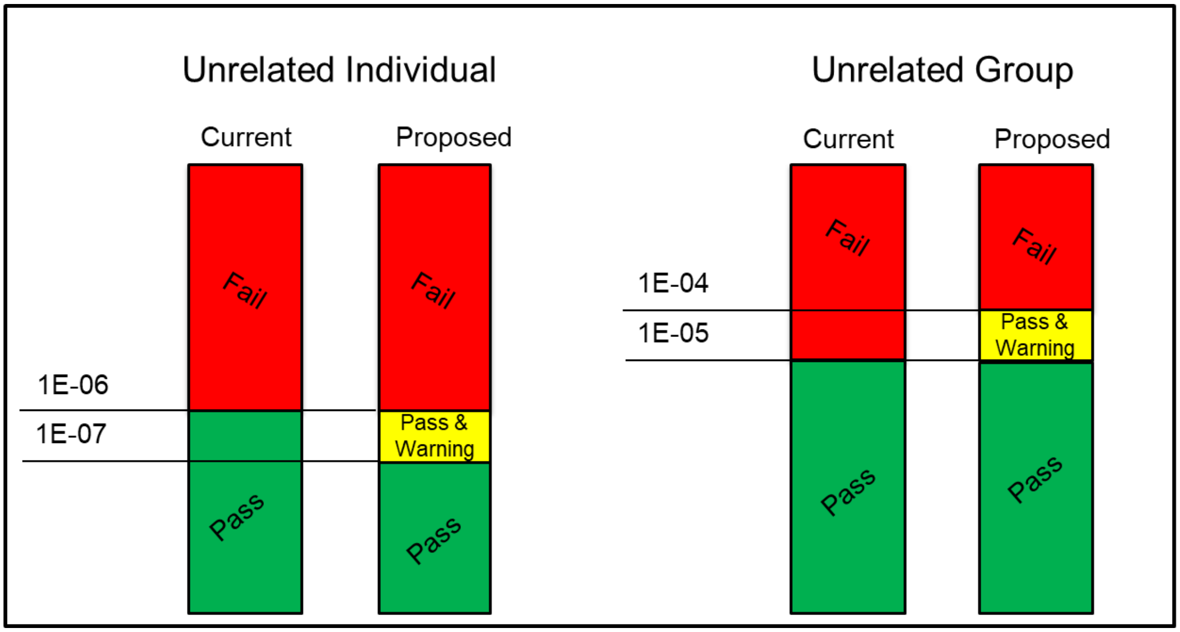


*Figure 3: RAPT Proposed Unrelated Criteria*

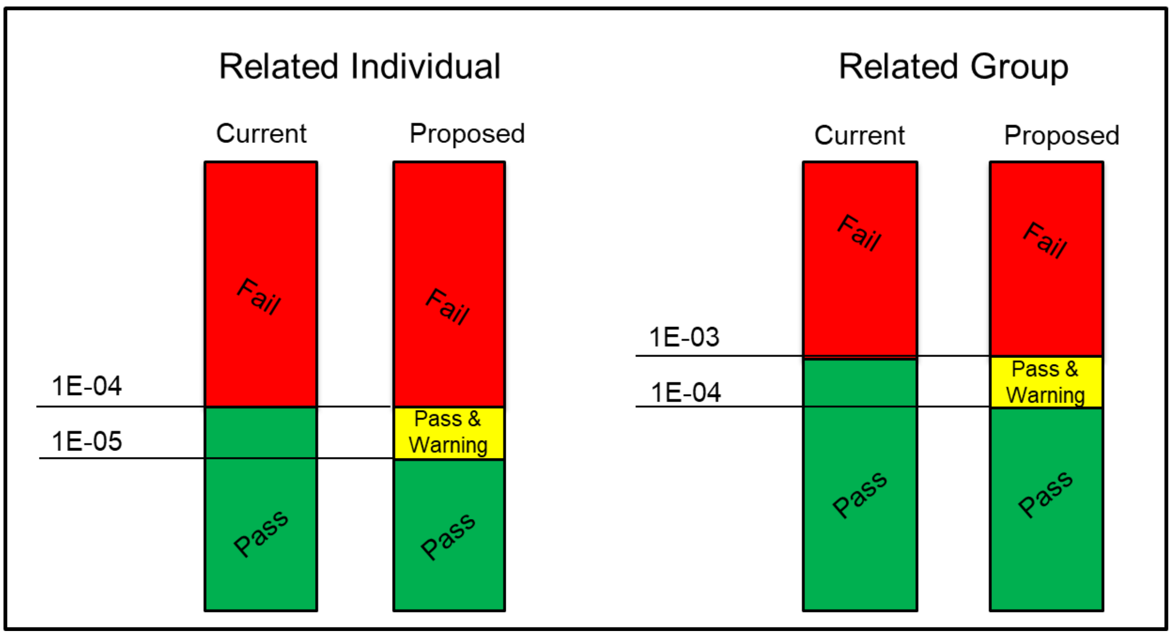


*Figure 4: RAPT Proposed Related Criteria*

An ALARP approach is the proposed Phase Two update to the current DDESB criteria. A three-level risk paradigm and an ALARP approach are very similar, but differ in how the warning ("Yellow") region is handled. Site plans will still be accepted in the broadly acceptable "Green" region and will still be rejected in the unacceptable "Red" region. Instead of requiring a simple warning, an ALARP approach will require a plan for handling site plans that fall in the "Yellow" region. At a minimum, the proposed plan for a site plan in the "Yellow" region should include steps the site will take to get out of the "Yellow" region, a time frame for the site to implement the proposed changes, and guidelines for how frequently progress should be reviewed. When developing a plan for a site in the "Yellow" region, risk should be weighed against the potential consequences, time, and money needed to control the risk. A graphical representation of the ALARP principle can be seen in Figure 5.

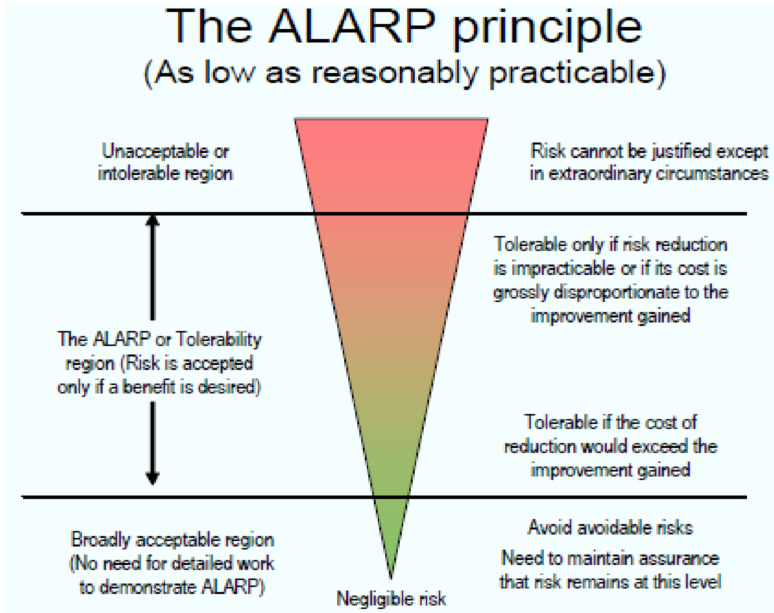


*Figure 5: ALARP Principle*

In order to implement an ALARP approach in the future, acceptable and unacceptable risk levels for individual and group exposures must be defined. These acceptable/unacceptable risk levels can be the same as the limits defined in the implementation of the three-level risk paradigm, or new limits can be defined for this phase two effort. Also, the additional submittal requirements for sites that fall in the "Yellow" region must be defined.

Implementation of an F/N process to consider catastrophic risk is the proposed Phase Three update to the current DoD criteria. F/N curves are the relationship between the probability (or frequency) per year (F) of accidents resulting in N or more fatalities. Figure 6 provides examples of F/N criteria used by several countries to assess societal risk. Each F/N curve is a criterion line that establishes the tolerable/intolerable risk level. Any site/process that falls above an F/N curve will be deemed to have an intolerable level of risk. Any site/process that falls below an F/N curve will be deemed to have a tolerable level of risk. It is also possible to have a system that uses two separate F/N curves to create a three-region criterion like the ALARP approach described above. Like the ALARP approach, anything falling in the middle region between the F/N curves will require a plan for risk mitigation.

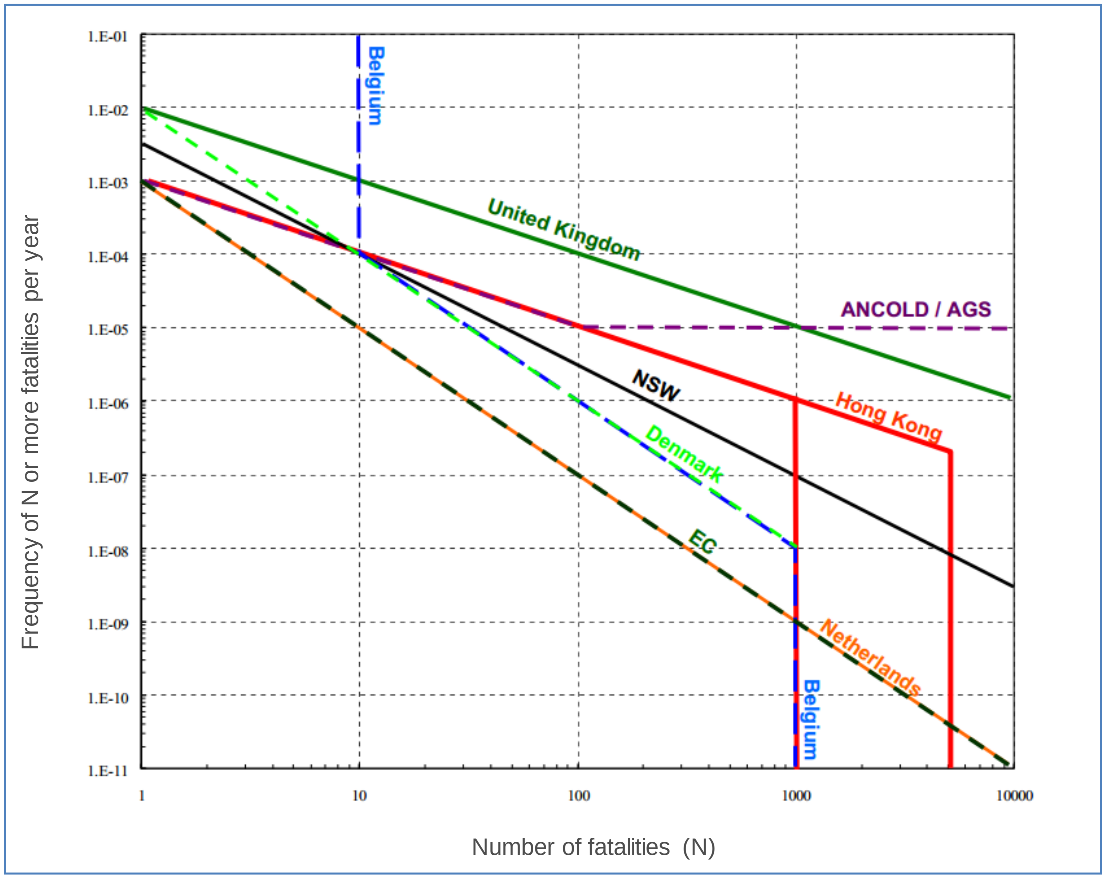


*Figure 6: F/N Curves from Multiple Countries*

Implementation of an F/N process is considered a long-term approach by the RAPT and implementation into the current risk-based methodology will be a very complex process.

## 2.4. Update to the Universal Risk Scales

The URS were developed in 1999 as part of the initial development of DDESB risk criteria. The purpose of the URS is to present various risk acceptability data in a common and easy-to-read format. The URS are a valuable tool when looking at risk-related criteria and help in the discussion of "How safe is safe enough?"

In 2014, the RBESCT tasked APT to update the URS. With guidance from DDESB, APT researched fatality statistics to update the data currently in the URS with more recent and representative risk values. Upon completion of the URS update effort, a summary report was created (Ref 4).

The URS provides two types of numerical data plotted alongside a logarithmic scale. On the left side, the URS summarizes legal precedents and standards that contain criteria for risk acceptance and compares those standard criteria to numerous data on the right side representing actual risk statistics derived from historical accident data. The URS consist of four separate scales: Voluntary Individual Risk, Voluntary Group Risk, Involuntary Individual Risk, and Involuntary Group Risk. The updated URS can be seen in Figure 7, Figure 8, Figure 9, and Figure 10.

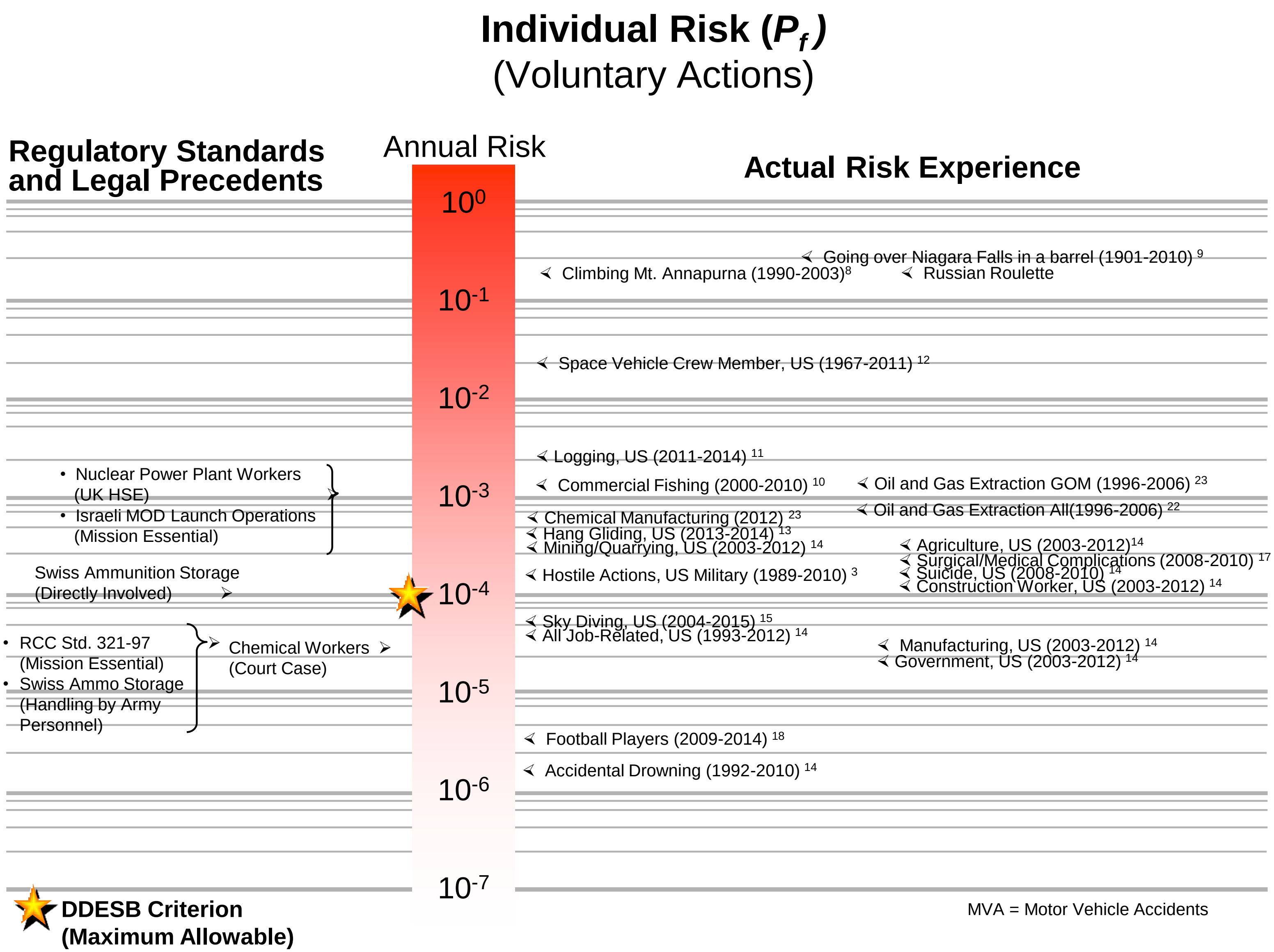


*Figure 7: Individual Risk (Voluntary Actions)*

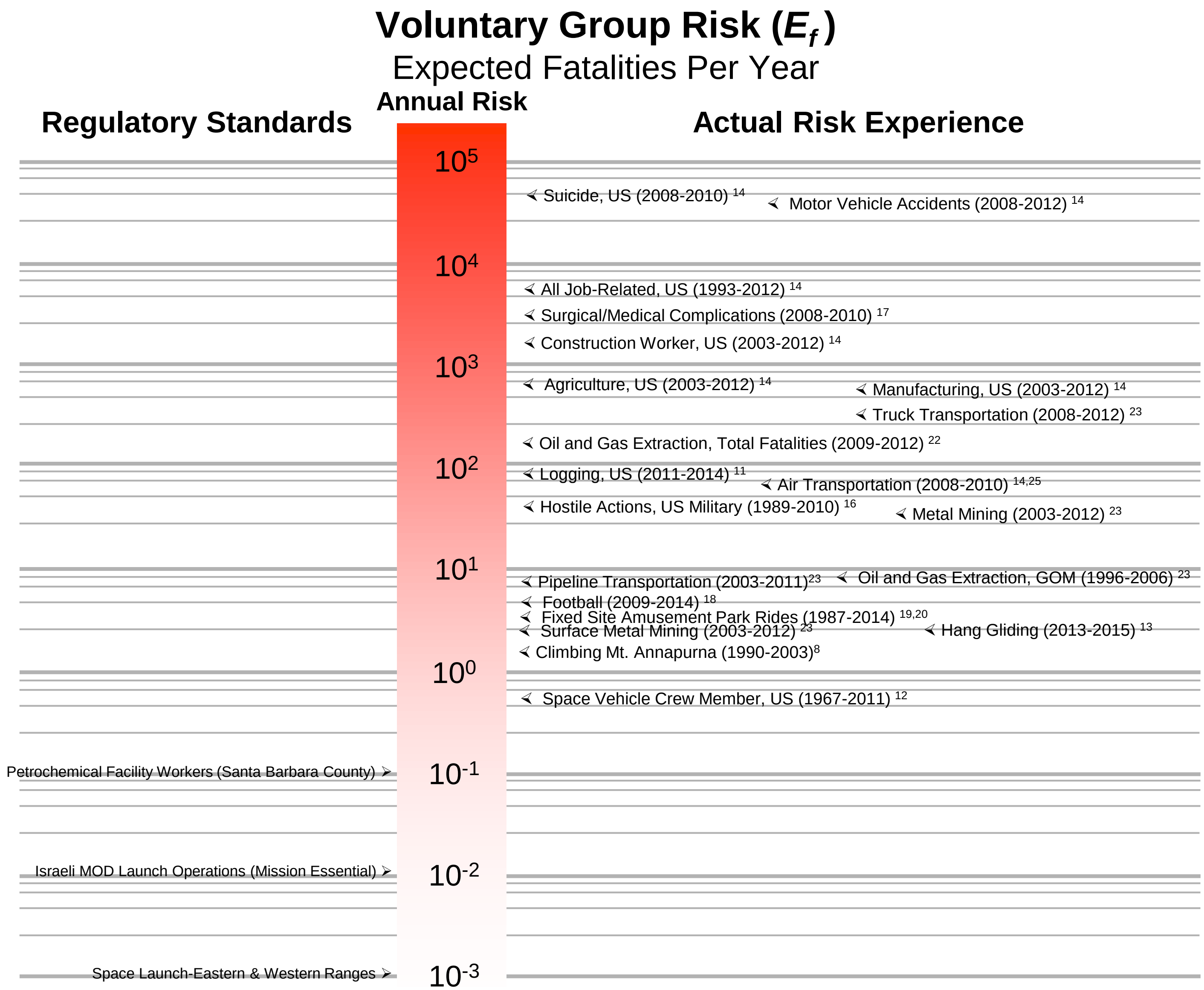


*Figure 8: Group Risk (Voluntary Actions)*

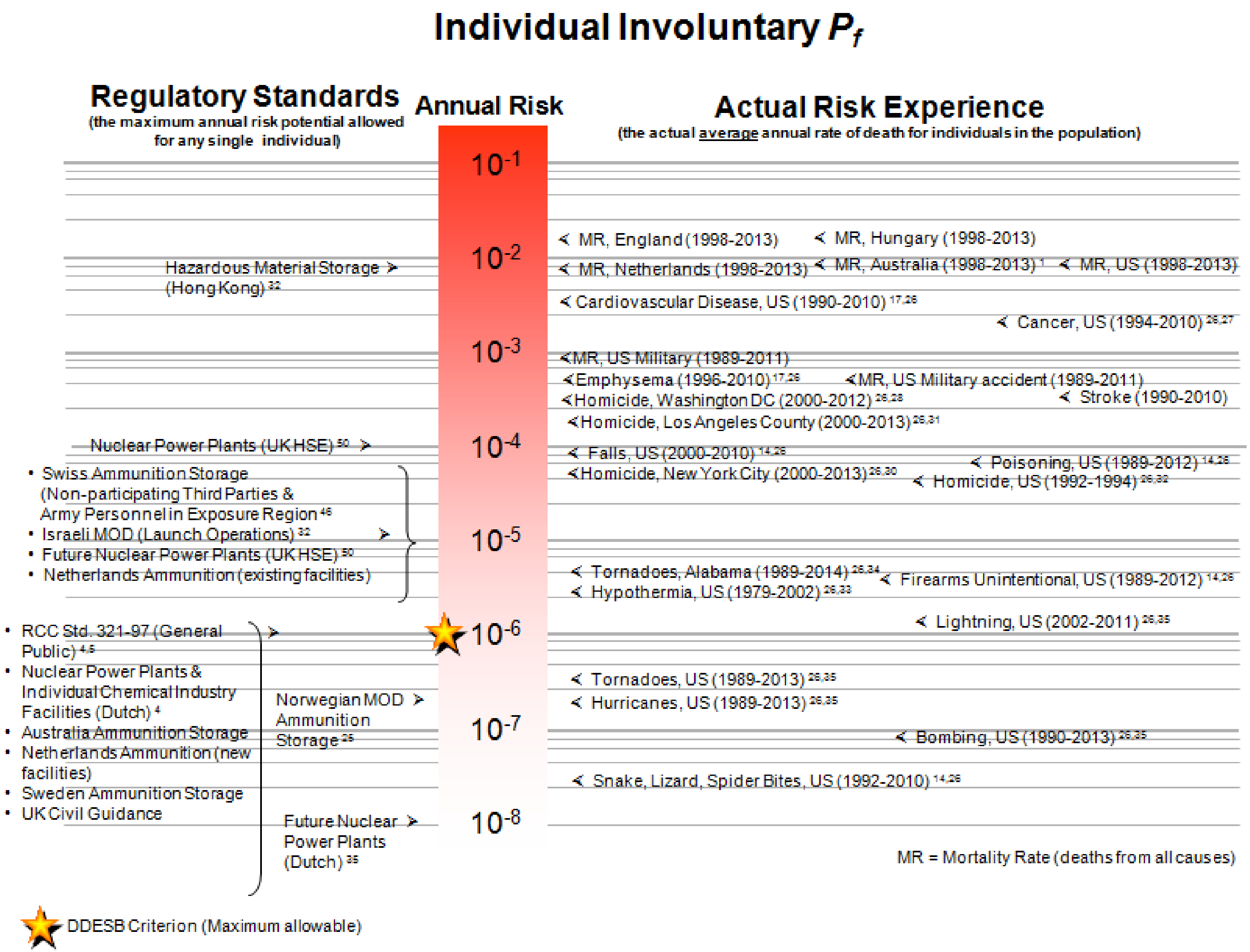


*Figure 9: Individual Risk (Involuntary Actions)*

## Involuntary Number of Fatalities Avg/Year

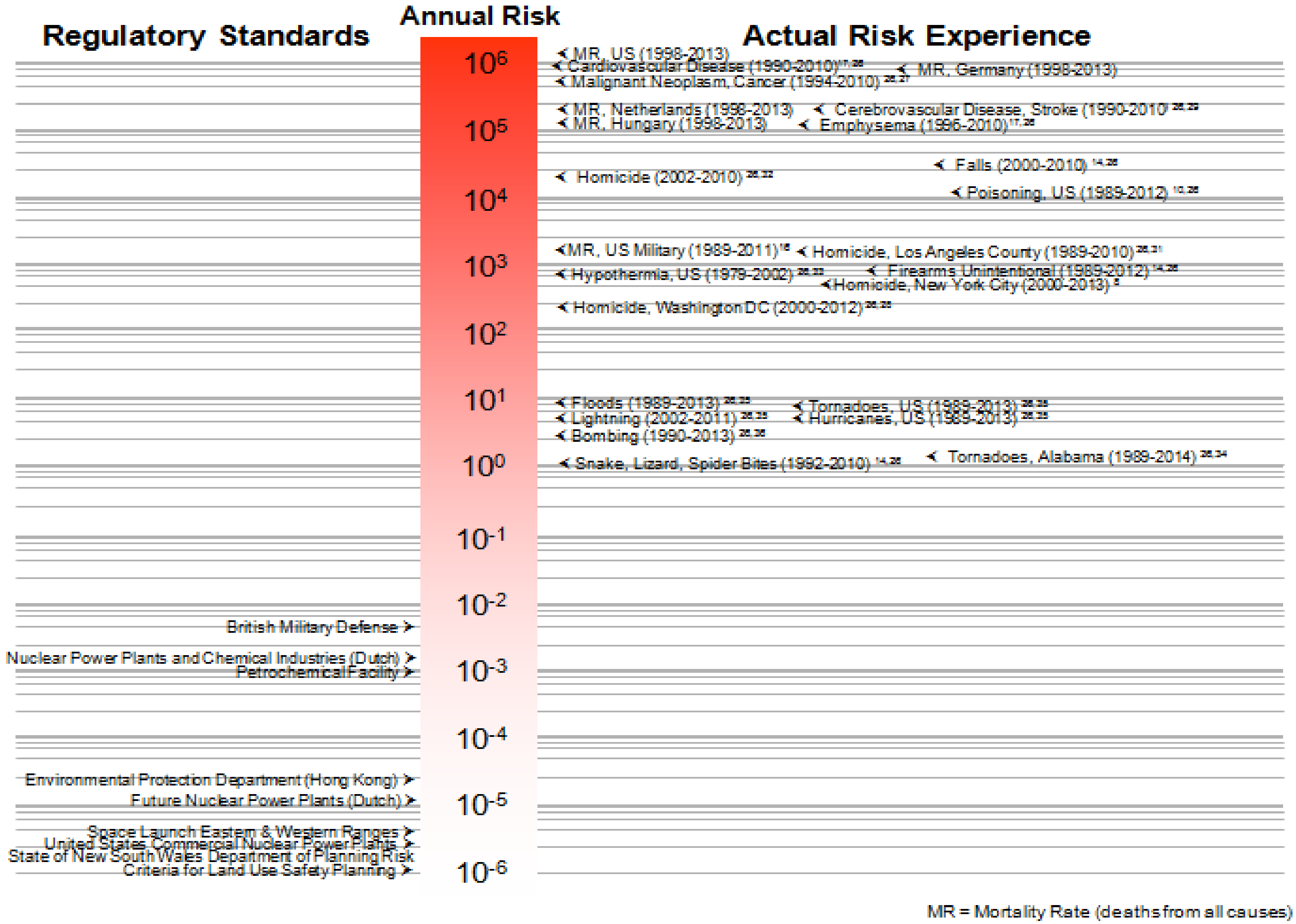


*Figure 10: Group Risk (Involuntary Actions)*

## 2.5. RBESS Module and Updates of TP-23 and TP-14

RBESS Module

RBESS is a module that will be incorporated within the ESS software. RBESS is comprised of multiple tools designed to model various explosives effects and consequences. These various tools are organized into groups, referred to as "tiers," based on the level of input and analysis detail required in the model. A summary of each tier is explained below:

Tier 1: This is a simplified Service (hybrid) qualitative risk management analysis requiring little to no additional user input beyond information already entered into ESS. The simplified analyses are based on translating scaled distances (K-factors) into estimates of consequences like a TP-23 type analysis. A Tier 1 Hybrid qualitative risk analysis should help a user complete a Deviation Approval and Risk Acceptance Document (DARAD) or other deviation forms.

Tier 2A: Advanced Service (hybrid) qualitative risk analysis – where a qualitative event probability (e.g., possible, seldom, unlikely, improbable, practically impossible) and the severity of consequences (e.g., catastrophic, critical, marginal, negligible) are used to make decisions.

Tier 2B: TP-14 quantitative risk analysis – where risk estimates based on numerical values for the event probability (e.g., 1x10-6 per year) and the probability of consequences given the event occurs (e.g., probability of fatality given the event = 2x10-3) are used to make decisions.

Tier 3: Advanced engineering analyses and other scenario-specific analyses that are not properly captured in a Tier 2 analysis.

As stated above, RBESS will be a module within ESS software. It is envisioned that RBESS can be assessed by the user if QD can't be met. Since RBESS is within ESS, it will use the existing data defined for QD purposes and ask the user for the additional information to conduct a TP-14 QRA. Also, because RBESS is a module within ESS, the data used for the TP-14 QRA will be stored within the ESS software.

Not only will RBESS be used for risk-based site planning, it will also have the ability to conduct risk management. It can be used to conduct a simplified risk management, using scaled distance (Tier 1) to setting up scenario-specific analysis (Tier 3). Using the ESS graphical user interface (GUI), RBESS will have the capability to visualize risk through various contours (debris, pressure, risk, etc.).

Tier 1 and Tier 2A of RBESS was incorporated into ESS v6.1.4. Validation efforts of both Tier 1 and Tier 2A are underway. The current plan is for ESS Web v2.0 (not v1.0) to have RBESS and include Tier 1, 2A and 2B. Both Tier 2A and 2B will use TP-14 Rev 5 models. Development of ESS Web v2.0 will begin after release of ESS Web 1.0, which is scheduled for March 2019.

TP-14

TP-14 – "Approved Methods and Algorithms for DoD Risk-Based Explosives Siting," is going through a major revision. The updated version, when completed, will be known as TP-14 Revision (Rev) 5 and will feature updated, state-of-the-art models for debris, pressure/impulse, building collapse, glass hazard, and thermal effects. Also, this revision will include updates to the probability of event ($P_e$) and the uncertainty model as discussed previously in this paper. Drafting of TP-14 Rev 5 is in its closing stages and the algorithms and methodology presented in the document will be incorporated into RBESS Tier 2B when it is developed.

Additional detail on the updates TP-14 can be found in another paper that is being presented at the 2018 International Explosives Safety Symposium & Exposition[2].

TP-23

TP-23 – "Assessing Explosives Safety Risks, Deviations and Consequences," is also going through a major revision. The updated TP-23 will expand on the Explosives Safety Risk Model (ESRM) and concentrate on the explosives safety of the life cycle of a munition, including research and development, manufacturing, transporting, storage, etc. The document will have step-by-step procedures, explaining how to use the various DDESB-sponsored explosive safety risk tools.

### 2.6. Support of NATO AASTP-4 Updates

AASTP-4 is the NATO guideline for conducting QRA studies for allied explosives facilities. This document (comprising two parts) discusses the national methods for assessing risk, to include probability of event and consequence modeling. The document also contains a "unified approach" section that describes the models and algorithms accepted by all participating nations.

The U.S. has supported the AASTP-4 Risk Assessment Working Group (RAWG) by contributing material to the document, hosting annual working meetings, and participating in studies conducted by the group. In addition to writing the U.S. approach sections in the document, the U.S. has contributed technically and provided secretarial support to produce ongoing updates. Most recently, the U.S. material was updated to reflect many of the model changes in accordance with moving from TP-14 Rev 4a to TP-14 Rev 5. The U.S. is planning to host the group's next meeting in October 2018.

## 3. Conclusions and Path Forward

Moving forward, RBESS will become web-based and will be incorporated into ESS software. The RAPT hopes that this will increased the usability of a QRA for explosives safety management by the Services will be increased after publishing RBESS. The incorporation of RBESS into ESS will allow the Services to simply turn on the tool, enter a few new inputs, and complete a QRA. One additional benefit of the new RBESS format is that it is modular. A modular tool is a huge advantage for the RAPT because the team can continue to improve the models used in the methodology without creating an entirely new tool.

The RAPT will continue to address the short-term and long-term goals discussed in this paper to attempt to improve the overall safety associated with explosives operations.

[2] "Updated Blast Effects and Consequence Models in DDESB Technical Paper 14" International Explosives Safety Symposium & Exposition 2018, Paper 21244; R. Conway, B. Fryman, J. Tatom, J. Covino.

# References

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