Part II/Risk-Based Siting Criteria – Current and Future 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 focuses on some details of the current efforts by the DDESB Risk Analysis Program that is overviewed by Part I of this paper. These details include relooking at the P_e, updating the uncertainty modeling, relooking at the risk acceptance criteria by which QRA are compared to, and updates to the Universal Risk Scale (URS). This paper also presents a way-ahead for this Program.

Introduction

The quantitative risk assessment (QRA) methodology established by the U.S. Department of Defense Explosives Safety Board (DDESB) is based on the basic concept of risk, where the risk to personnel can be defined as:

$$Risk = Probability\ of\ Event \times Consequences \times Exposure \quad (1)$$

Eq. (1) provides the basis to calculate the annual probability of fatality to any individual (P_f), which may be defined as the product of the three components, as shown in Eq. (2) below:

$$Risk = P_f = P_e \times P_{f|e} \times E_p \quad (2)$$

where 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 mishap and the presence of any individual. E_p is defined as the exposure of one person (as a fraction of a year) to the PES in a year.

Eq. (1) also provides the basis to calculate the risk to an entire group of people (*i.e.* the "Group Risk"), which may be measured by the average number of potential fatalities per year. Currently, the "Group Risk" is calculated as the summation of individual risk within the group.

As stated in Part I of this paper, one of the goals of the current Risk Analysis Program sponsored by DDESB is to improve each of the elements in calculating risk within DDESB's QRA methodology. These elements include estimating the probability of events (P_e,), uncertainty modeling, and establishing risk acceptance criteria.

Current Efforts in Updating Probability of Event (P_e)

The probability of event (P_e) is a critical component in QRA because P_e is a term directly included in Eq. (2). The current version of TP 14 (*i.e.* TP 14 Rev 4a) defines a P_e matrix as shown in Table 1, which is a function of the activity type and "element". An "element" is defined by the compatibility group of the explosives. 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 that are deemed to increase the P_e of an activity. The current list of environmental factors can be seen in TP-14 Rev 4a [1].

Table 1: P_e Matrix in TP 14 Rev. 4a

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: Elements in P_e Matrix

The DDESB Risk Analysis Program 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 describes the process for creating a P_e matrix. 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, only 138 mishaps, their descriptions, and activity type are listed in Attachment 10 of TP-14 Rev 4a. 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 rest of 103 mishaps were from the Army IOC Report on the Army incident data from FY1987-1996, but the specific incidents and their descriptions are not listed. The current P_e matrix in TP 14 Rev 4a 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 hazard division (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. (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 each member conducted an independent scrub, 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 [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 DDESB Risk Analysis Program 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.

Current Efforts in Uncertainty Modeling

The need to address uncertainty in the TP-14 QRA model was identified 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 outputs. A description of this model can be found in TP-14 Rev 4a.

Recently the DDESB Risk Analysis Program 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 DDESB Risk Analysis Program 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.

Current Efforts in Updating Risk Acceptance Criteria

Recently, the DDESB Risk Analysis Program 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 Program searched multiple sources to compile as many applicable documents as possible. These sources 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 [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 risk criteria currently used in TP-14. Phase I would be a three-level risk paradigm or a “warning system”. Phase II would be implementing an ALARP approach. Phase III would be developing and implementing an F/N process to consider catastrophic risk.

At the in-person meeting at APT in February 2018, the Risk Analysis Program discussed a path forward for implementing new risk acceptance criteria. It was agreed on the previously mentioned three-phase approach to updating the risk acceptance criteria used in TP-14.

Currently, the DDESB criterion for QRA 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

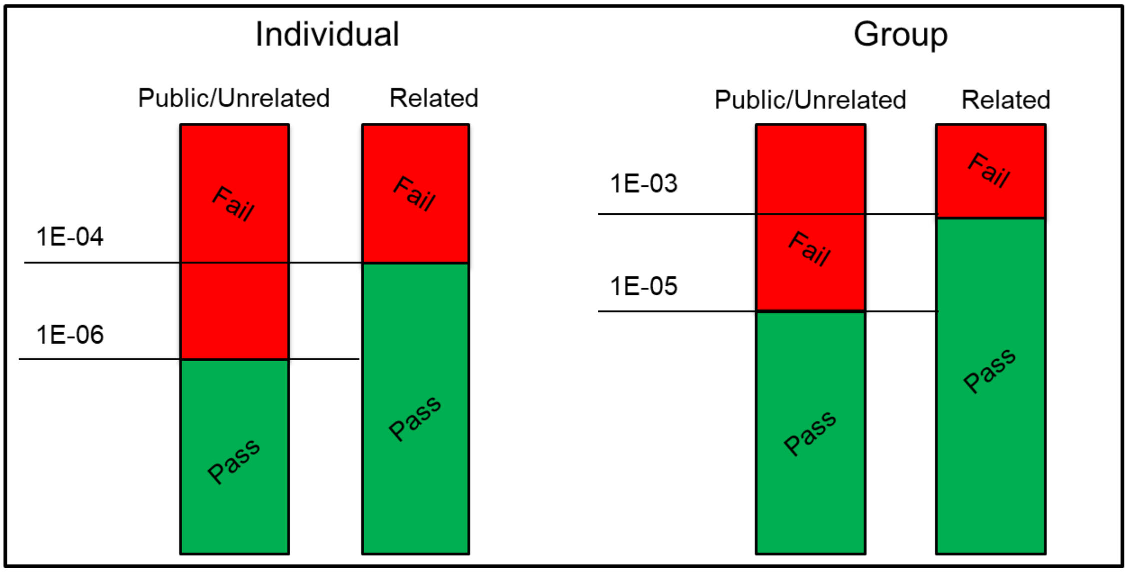

Figure 2: Current DoD Pass/Fail Criterion

A three-level risk paradigm, or warning system, is the proposed Phase I 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 in-person meeting, the DDESB Risk Analysis Program proposed the 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: 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

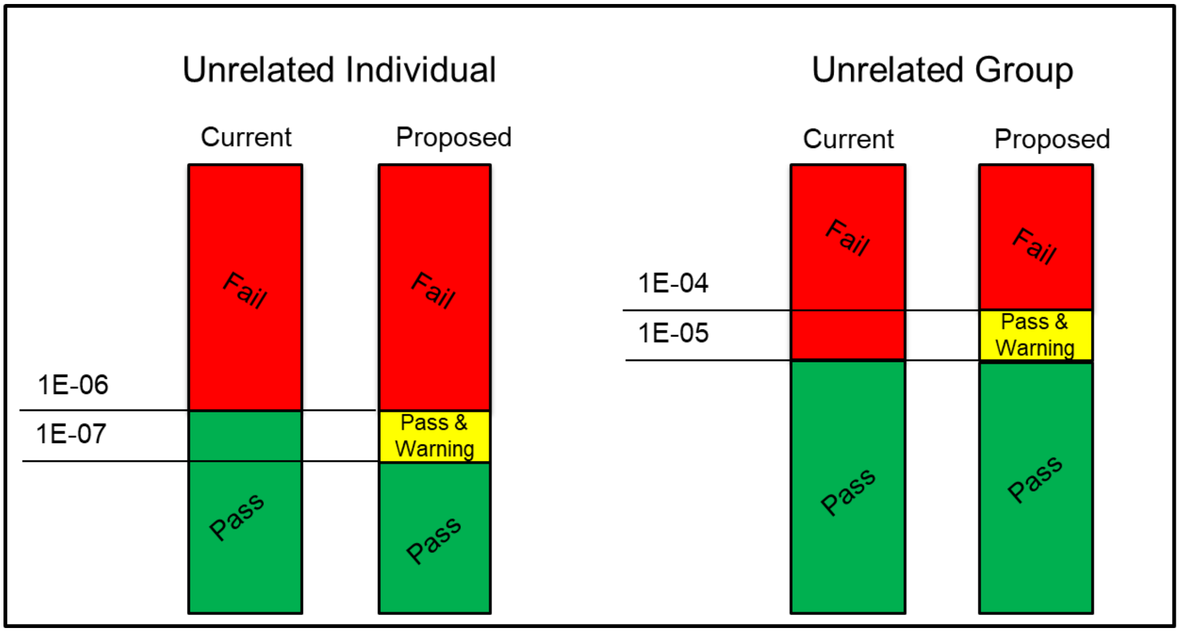

Figure 3: Proposed Unrelated Criteria

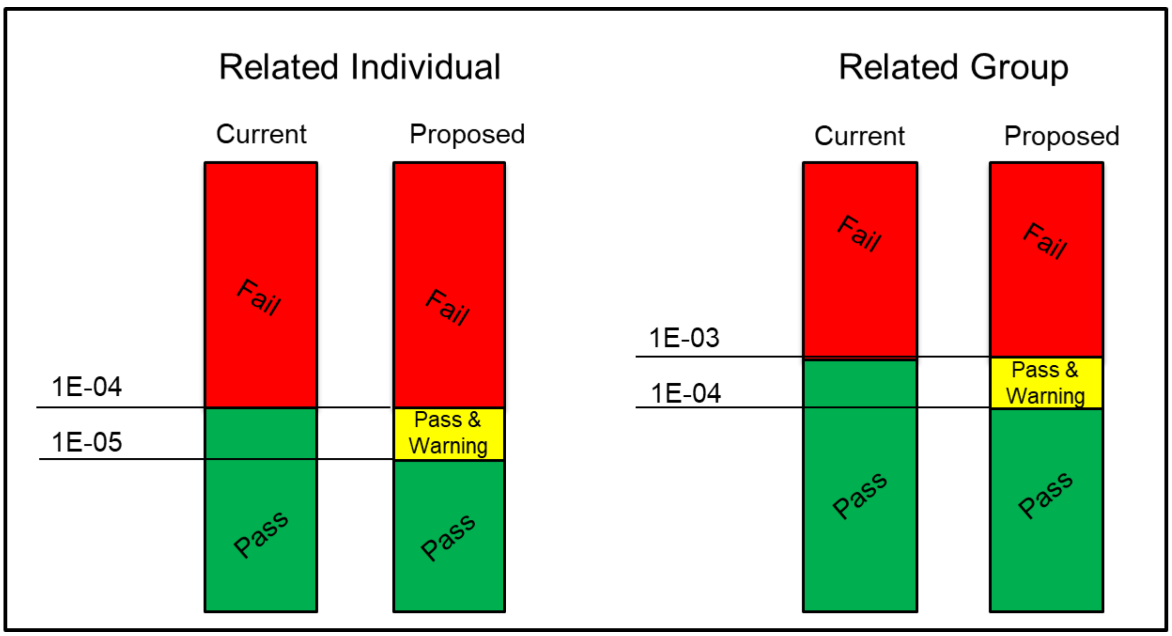

Figure 4: Proposed Related Criteria

An ALARP approach is the proposed Phase II 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.

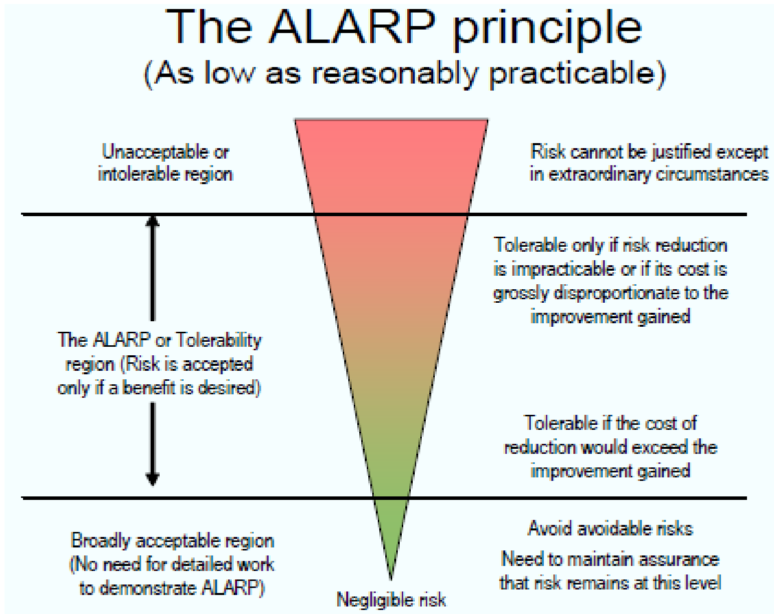

Figure 5: ALARP Principle

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 III 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.

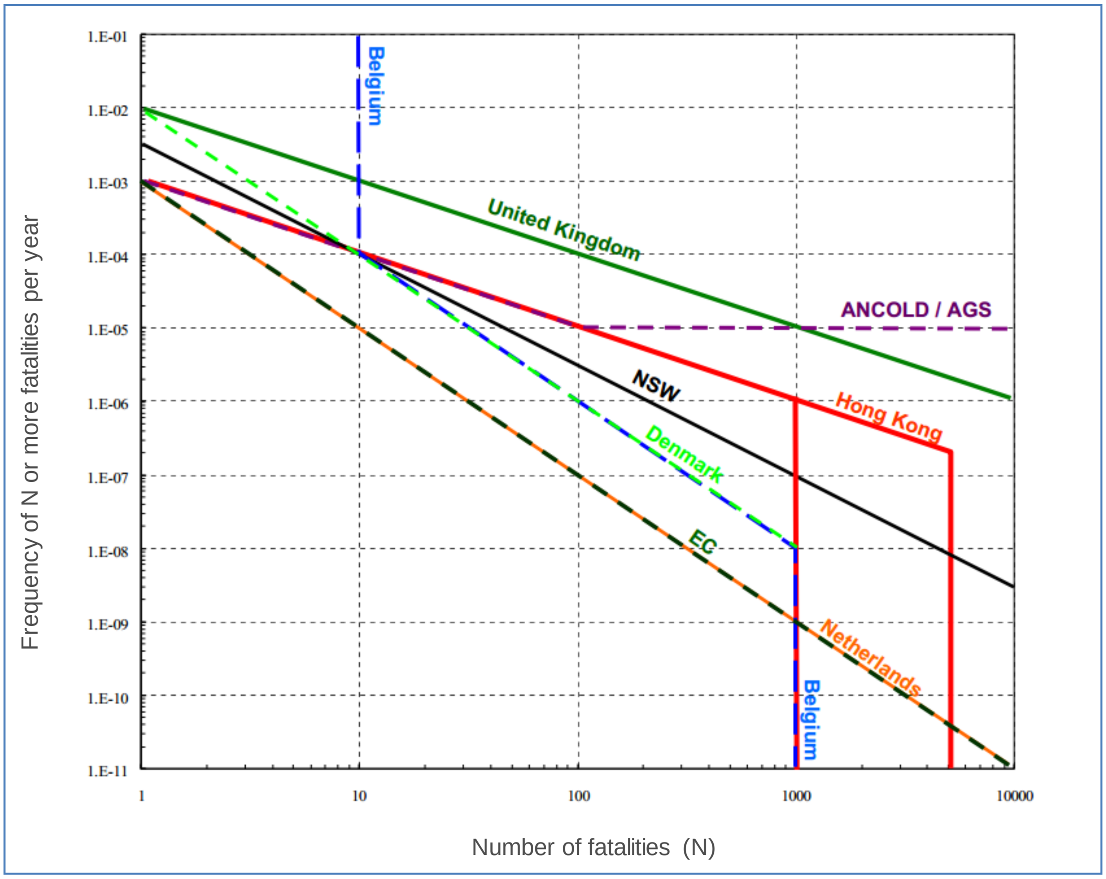

Figure 6: F/N Curves from Multiple Countries

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

Current Efforts in 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 then Risk-Based Explosives Safety Criteria Team (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 [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 from Figure 7 to 10.

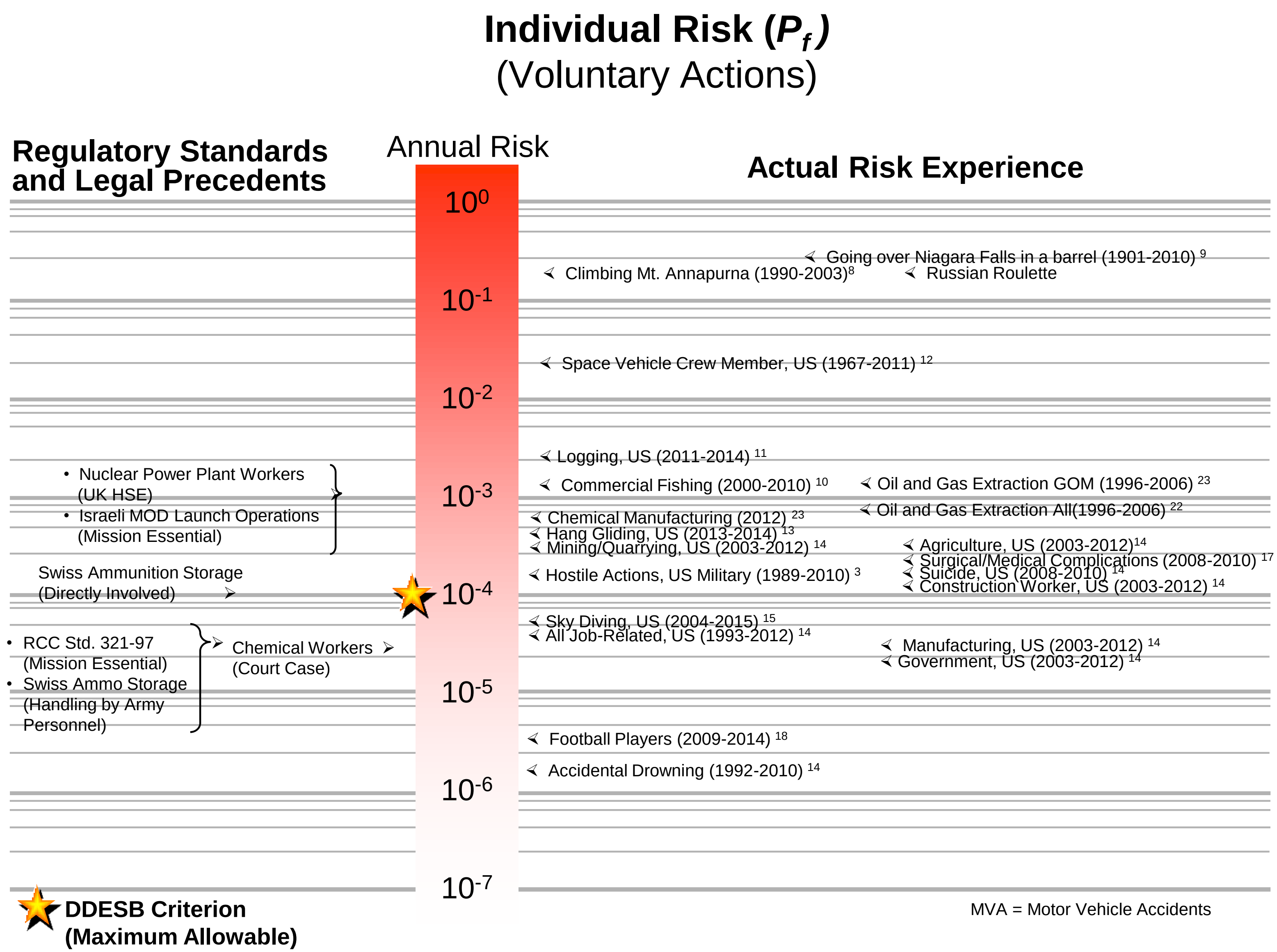

Figure 7: Individual Risk (Voluntary Actions)

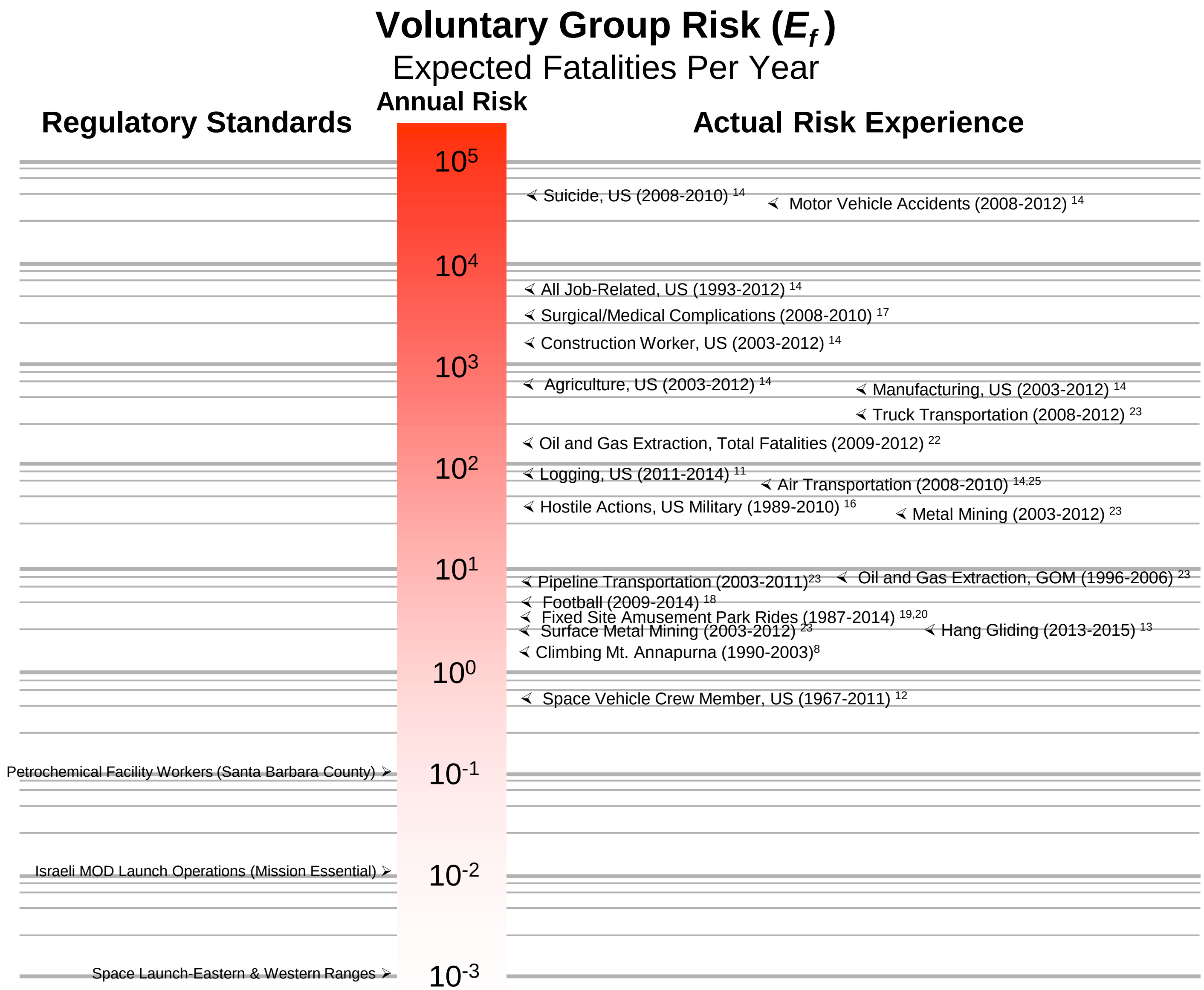

Figure 8: Group Risk (Voluntary Actions)

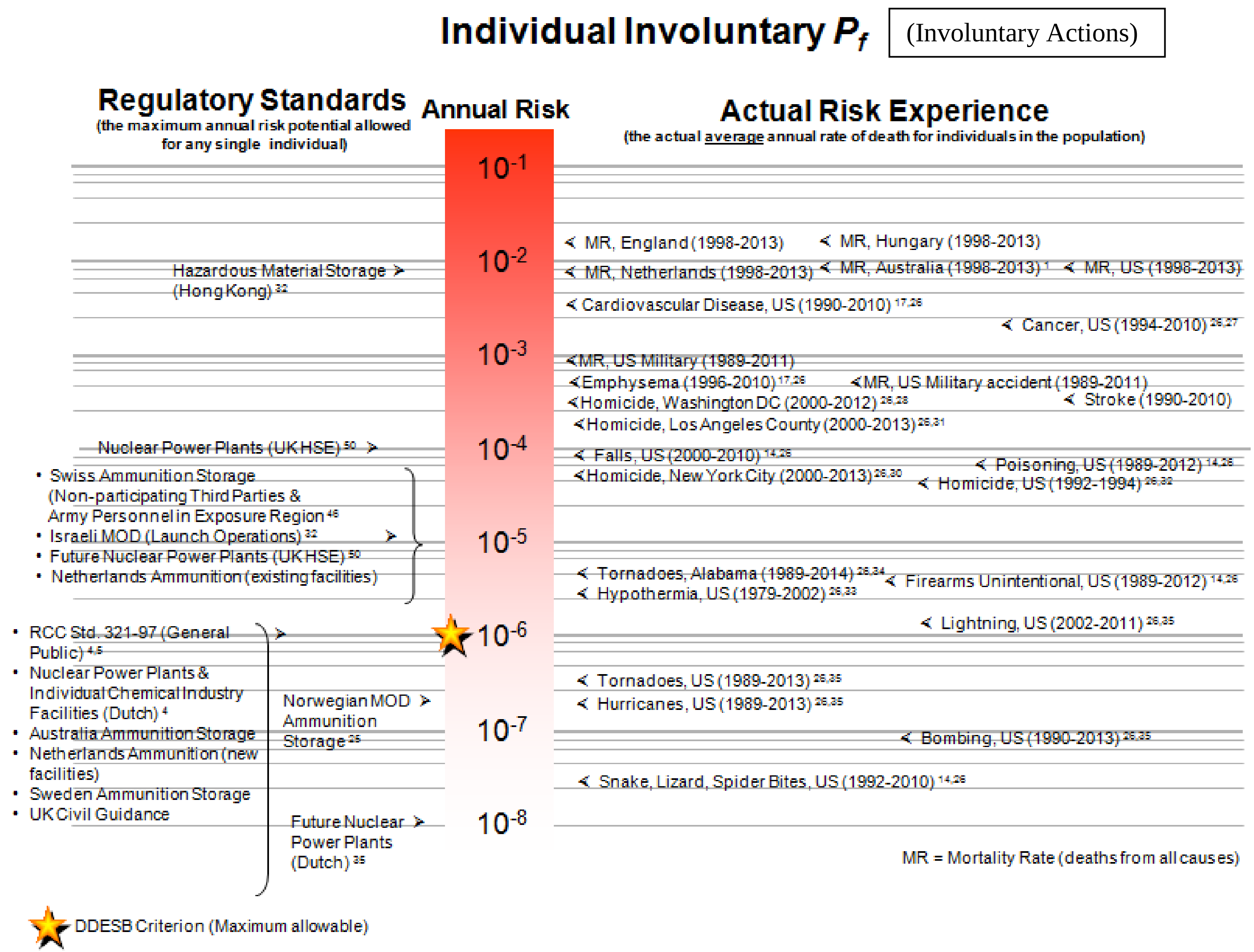

Figure 9: Individual Risk (Involuntary Actions)

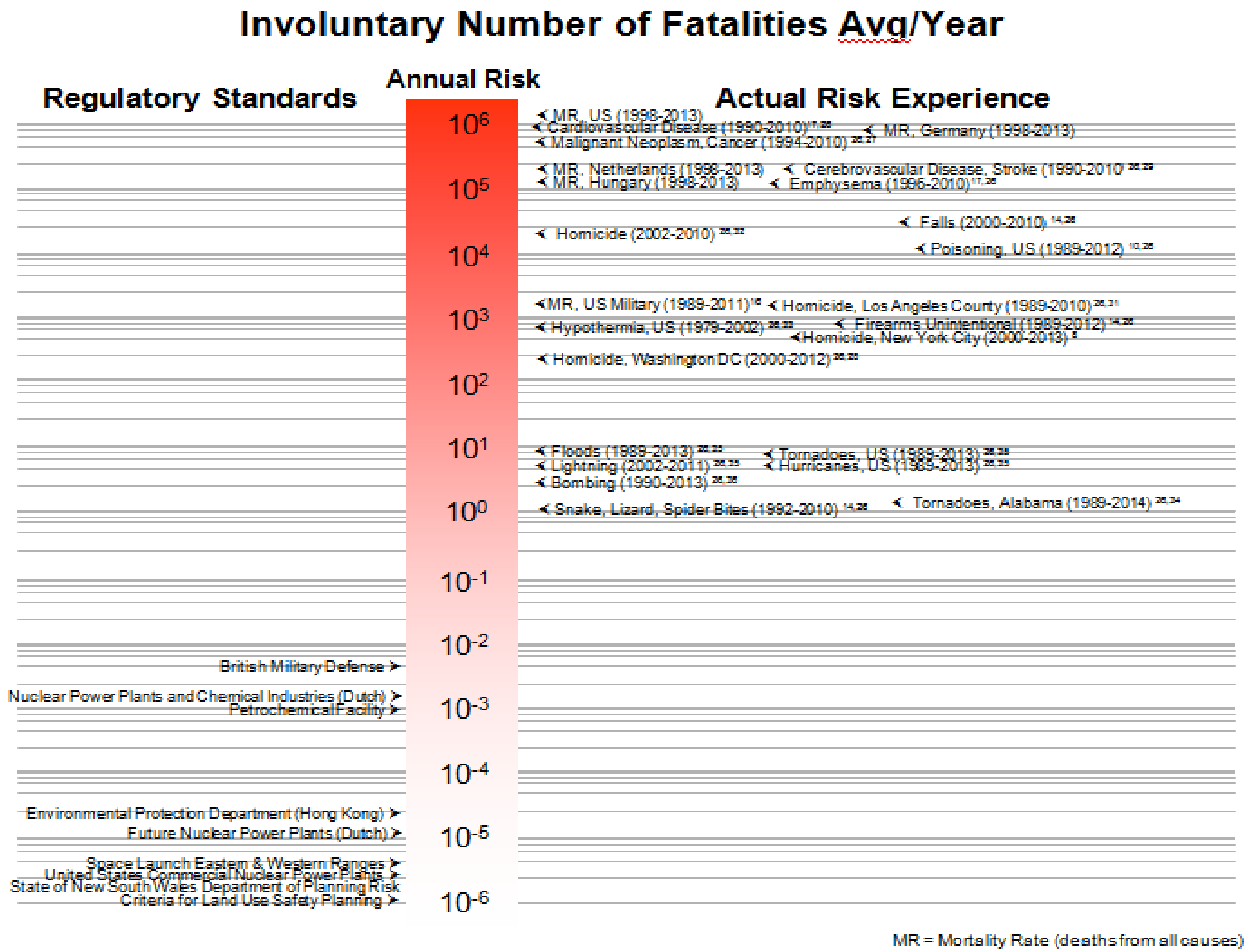

Figure 10: Group Risk (Involuntary Actions)

Conclusions and Path Forward

Moving forward, the DDESB Risk Analysis Program hopes that the usability of QRA for explosives safety management by the Services will be increased. The development of the computer module to implement the DDESB QRA methodology will allow the Services to simply turn on the tool, enter a few new inputs, and complete a QRA. The DDESB Risk Analysis Program will continue to address how to improve each of the elements in calculating risk within DDESB's QRA methodology, including estimating the probability of events (P_e,), uncertainty modeling, and establishing risk acceptance criteria, which has been discussed herein to attempt to improve the overall safety associated with explosives operations.

Acknowledgement

The current Risk Analysis Program sponsored by DDESB has been or will be conducting science improvement projects geared to improve both the Quantity-Distance (QD) tables in DODM 6055.09-M and the consequence models in TP-14. Under the leadership of Dr. Josephine Covino of DDESB, the Naval Facilities Engineering & Expeditionary Warfare Center (NAVFAC EXWC) in Port Hueneme, California is executing the Program, which is supported by the primary contractor of the A-P-T Research Inc. in Huntsville, Alabama and the sub-contractor of ACTA in Torrance, California. Additionally, Mr. Robert Conway and Dr. Michael Oesterle of NAVFAC EXWC have been making significant contributions to the Program.

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