Public Risk Criteria and Rationale for Commercial Launch and Reentry

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by

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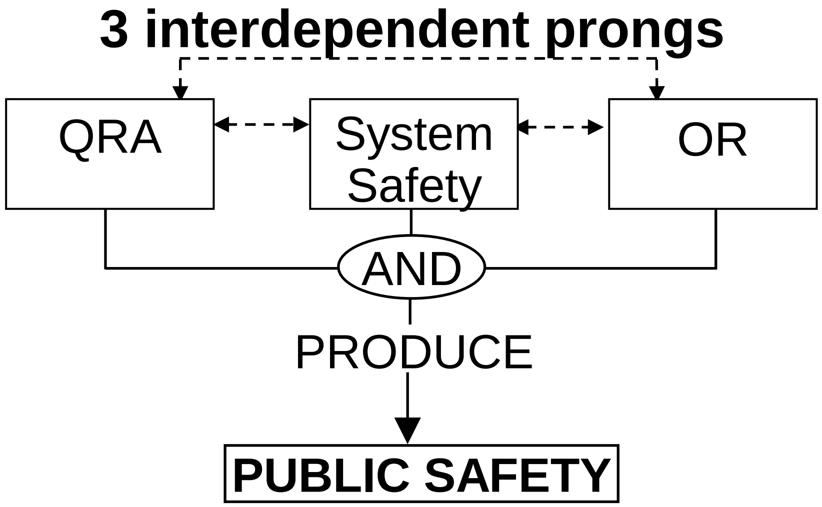
Overview

- Introduction to Launch and Re-entry Safety Risks
- Recommended Safety Goals and Quantitative Criteria
- Rationale
- IAASS Working Group* for benchmarking risk estimates
- In Back-up –
  - Important Definitions
  - Introduction to Launch and Reentry Risk Management

*Note: Experts in the IAASS WG do NOT represent their organization. They speak only on the basis of their own expertise.

Launch and Re-entry Safety Basics

- Primary risks associated with falling debris
  - Large toxic and explosive events (mostly near launch point)
  - Debris risks, especially during re-entry, are often international
- Rigorous safety best practices include
  - System safety process
  - Quantitative risk analysis (QRA)
  - Operational restrictions (OR)
- Important risk mitigations include
  - Controlled re-entry
  - Launch corridors over sparsely populated areas
  - Warning to ships and aircraft for planned debris areas



General Goals of Quantitative Risk Criteria

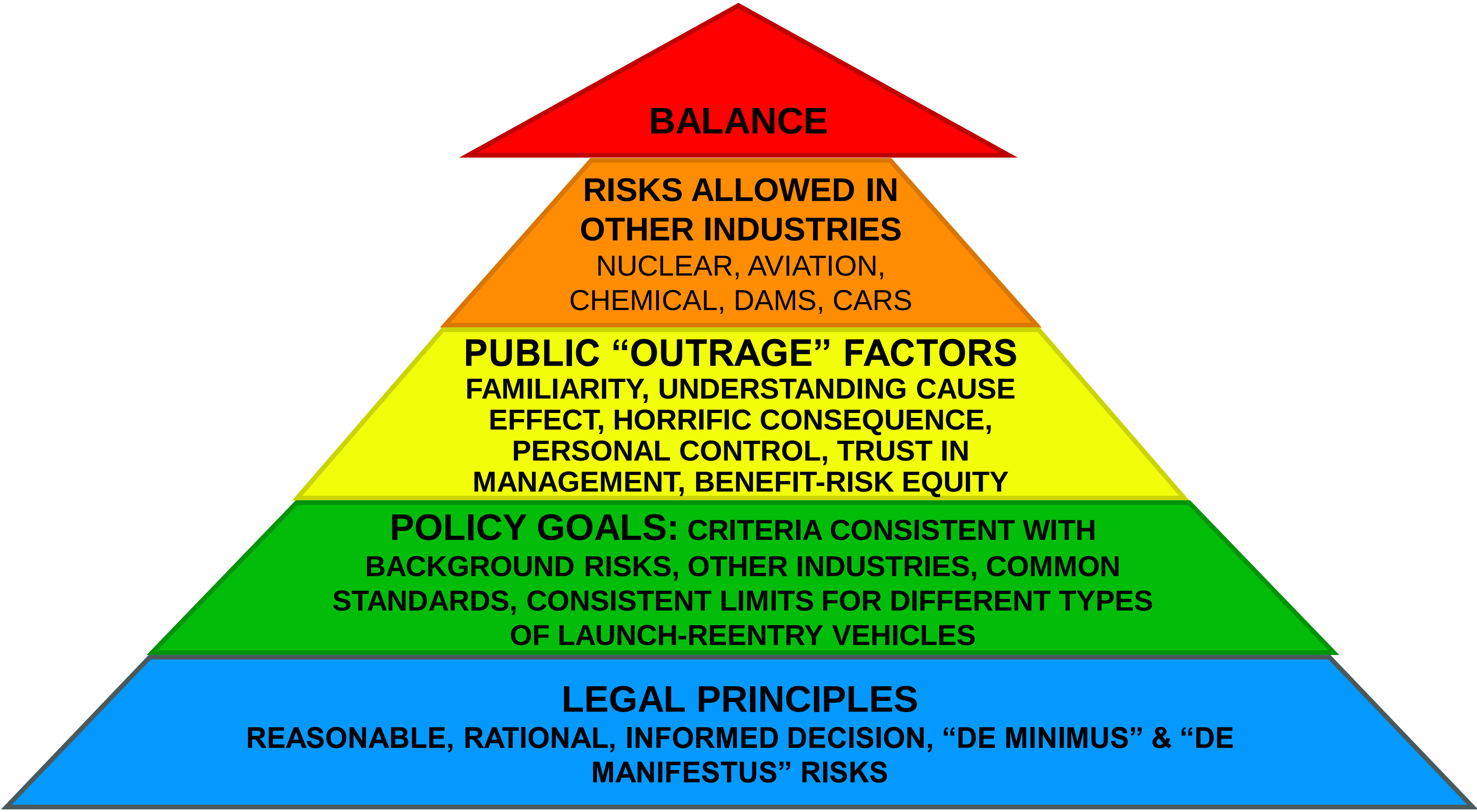
Recommended public risk criteria:

1. **Allow a reasonable fraction of background risks**; specifically a reasonable fraction of the risks to third parties posed by other modes of transport
2. **Consistent with other agencies that regulate public risks,** particularly after accounting for public perceptions and "outrage" factors
3. **Result in no public casualties statistically expected for many years**
4. **Published in advance of any use**
5. **Credible metrics/tools: match benchmark data**

Recommended Quantitative Risk Criteria

1. Maintain individual risk limit 1E-6 maximum Probability of Casualty (PC) per-mission.
2. For annual collective risks, three times lower than conventional aviation (for people on the ground) based on current conditions:
   - Apply equal limits to orbital and suborbital launches,
   - **Limit each launch or reentry mission to a best estimate of 1E-4 Expected Casualties (EC).** This equates to ~1 casualty in 50 years for worldwide space operations.
   - Apply 1E-4 per-mission for each vehicle element (i.e. stage or spacecraft) that returns from orbit.
3. No distinction between domestic and international populations for the public risk limits: equal protection for all members of the public. Continue common practice to allow mission essential personnel ten times higher risks, both as individuals and collectively.

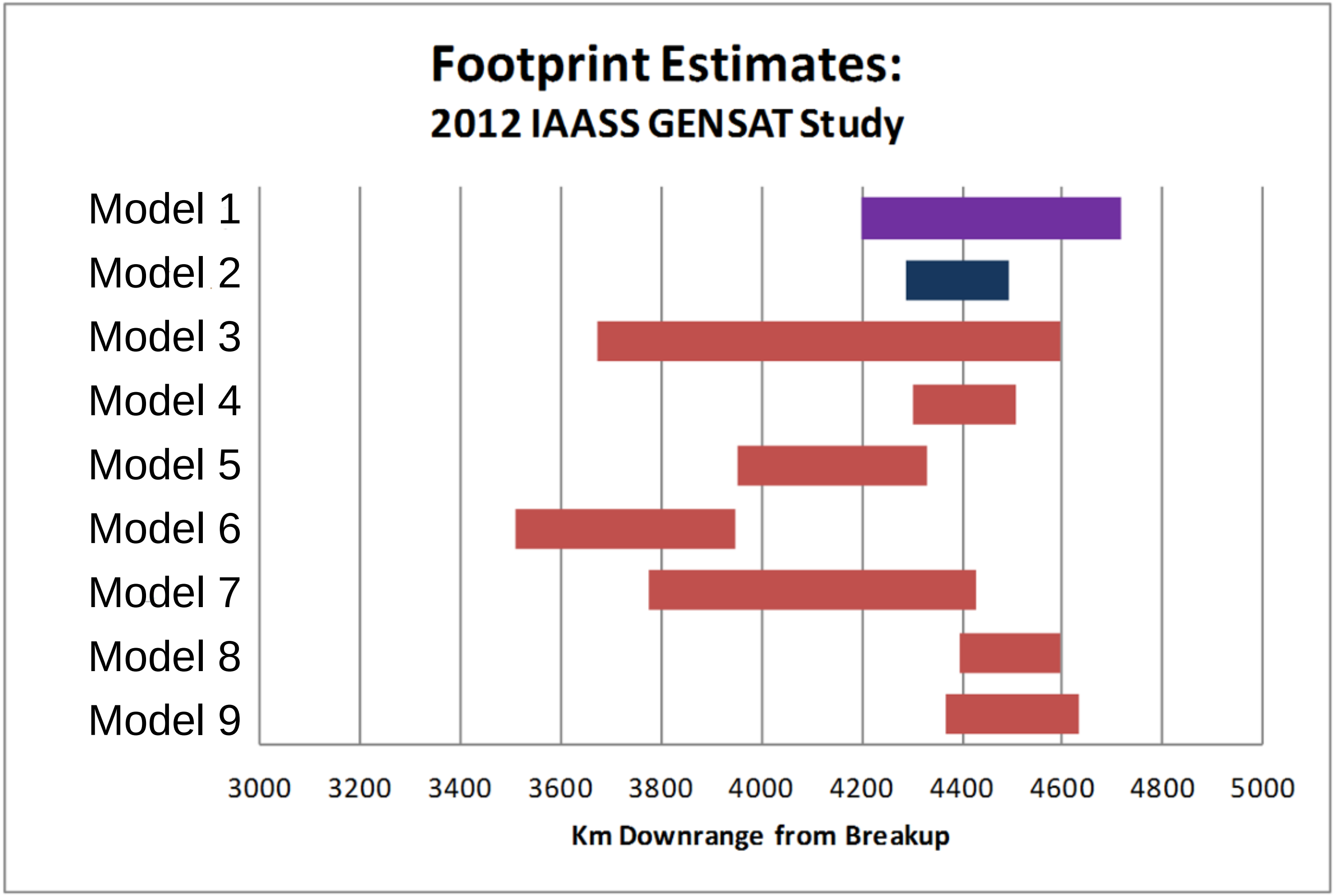
Overview of Risk Criteria Rationale



IAASS Working Group On Public Safety

- **Focus on orbital launch and re-entry events**
  - Account for the general public on land, at sea, and in aircraft
  - Identify input data, definitions, and methods used for risk analyses
  - Sample topics: probability of failure, fragmentation, debris survivability, population data, vulnerability models, casualty areas, debris "footprints"
- **Approach taken to compare risk computational practices**
  - Define benchmark cases, preferably with data from observation of actual events (e.g. Delta II upper-stages, ATV-1, ATV-5)
  - Compare computed results and actual data from a variety of toolsets
- **Objectives**
  - Identify reasons for significant differences and sensitivities
  - Identify modeling uncertainties and which sub-models to improve
  - Provide basis for confidence in estimates
  - Document IAASS "*best practices*" and recommendations, including performance requirements and sample methods

GENSAT Re-entry Case Benchmarking Results



Sample results from models used by US and European agencies

CONCLUSIONS

Considering that launch and re-entry public safety risks are often of international nature, **the IAASS recommends**:

- The **publication by any country** involved in launch and re-entry operations **of their practices for identification, evaluation, and management of quantitative risk criteria**
- The **development of voluntary international guidelines based on best practices for identification and management of quantitative public safety risk criteria** related to launch and re-entry operations
- The **development of voluntary international guidelines and benchmarks for the computation of public risks** to ensure consistency of risk estimates by operators.

Backup Slides

Basic Definitions – Collective Risk

- Expectation of Casualty (EC)
  - Measure of collective risk, not a probability.
  - **Average number of people expected to become casualties.**
  - An EC value of 30E-6 casualties for a given mission means that one million missions of that type would produce a total of 30 casualties on average; equates one casualty on average after 33 missions per year for 1000 years

- Empirical data from NTSB: 1E-6 EC on the ground from each airliner flight from 1984 to 2003 (excluding sabotage)
  - Limit of 100E-6 EC means that a launch may present no more risk to the people on the ground than the 100 airliner flights

Basic Definitions – Individual Risk

- Casualty

  A serious injury or worse: requires overnight hospitalization, including death.

- Probability of Casualty (Pc)
  - Measure of individual risk
  - Answers the question: **“What is my chance of being hurt?”**
  - The chance an individual person of being struck by debris <u>and</u> that debris causing a casualty.
  - The maximum Pc describes the highest risk to any individual from an activity (e.g., launch or reentry).
  - **14 CFR 417.107(b) limits the public to a maximum of 1E-6 Pc**
  - Thus, a launch is not authorized to proceed unless the probability of an individual being a casualty in the riskiest location is no more than one in a million.
  - Individual risk limit determines the minimum size of hazard areas (e.g. where people must be evacuated from near the launch point)

Logic Tree: Major QRA Criteria Decisions

RECOMMENDED OPTION IN GREEN BOX WITH REDLETTERS

APPLY SEPARATE CRITERIA TO LAUNCH AND REENTRY?

YES ⇐ ⇒ NO

- YES: **SEPARATE CRITERIA FOR LAUNCH OR REENTRY (DEFINE EXTENT OF EACH)**
- NO: ONE CRITERION FOR THE COMBINATION OF LAUNCH AND REENTRY

LIMIT TOTAL RISK?

YES ⇐ ⇒ NO

- YES: **SEPARATE CRITERIA TO LIMIT TOTAL RISK FROM LAUNCH OR REENTRY**
- NO: SEPARATE CRITERIA TO LIMIT RISK FROM EACH HAZARD FROM LAUNCH OR REENTRY

INCLUDE SHIPS AND AIRCRAFT IN COLLECTIVE RISK LIMITS?

YES ⇐ ⇒ NO

- SEPARATE CRITERIA TO LIMIT TOTAL RISK FROM LAUNCH OR REENTRY, INCLUDING SHIPS & AIRCRAFT
- **SEPARATE CRITERIA TO LIMIT TOTAL RISK FROM LAUNCH OR REENTRY, EXCLUDING SHIPS & AIRCRAFT**
- SEPARATE CRITERIA FOR EACH HAZARD FROM LAUNCH OR REENTRY INCLUDING SHIPS & AIRCRAFT
- SEPARATE CRITERIA FOR EACH HAZARD FROM LAUNCH OR REENTRY EXCLUDING SHIPS & AIRCRAFT

"Launch Mission" Definition

For the purposes of the public QRA, define the extent of launch missions as follows (consistent with RCC).

- Define a **launch mission to begin with lift-off, end at orbital insertion**, and include impacts from all planned debris released prior to orbital insertion.
  - **Lift-off** occurs during a launch countdown with any motion of the launch vehicle with respect to the launch platform (which includes a carrier aircraft), including any **intentional or unintentional separation from the launch platform**.
  - **Orbital insertion** occurs when the vehicle achieves a **minimum 70 nm (130 km) perigee** based on a computation that accounts for drag.
- Define a **suborbital launch mission as any flight of a suborbital rocket that does not achieve orbital insertion**
  - No reentry mission: can only "reenter" after orbital insertion

"Reentry Mission" Definition

For the purposes of the public QRA, define a reentry mission to include both controlled and uncontrolled:

- A controlled reentry mission **begins with the final commitment to enter the atmosphere** from orbit (or otherwise from outer space) and **ends when all vehicle components** associated with the reentry **come to rest** on the Earth (or are otherwise secured). (E.g. a controlled reentry mission could begin with the final command to commit the vehicle to a perigee below 70 nm and end when all vehicle components come to rest.)
- Use the NASA TS 8719.14 definition of an uncontrolled reentry mission: "the atmospheric reentry of a space structure in which the surviving debris impact cannot be guaranteed to avoid landmasses." **An uncontrolled reentry mission begins when** the object naturally decays to a **perigee below 70 nm** and ends when all vehicle components associated with the reentry come to rest on the Earth (or are otherwise rendered harmless).
- Consistent with various US government standards, the **reentry of upper-stages and payloads are treated as separate reentry missions**.

Overview of Risk Management

Risk management **is** a systematic and logical process to identify hazards and control the risks they pose.

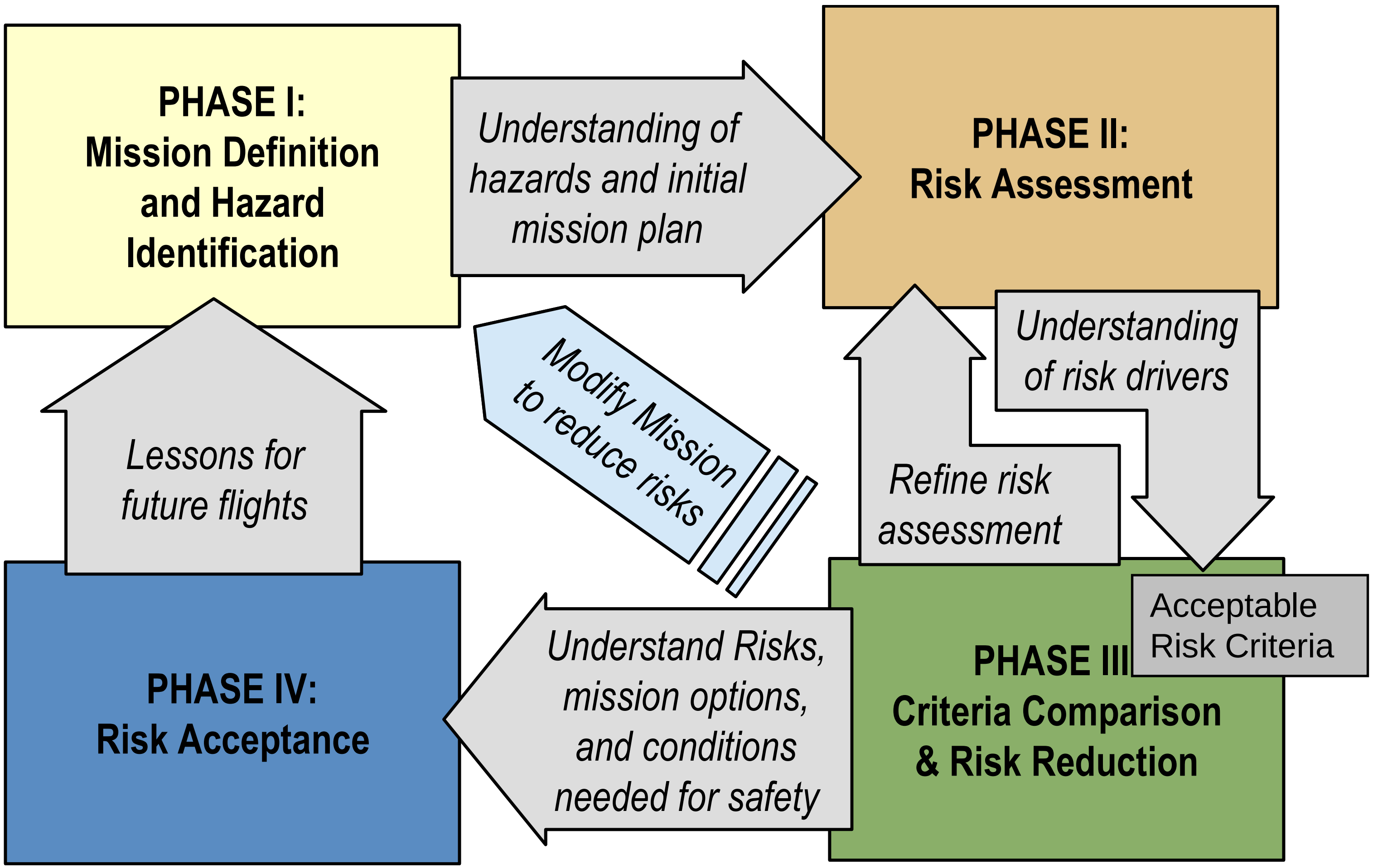


Figure is taken from Range Commanders Council (RCC) 321-07

Specific Goals of QRA and Risk Criteria

1. Ensure public safety and financial responsibility
   - QRAs provide a means to compare the estimated public risks to predefined criteria, as well as information vital to the FAA's determination of sufficient insurance coverage.
2. Understand risk drivers and identify risk reduction measures
3. Understand sources of uncertainty and means to reduce
   - US Nuclear Regulatory Commission has also found that "through use of quantitative techniques, important uncertainties have been and continue to be brought into better focus and may even be reduced compared to those that would remain with sole reliance on deterministic decision-making.
4. "Fully inform" decision-maker: best available data and methods
   - Protection under the US Federal Tort Claims Act (FTCA) requires that the decision-making official be fully advised and informed of the known risks.
5. Provide transparency that facilitates fair access to space
   - The scientific and quantitative nature of a QRA clears the regulatory environment of the vagaries of purely subjective approaches.

Current Formal Regulatory Goals in US

1. **Commensurate with background risk** - The requirements should "accomplish the regulatory objective of ensuring that persons … are not exposed to greater than normal background risk"

2. **Consistent level of protection from all hazards posed by all types of launch and reentry vehicles** - "not expose the public to greater risk than that defined as acceptable by the FAA in other commercial space transportation regulations."

3. **Commonality with the USAF** - "The Air Force and the FAA remain committed to the partnership outlined in the MOA and … developing common launch safety requirements and for coordinating the common requirements."

Influence of Public Perception

- **The lack of clear definitions for important legal terms,** such as “unreasonable” and “trivial” risks specifically, **AND the wide range of risks accepted by regulatory of various industries suggests that the perception of risks by the general public are relevant to both the legal and political ramifications** of launch or reentry accidents and the risk acceptability criteria.
- **Risk perception and tolerability** is highly variable from person to person, and **may depend on “many factors, as opposed to rational judgments based on the likelihood of harm**.”
  - Lay perceptions of risk can vary greatly from those of experts.

Public Outrage Factors

- Experts have identified six factors that "research suggests correlate well with overall levels of public concern" (i.e. outrage factors):
  1. ***Familiarity and experience of the risk*** – People more concerned about risks which are new or with little experience
  2. ***Understanding of the cause-effect mechanism*** – People more concerned if the cause-effect mechanism is unknown, uncertain, or difficult to understand
  3. ***Equity of the consequences of the risk and the benefits*** – People more concerned if they perceive that the effects fall unfairly on a specific group in society
  4. ***Fear of the risk consequences*** – People more concerned if the hazard is particularly horrific: if it involves: long term extreme pain; impacts on future generations; widespread impact; or because the harm (or degree of harm) is unknown or

Public Outrage Factors (2)

- Last two of six factors outrage factors:
  5. ***Control of the risk*** – People more concerned if they feel they have no control over the risks involved; and,
  6. ***Trust in risk management*** – People more concerned if, without personal control over the risks, they do not trust those responsible for managing the risk on their behalf.
- Outrage rating for launch/re-entry public risks? Moderate
  1. ***Familiarity and experience of the risk*** – Moderate, as long as people view the risks as similar to conventional aircraft
  2. ***Understanding of the cause-effect mechanism*** – Low: good understanding of debris risks, but less so for toxic;
  3. ***Equity of the consequences of the risk and the benefits*** – High: benefits likely perceived as going to few
  4. ***Fear of the risk consequences*** – Modest, unless catastrophe
  5. ***Control of the risk*** – High outrage for third parties at risk
  6. ***Trust in management*** – Unknown now, but poor after accident

Risks Tolerated in Other Industries

- Wide range of annual risks tolerated:
  - Annual risk of an average individual dying in an automobile accident in the US was about 1.5E-4 in 2006;
    - Public not demanding further reductions
  - Individual risk limits used to regulate nuclear power are far lower than risks from an automobile accident.
- Industries with high outrage factors (e.g. nuclear power) have relatively stringent & explicit risk limits
  - Compared to the third party risk from cars, nuclear power risks are relatively unfamiliar, hard to understand in terms of cause and effect, likely to involve long term extreme pain, beyond personal control, managed by people that may be perceived as not entirely trustworthy, and with unequally distributed benefits provided.
- Suggests one criteria inappropriate for all industries

Risks Tolerated in US Nuclear Industry

- **Nuclear Regulatory Commission (NRC) qualitative safety goals are as follows:**
  - "*Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that **individuals bear no significant additional risk to life and health**.*
  - *Societal risks to life and health from nuclear power plant operation should be **comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks**.*"

Risks Tolerated in US Chemical Industry

- No US national or state-wide criteria set
- Some counties have published a risk acceptability criteria: County of Santa Barbara (CSB)
  - "**acute risk**: [the] chance of fatality or serious injury due to a single, short-term, involuntary exposure," and "**do not address issues of chronic risks**."
  - **Protect against serious injuries as well as fatalities**
  - **Criteria given as a risk profile *for each facility* that equates to an annual limit of 2.2E-3 EC in the absence of "substantial evidence** in the record" showing "that the benefits of the proposed development exceed its adverse impacts to public safety,"
  - **The CSB catastrophe aversion guidelines are more stringent** than the RCC provisional criterion for launch and reentry.

Risks Tolerated in US Dam Industry

- Department of Interior (DOI) guidelines for dam safety decision-making
  - **Goal: keep the risks posed by dam failures below those posed by auto accidents and disease**
    - Effectively seeks to limit the annual individual risk to a level below 1E-4 probability of fatality (P_F)
  - **Uses 0.01 and 0.001 annual expected fatalities as important threshold values for public risk acceptability criteria**

  - DOI, Bureau of Reclamation, *Guidelines for Achieving Public Protection in Dam Safety Decision-Making*, Denver Colorado, June 15, 2003

Differences Between CST and Dam Risks

- Same six reasons justify a higher degree of conservatism in the risk criteria for ST compared to those used for dam safety decision-making.
- Also, the outrage factors for CST are obviously higher than those for dam management.
  - Specifically people are expected to be more tolerant of the risks posed by floods, which are likely to be perceived as
    - **Familiar**
    - **Natural**
    - **Fairly distributed**
  - In contrast to accidents/risks from CST activities, which are
    - **Exotic**
    - **Man-made**
    - **Likely to capture a great deal of media attention**

Risk from Over Flight of Conventional Aircraft

- The RCC, the USAF, an American National Standard, the Commonwealth of Australia, and the original act of Congress for the establishment of the ER have all **identified the risk posed by conventional aircraft as an important benchmark for the acceptable risk** from launch vehicles
  - "**Should present no greater risk to the general public than that imposed by the over flight of conventional aircraft**."
- Previous studies **showed**:

1. **Risk to people near airports also equates to more than the annual goal of 0.003 EC from launch and reentry**
2. **Risk from an average commercial transport flight is 1E-6 EC**

Differences Between Aviation and Space Transportation (ST)

- A 1971 USAF study of acceptable risk for launch "**the important difference between aircraft and missile operations is the degree of public acceptance of accidents.**"
- The rationale for the annual EC limit for ST to be ~3x lower than the risks posed by over-flight of conventional aircraft:
  1. **Different response to aviation and launch accidents**
  2. **Third party casualties especially damaging to ST industry: much longer return to flight times are typical for ST**
  3. **More "outrage" factors than aviation**
  4. **Dramatically different accident rates**
  5. **Inherent risks and complexities with spaceflight**
  6. **ST is in its infancy not a mature transport industry**
  7. **Higher per-mission limits would be unprecedented**

Balance and Common Standards for Commercial, Civil, and Military ST

- Launch or reentry vehicles **cannot be fully tested without flight of the integrated vehicle**.
- The **hazards from orbital flight tests cannot be contained**, so public risk is inherent and inevitable in advancing the state of the art in launch and reentry technologies.
- **New vehicles are likely** in the ST industry for the foreseeable future.
- Authorities must strike **a balance to allow advancement of ST technologies, but maintain an excellent safety record or risk shackling the industry by overreaction to a future accident**.
- Adopting **per mission limits that are as high as those widely accepted for U.S. civil and military launch and reentry is a reasonable means to allow the industry to advance.**
- Limits at higher (unprecedented) levels risks an accident that could cripple the industry in the short term and shackle industry for years.

Findings About Launch and Reentry Risks

- **Congressional findings**
  - “Space transportation is **inherently risky**…”
  - Space transportation is “**vital to the Nation's economic well-being and national security**”
  - Congress acknowledged that some risk is acceptable
- **Columbia Accident Investigation Board Findings**
  - “Building and launching rockets is still **a very dangerous business, and will continue to be so for the foreseeable future** while we gain experience at it. It is unlikely that launching a space vehicle will ever be as routine an undertaking as commercial air travel.”
  - “Throughout the Columbia accident investigation, the Board has commented on the widespread but erroneous perception of the Space Shuttle as somehow comparable to civil or military air transport. They are not comparable; **the inherent risks of spaceflight are vastly higher**, and our experience level with spaceflight is vastly lower.”