NASA Activities in Risk Assessment

NASA Project Management Conference

March 30-31, 2004

Michael G. Stamatelatos, Ph.D.,Director
Safety and Assurance Requirements Division
Office of Safety and Mission Assurance
NASA Headquarters

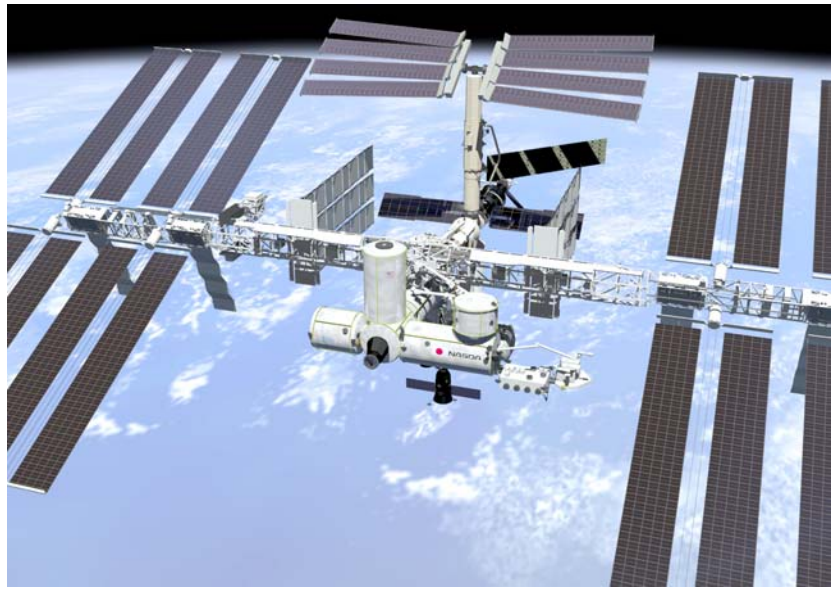
NASA is a Pioneer and a Leader in Space; Therefore Its Business Is Inherently Risky

Space Transportation

- Space Shuttle
- Orbital Space Plane

International Space Station

- Safe assembly and operation



Our Goal

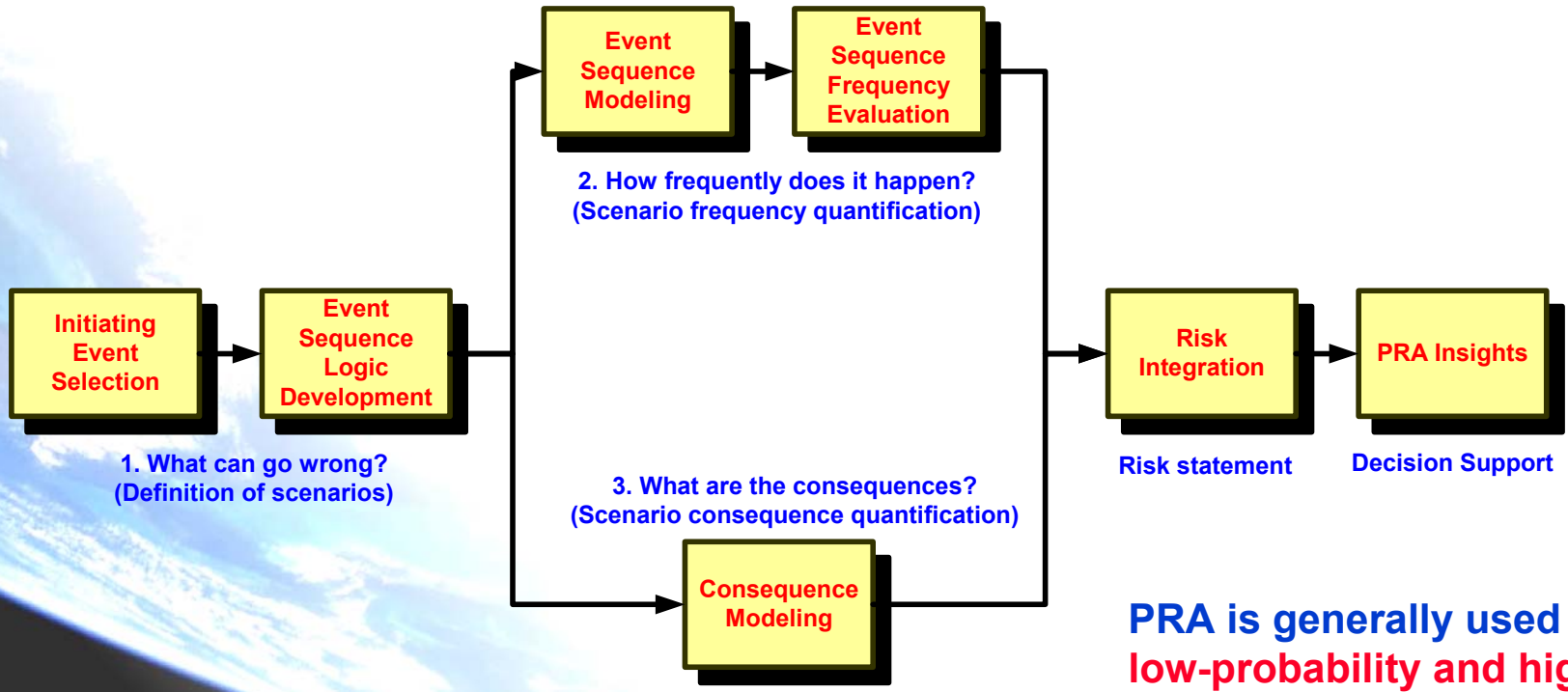
- ***Improve risk awareness in the Agency***
  - *Conduct PRA training for line and project managers and for personnel*
- ***Develop a corps of in-house PRA experts***
- ***Transition PRA from a curiosity object to baseline method for integrated system safety, reliability and risk assessment***
- ***Adopt organization-wide risk informed culture***
  - *PRA to become a way of life for safety and technical performance improvement and for cost reduction*
  - *Implement risk-informed management process*

Probabilistic Risk Assessment (PRA) Answers Three Basic Questions

Risk is a set of triplets that answer the questions:

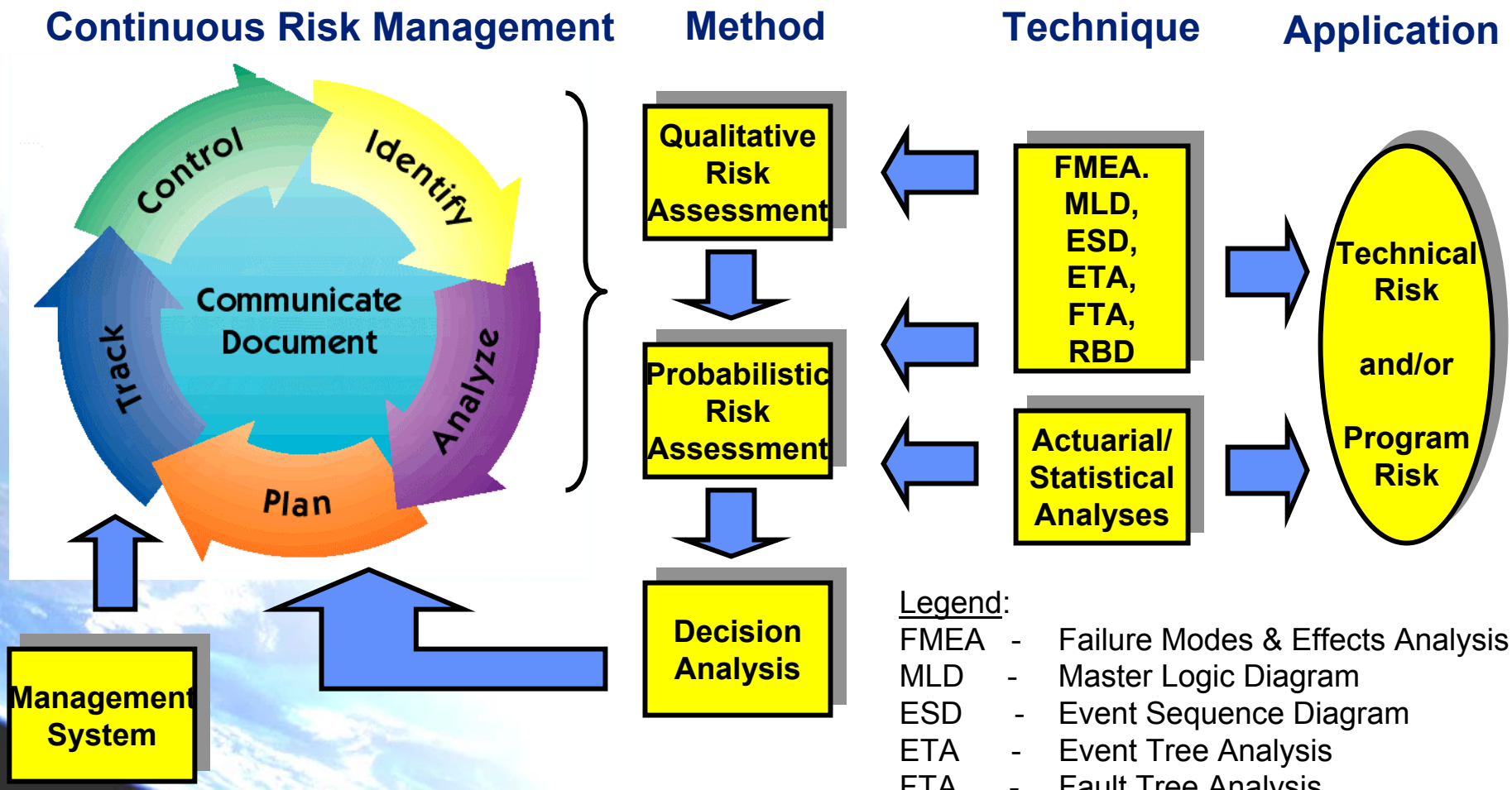
1) **What can go wrong? (accident scenarios)**
2) **How likely is it? (probabilities)**
3) **What are the consequences? (adverse effects)**

Kaplan & Garrick, *Risk Analysis,* 1981



PRA is generally used for low-probability and high-consequence events

Relationship Between Risk Management and Probabilistic Risk Assessment (PRA)



Legend:

FMEA - Failure Modes & Effects Analysis
MLD - Master Logic Diagram
ESD - Event Sequence Diagram
ETA - Event Tree Analysis
FTA - Fault Tree Analysis
RBD - Reliability Block Diagram

NASA Risk Management and Assessment Requirements

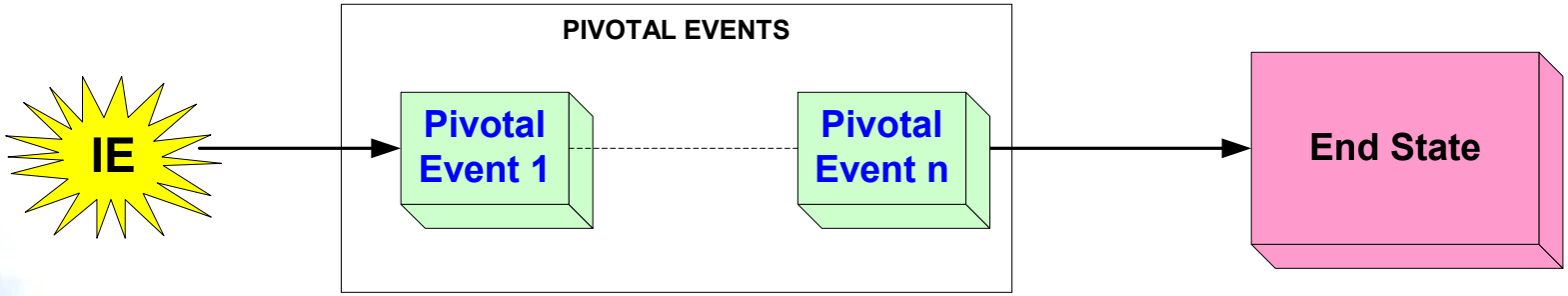
- ***NPG 7120.5A, NASA Program and Project Management Processes and Requirements***
  - *The program or project manager shall apply risk management principles as a decision-making tool which enables programmatic and technical success.*
  - *Program and project decisions shall be made on the basis of an orderly risk management effort.*
  - *Risk management includes identification, assessment, mitigation, and disposition of risk throughout the PAPAC (Provide Aerospace Products And Capabilities) process.*
- ***NPG 8000.4, Risk Management Procedures and Guidelines***
  - *Provides additional information for applying risk management as required by NPG 7120.5A.*
- ***NPG 8705.x (draft) PRA Application Procedures and Guidelines***
  - *Pro*
    progra

How Does PRA Help Safety?

Provides a basis for risk reduction through:

1. ***Accident/Mishap Prevention***
2. ***Accident/Mishap Consequence Mitigation***

The Concept of an Accident Scenario



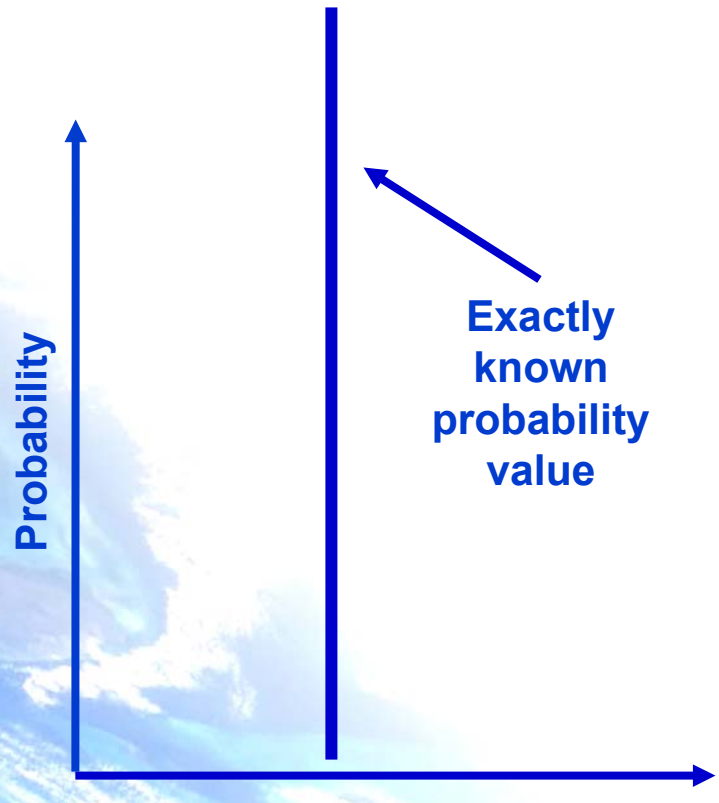
The perturbation

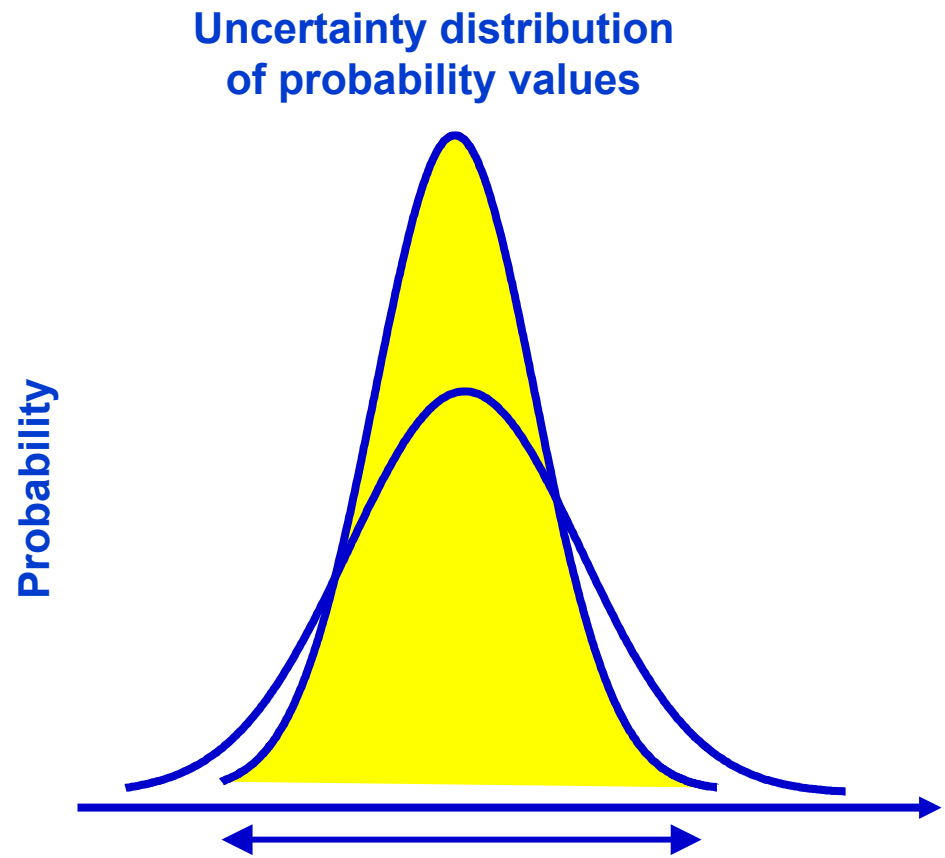
- Mitigative
- Aggrevative

Detrimental consequence of interest (Quantity of intereset to decision-maker)

Risk Scenario is a string of events that (if they occur) will lead to an undesired end state.

Exact vs. Uncertain Probabilities





A narrower range means a more precise knowledge of the distribution, or less uncertainty

Quantification of Uncertainty

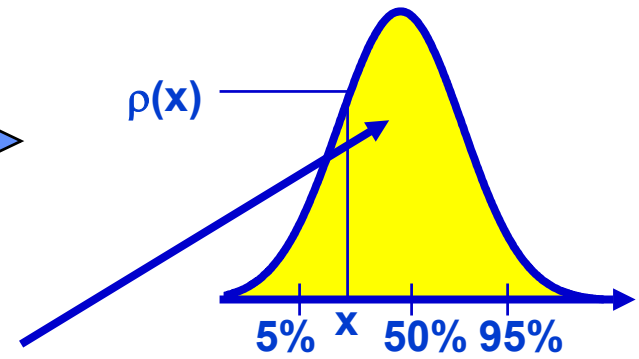
Probability density function,
e.g., probability of LOCV

Uncertainty Distribution:

P(x) is the probability (or x^{th} percentile confidence) that the result value is x

median is the 50th percentile

P(x) is area under curve between 0 and x



Median

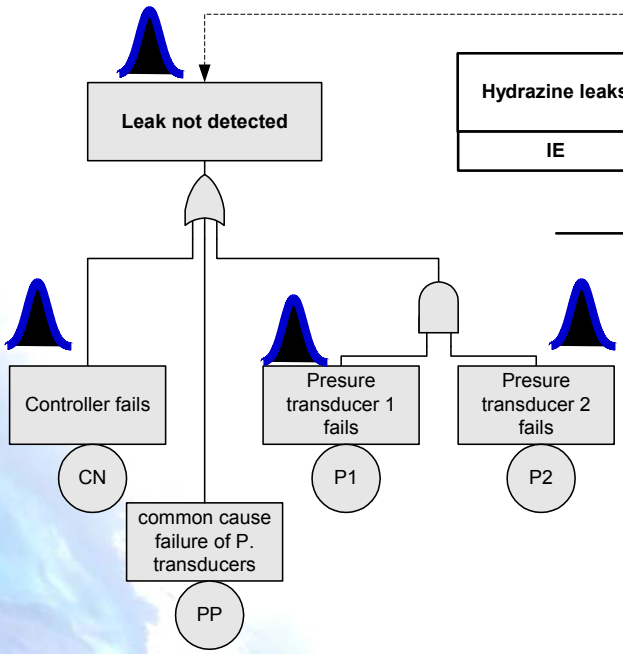
Uncertainty Range:

Uncertainty range (spread) from the 5th to the 95th percentile

5th percentile **95th percentile**

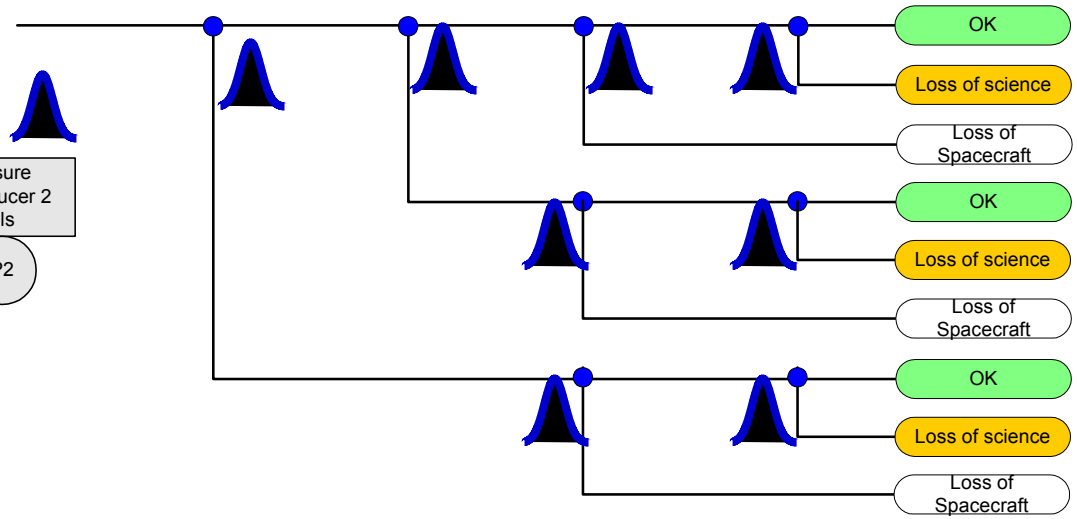
Uncertainty (confidence) range

Event- and Fault-Tree Scenario Modeling



Fault tree

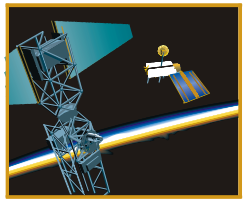
Hydrazine leaks	Leak detected	Leak isolated	No damage to flight critical avionics	No damage to scientific equipment	End state
IE	LD	LI	A	S	



Event tree

PRA Methodology Synopsis

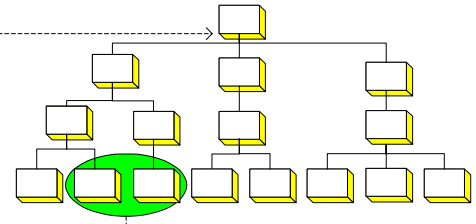
Inputs to Decision Making Process



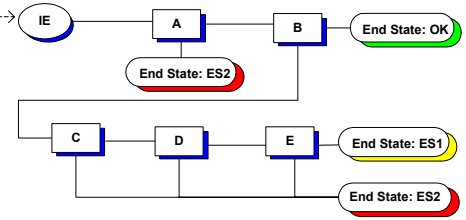
End State: ES1

End State: ES2

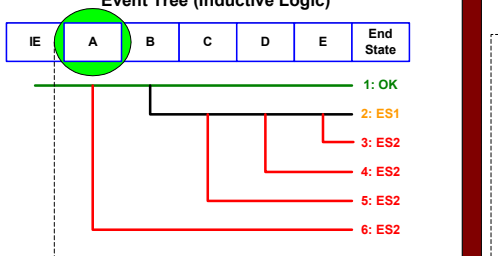
Master Logic Diagram (Hierarchical Logic)



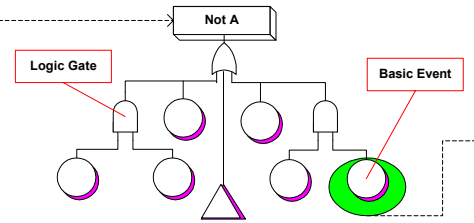
Event Sequence Diagram (Logic)



Event Tree (Inductive Logic)



Fault Tree (Logic)



One to Many Mapping of an ET-defined Scenario

NEW STRUCTURE

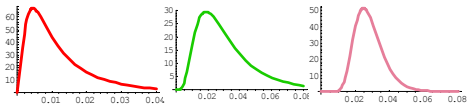
- Internal initiating events
- External initiating events
- Hardware components
- Human error
- Software error
- Common cause
- Environmental conditions
- Other

One of these events

AND

one or more of these elementary events

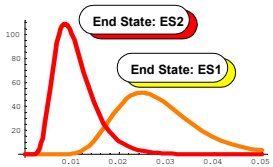
Probabilistic Treatment of Basic Events



Examples (from left to right):
Probability that the hardware x fails when needed
Probability that the crew fail to perform a task
Probability that there would be a windy condition at the time of landing

The uncertainty in occurrence of an event is characterized by a probability distribution

Model Integration and Quantification of Risk Scenarios



Integration and quantification of logic structures (ETs and FTs) and propagation of epistemic uncertainties to obtain

- minimal cutsets (risk scenarios in terms of basic events)
- likelihood of risk scenarios
- uncertainty in the likelihood estimates

Risk Results and Insights

- Displaying the results in tabular and graphical forms
- Ranking of risk scenarios
- Ranking of individual events (e.g., hardware failure, human errors, etc.)
- Insights into how various systems interact
- Tabulation of all the assumptions
- Identification of key parameters that greatly influence the results
- Presenting results of sensitivity studies

LOGIC MODELING

PROBABILISTIC

What Decision Types Can PRA Support?

- ***Safety improvement** in design, operation, maintenance and upgrade (throughout life cycle);*
- ***Mission success enhancement;***
- ***Performance improvement; and***
- ***Cost reduction for design, operation and maintenance***

For all these areas of application, PRA can help:

- **Identify leading risk contributors and their relative values**
- **Indicate priorities for resource allocation**
- **Optimize results for given resource availability**

Areas of PRA Application at NASA

- *In Design and Conceptual Design (e.g., Crew Exploration Vehicle, Mars missions, Project Prometheus)*
- *For Upgrades (Space Shuttle)*
- *For Development/construction/assembly (e.g., International Space Station)*
- *When there are requirements for Safety Compliance (e.g., nuclear missions like Mars '03; Project Prometheus, Mars Sample Return)*

NASA Procedural Requirement NPR 8705
(Draft)

CONSEQUENCE CATEGORY	CRITERIA / SPECIFICS		NASA PROGRAM/PROJECT (Classes and/or Examples)	PRA SCOPE
Human Safety and Health	Public Safety	Planetary Protection Program Requirement	Mars Sample Return Missions	**F**
		White House Approval (PD/NSC-25)	Nuclear Payloads (e.g., Cassini, Ulysses, Mars 2003)	**F**
		Space Missions with Flight Termination Systems	Launch Vehicles	**F**
	Human Space Flight		International Space Station	**F**
			Space Shuttle	**F**
			Orbital Space Plane/Space Launch Initiative	**F**
Mission Success (for non-human rated missions)	High Strategic Importance		Mars Program	**F**
	High Schedule Criticality		Launch Window (e.g., planetary missions)	**F**
	All Other Missions		Earth Science Missions (e.g., EOS, QUICKSCAT)	**L/S**
			Space Science Missions (e.g., SIM, HESSI)	**L/S**
			Technology Demonstration/Validation (e.g., EO-1, Deep Space 1)	**L/S**

PRA Scope Legend: F = Full

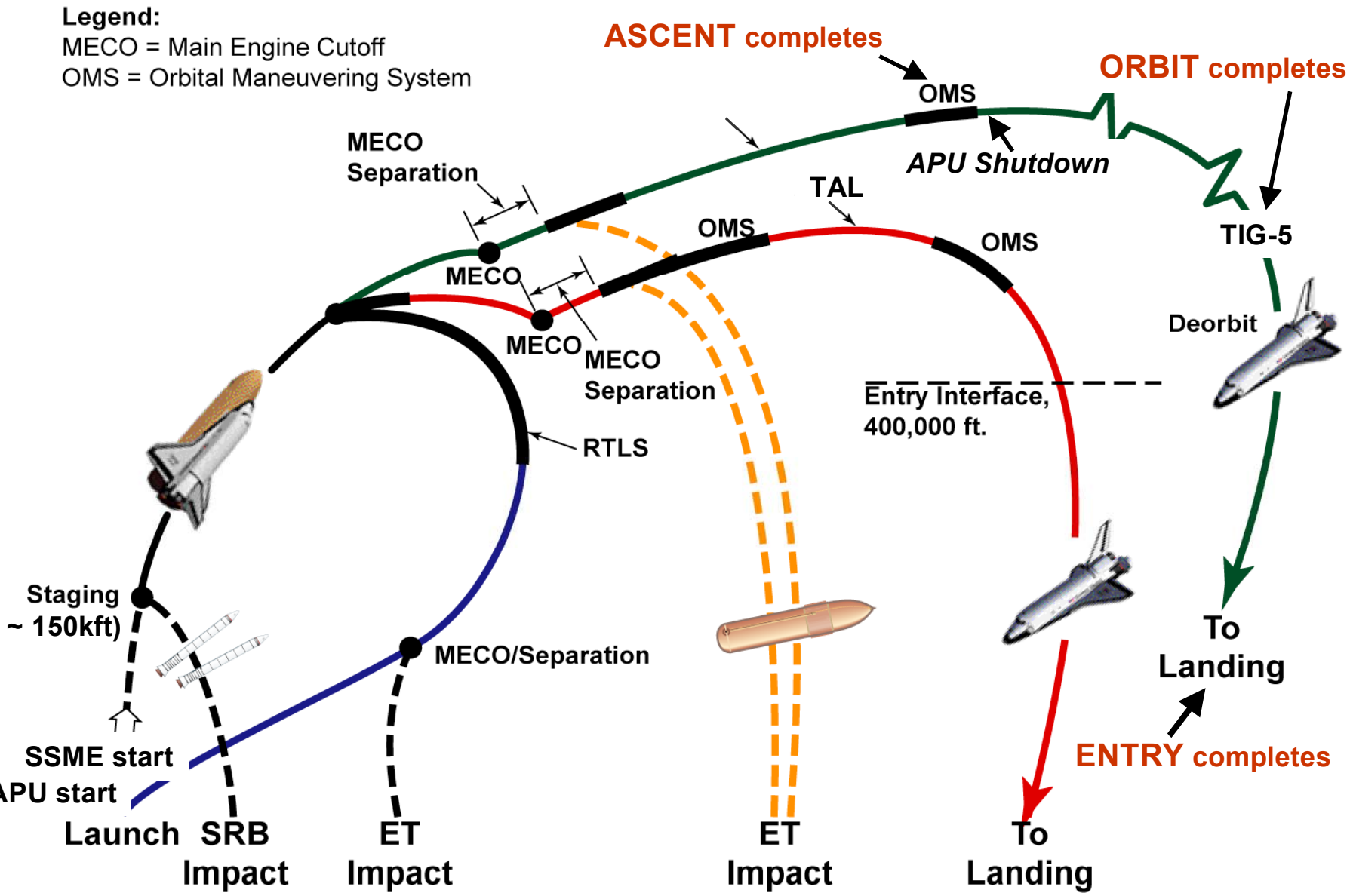
F = Full scope; L/S = Limited or Simplified

NASA Special PRA Methodology Needs

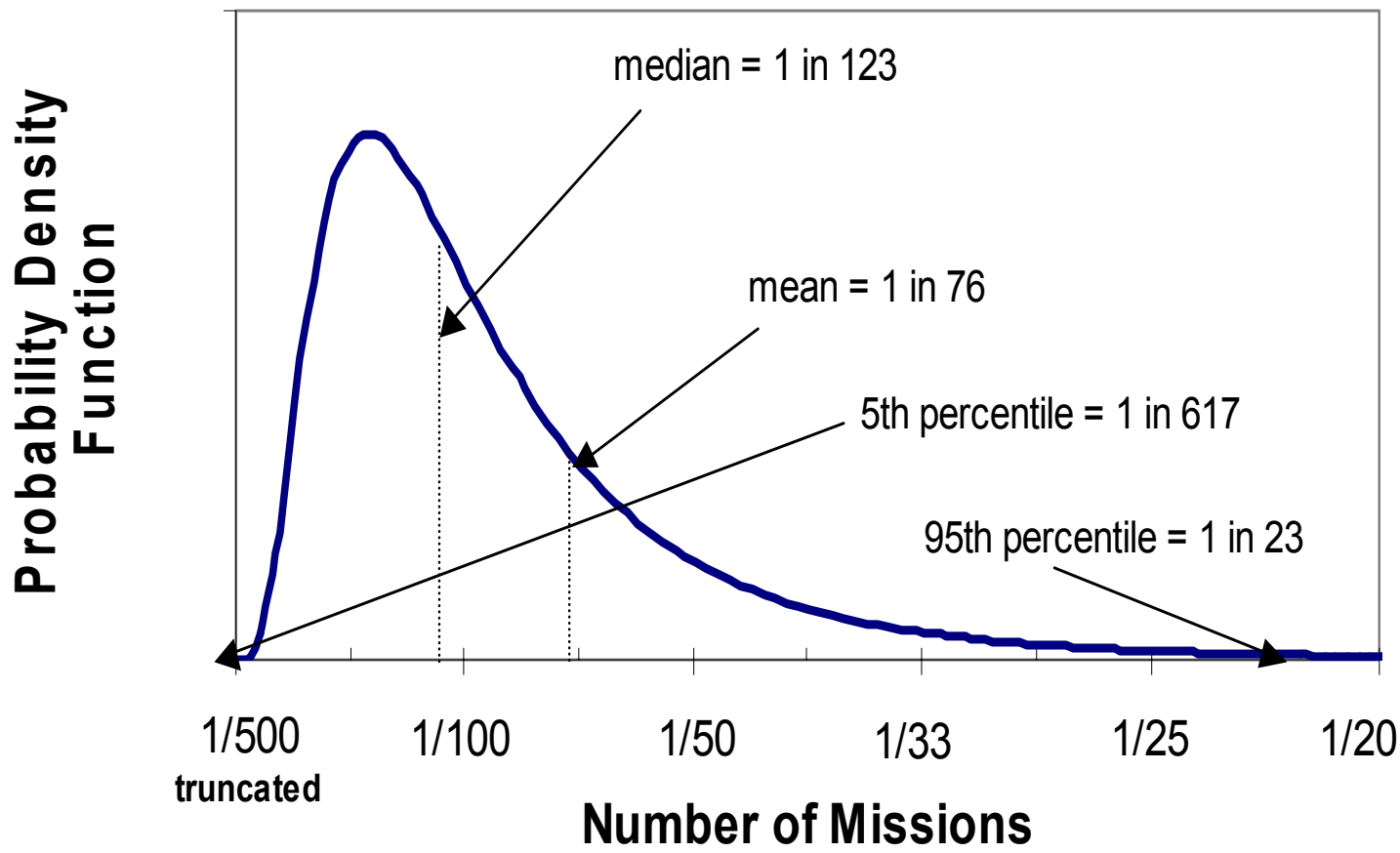
- ***Broad range of programs*: Conceptual non-human rated science projects; Multi-stage design and construction of the International Space Station; Upgrades of the Space Shuttle**
- ***Risk initiators* that vary drastically with type of program**
- ***Unique design and operating environments* (e.g., microgravity effects on equipment and humans)**
- ***Multi-phase* approach in some scenario developments**
- ***Unique external events* (e.g., micro-meteoroids and orbital debris)**
- ***Unique types of adverse consequences* (e.g., fatigue and illness in space) and associated *databases***
- ***Different quantitative methods for human reliability* (e.g., astronauts vs. other operating personnel)**
- ***Quantitative methods for software reliability***

Space Shuttle Probabilistic Risk Assessment

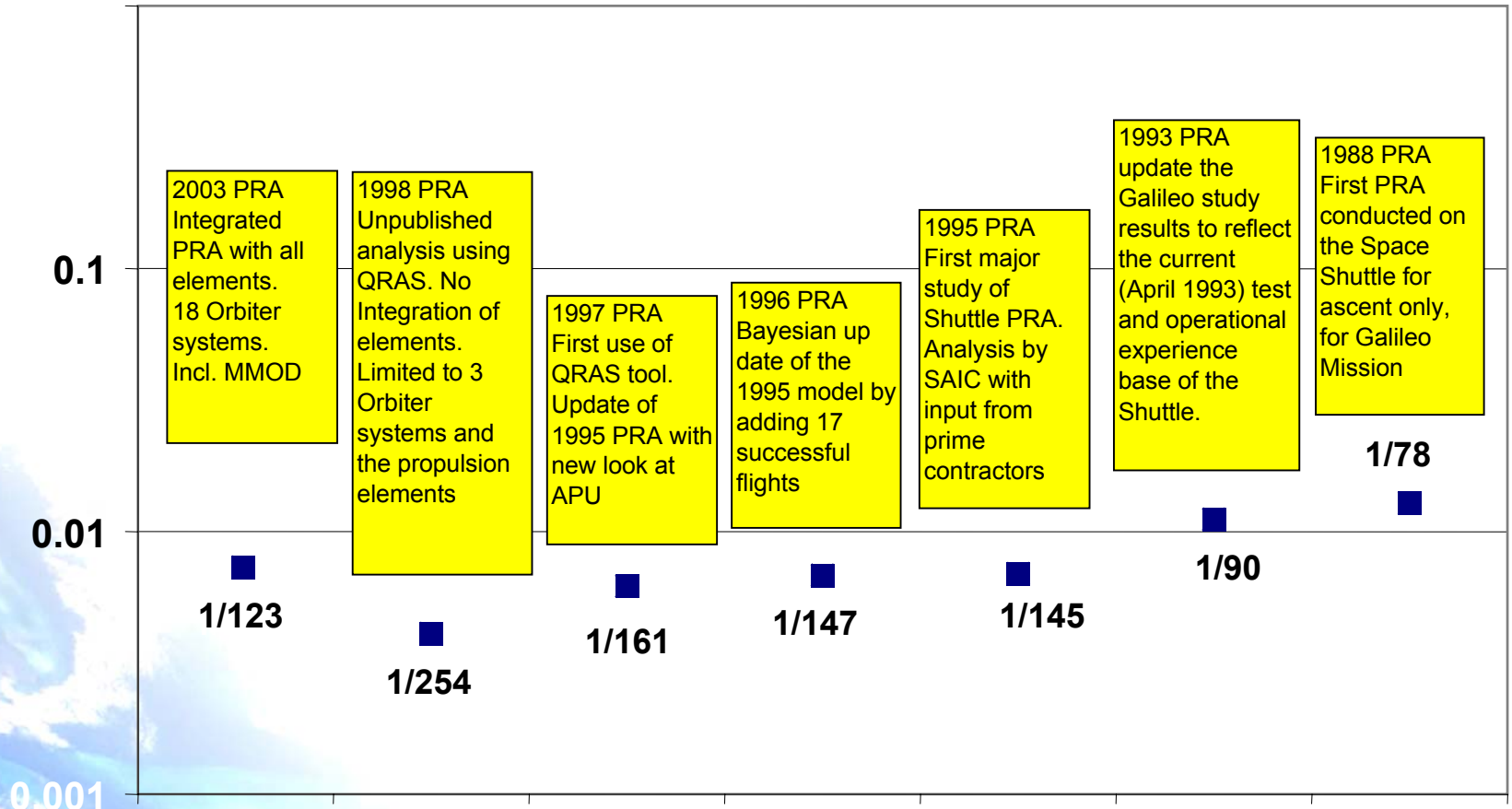
STS Nominal Mission Profile



Current Shuttle PRA Results for LOCV (provisional)



Summary of Shuttle PRA Historical Results



Annual Voluntary Risks in Some Sports - Comparable in Magnitude to Shuttle Risk

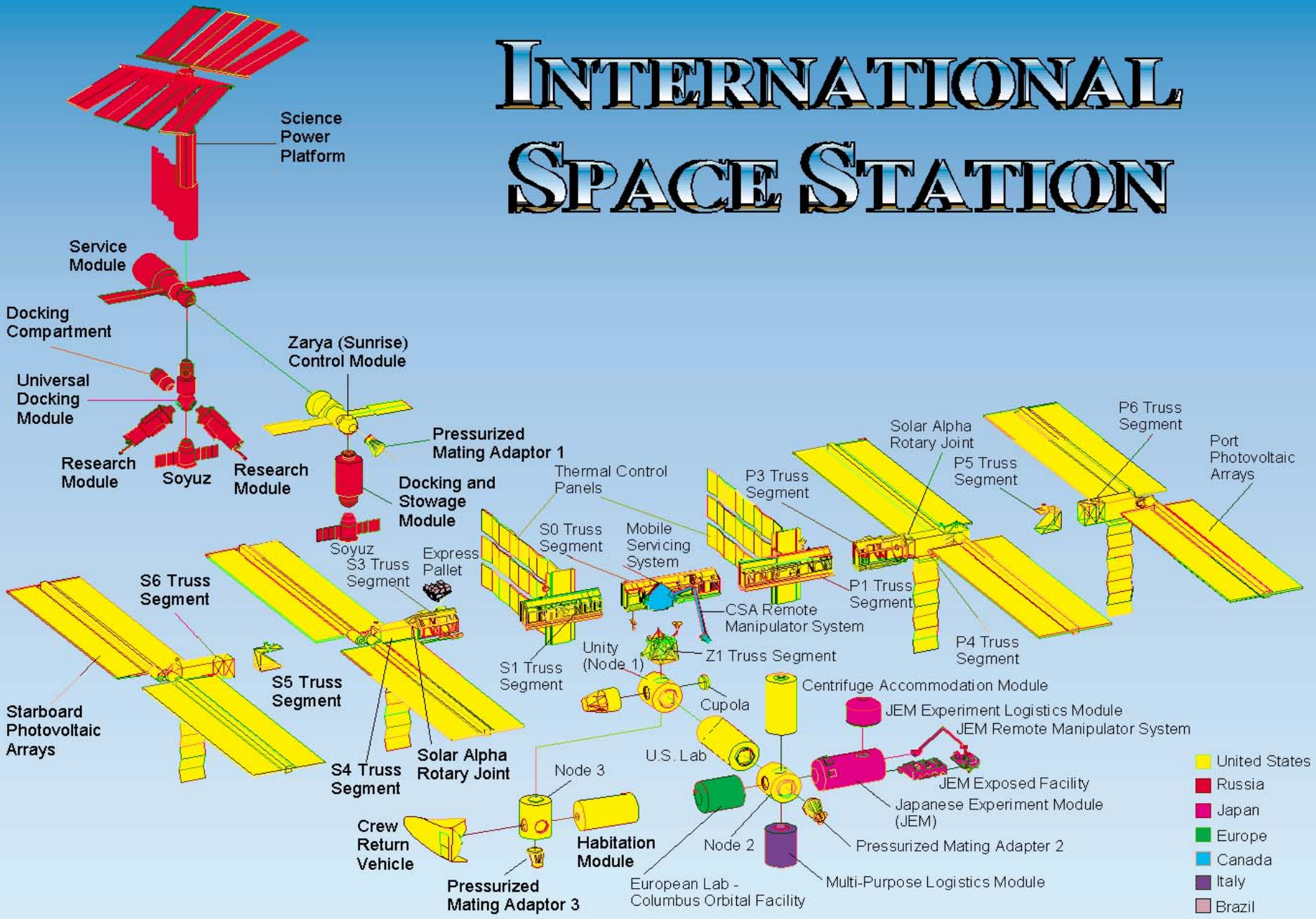
• *Professional stunting*	*1/100*
• *Dedicated mountain climbing*	*1/167*
• *Air show/air racing and acrobatics*	*1/200*
• *Amateur flying in home-built aircraft*	*1/333*
• *Experienced whitewater boating*	*1/370*
• *Sport parachuting*	*1/500*

Source: R. Wilson and E. Crouch, Risk-Benefit Analysis, Harvard University Press, 2001

International Space Station (ISS) PRA

- **1999 -- The NASA Advisory Council recommended, the NASA Administrator concurred, and the ISS Program began a PRA.**
  - **The modeling will be QRAS-compatible.**
  - **First portion of PRA (through Flight 7A) - delivered in Dec. 2000; Second portion (through Flight 12A) delivered in July 2001.**

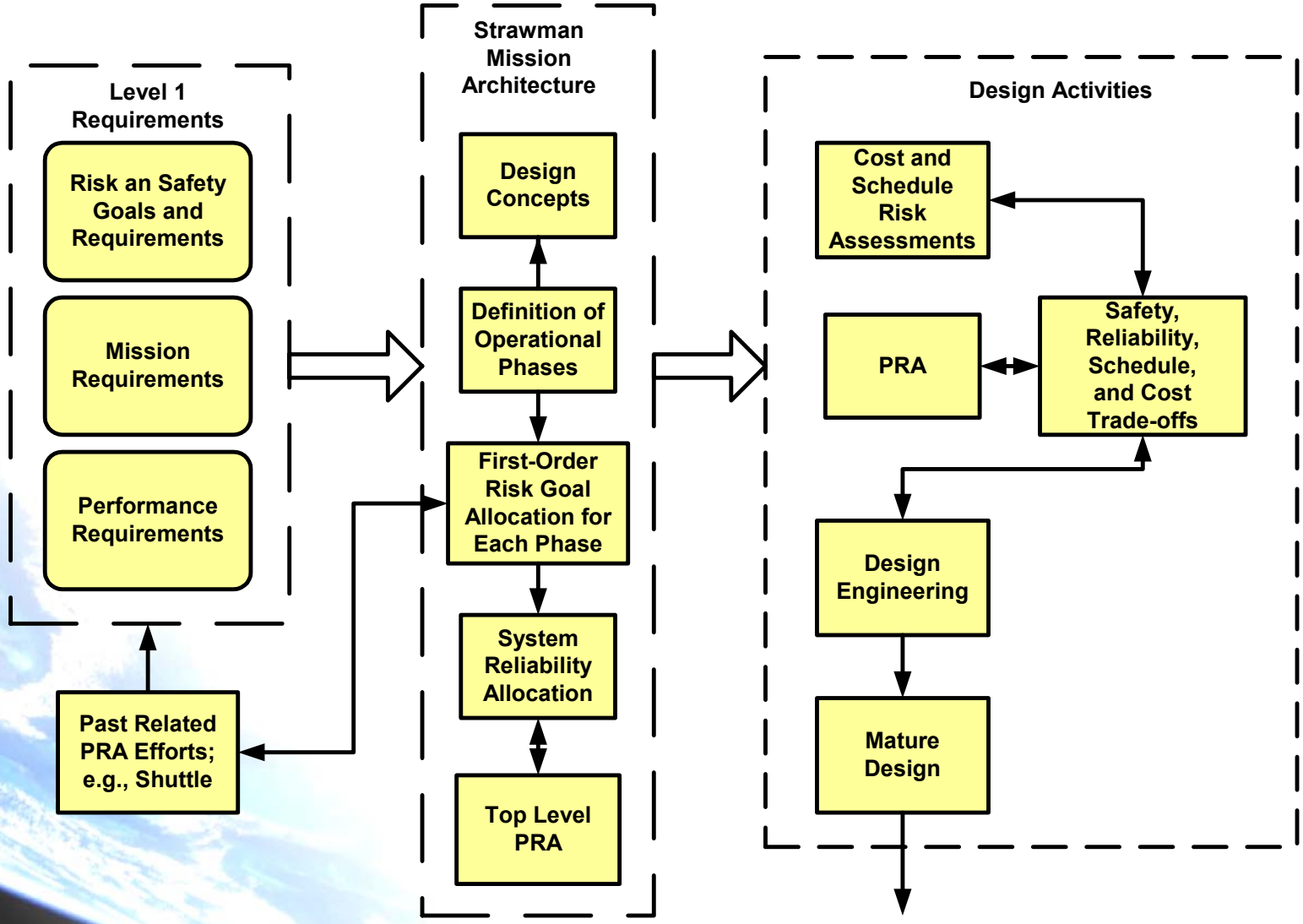
International Space Station



Important ISS PRA Findings

- **MMOD: lead contributor to loss of station (LOS) risk**
- **Illness in space: lead contributor to loss of crew (LOC) risk**

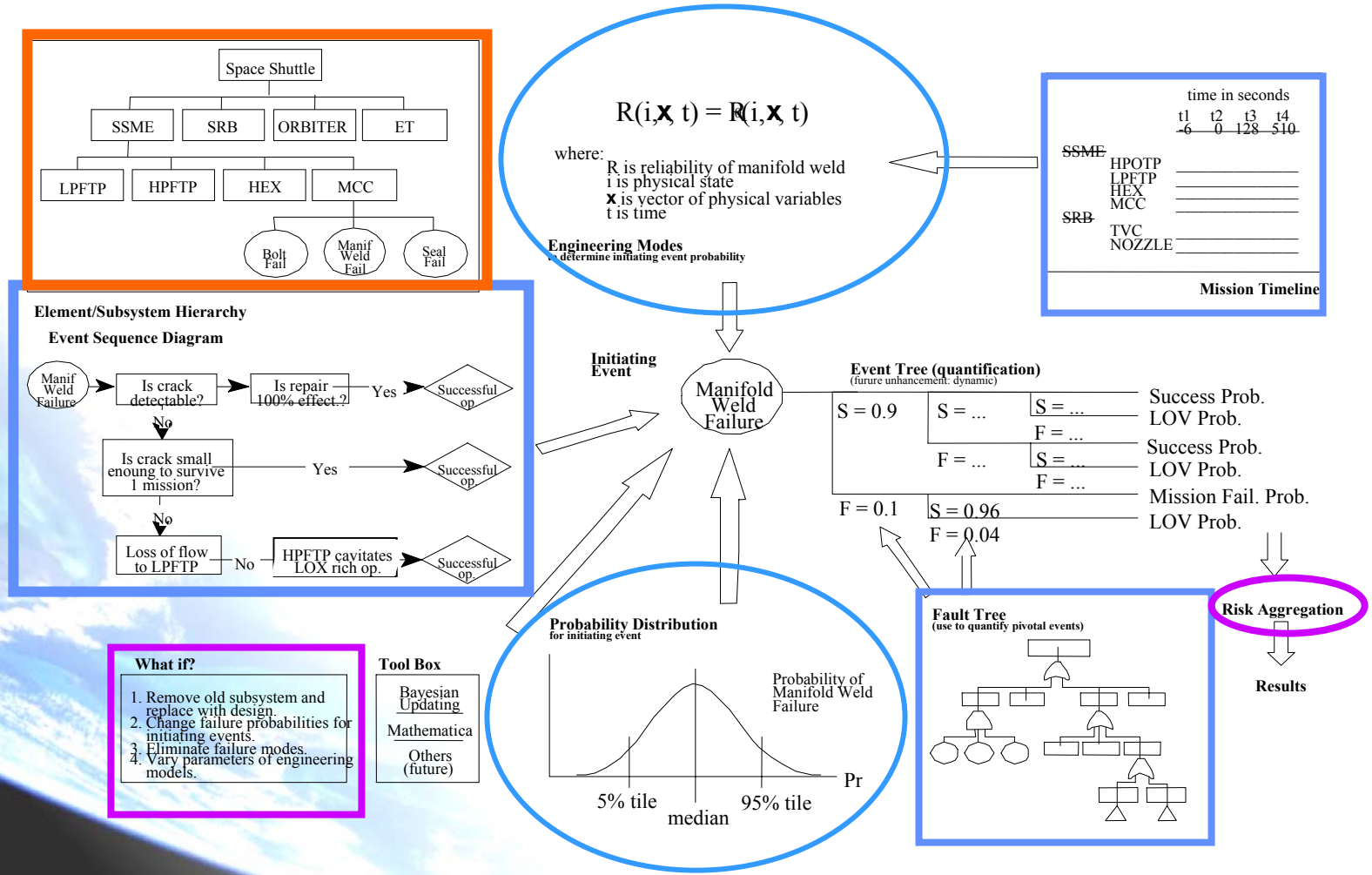
Approach to PRA for NASA Top-Level Designs (e.g., Crew Exploration Vehicle)



Advanced PRA Methods or Tools

- ***QRAS*** ***(Quantitative Risk Assessment System) – a state of the art integrated PRA computer program***
- ***Galileo/ASSAP*** ***– Dynamic fault tree program***
- ***Software reliability*** ***methodology for use in PRA***
- ***External event methodology for*** ***micro-meteoroid and orbital debris (MMOD)*** ***risk into the overall risk assessment***

QRAS 1.7 Is Being Commercialized



In Summary, We Plan to

- ***Continue to improve risk awareness***
  - *Conduct PRA training for line and project managers and for personnel*
- ***Continue to develop a corps of in-house PRA experts***
- ***Transition PRA to baseline method for safety assessment***
- ***Integrate risk assessment with system safety and reliability assessment***
- ***Adopt organization-wide risk informed culture***
  - *PRA to become a way of life for safety and technical performance improvement and for cost reduction*
  - *Implement risk-informed management process*