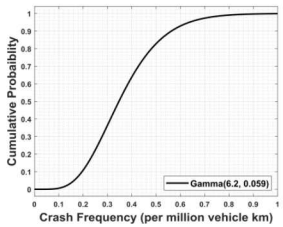
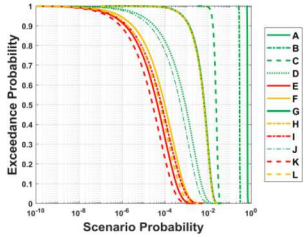
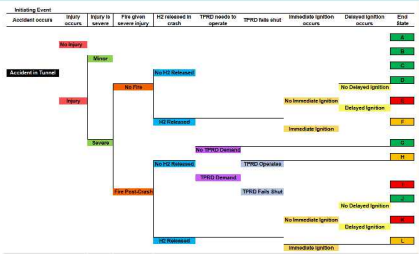
SAND2019-4300PE

Implementation of Uncertainty In Analysis of Hydrogen Vehicles in Tunnels







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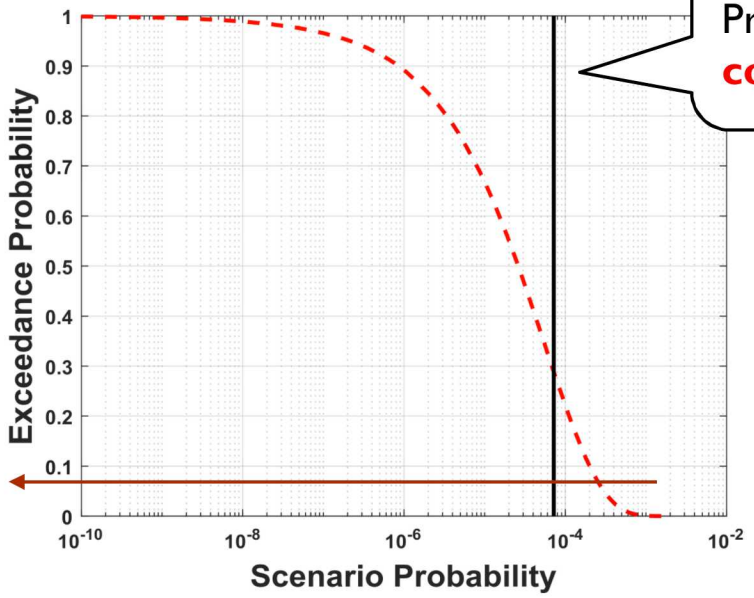
Why use uncertainty analysis?

A scenario occurs because of a sequence of events

- Each event in the sequence must occur
- Each event has a probability of occurrence
- Each probability of occurrence has uncertainty due to lack-of-knowledge

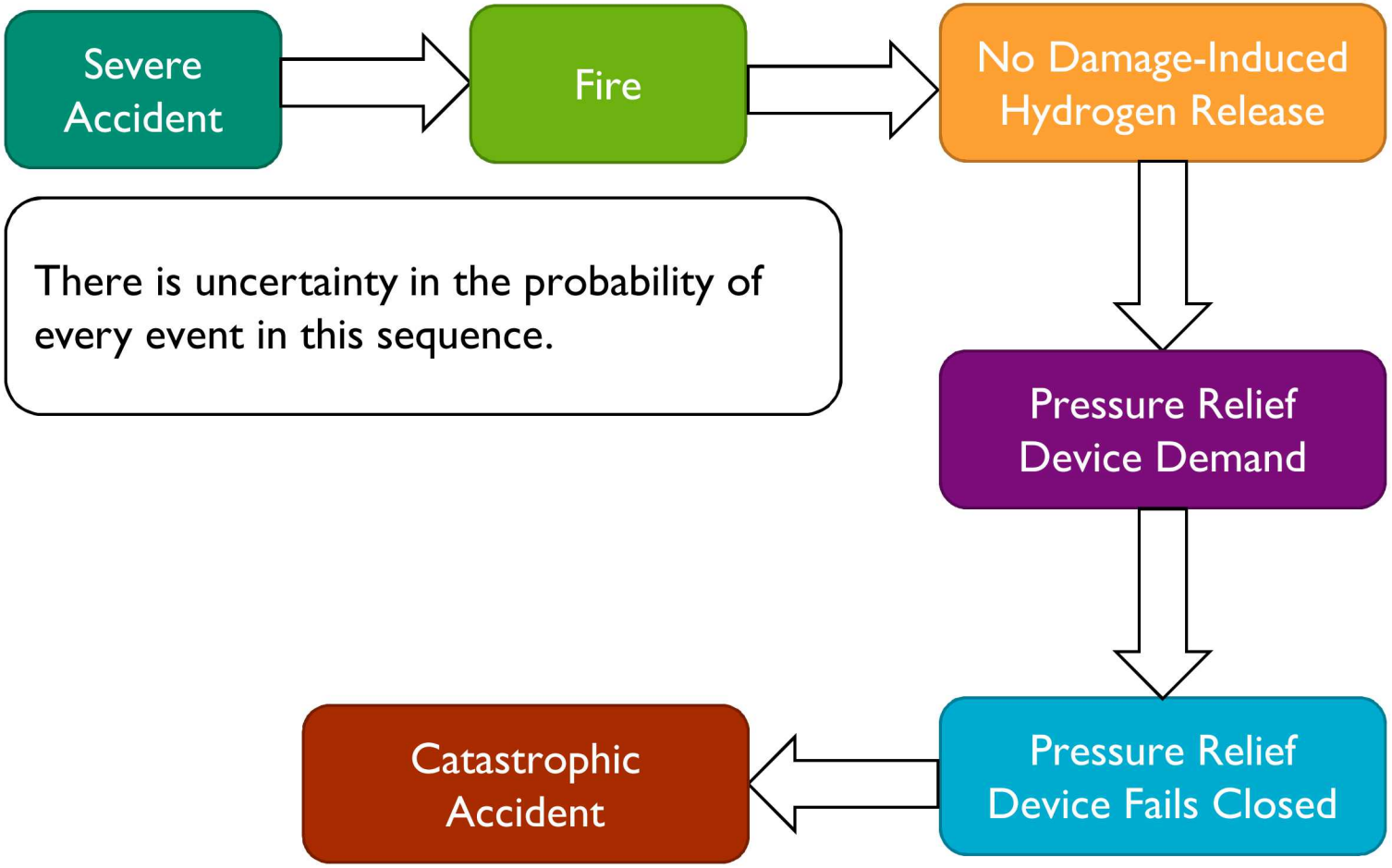
Presenting a point estimate for the probability of the sequence can be misleading – decision makers may think the likelihood is lower than it may actually be leading to unsafe approvals or inappropriate prioritization of mitigations

Point estimate $\approx 7E-05$
Probability of a **catastrophic consequence** scenario

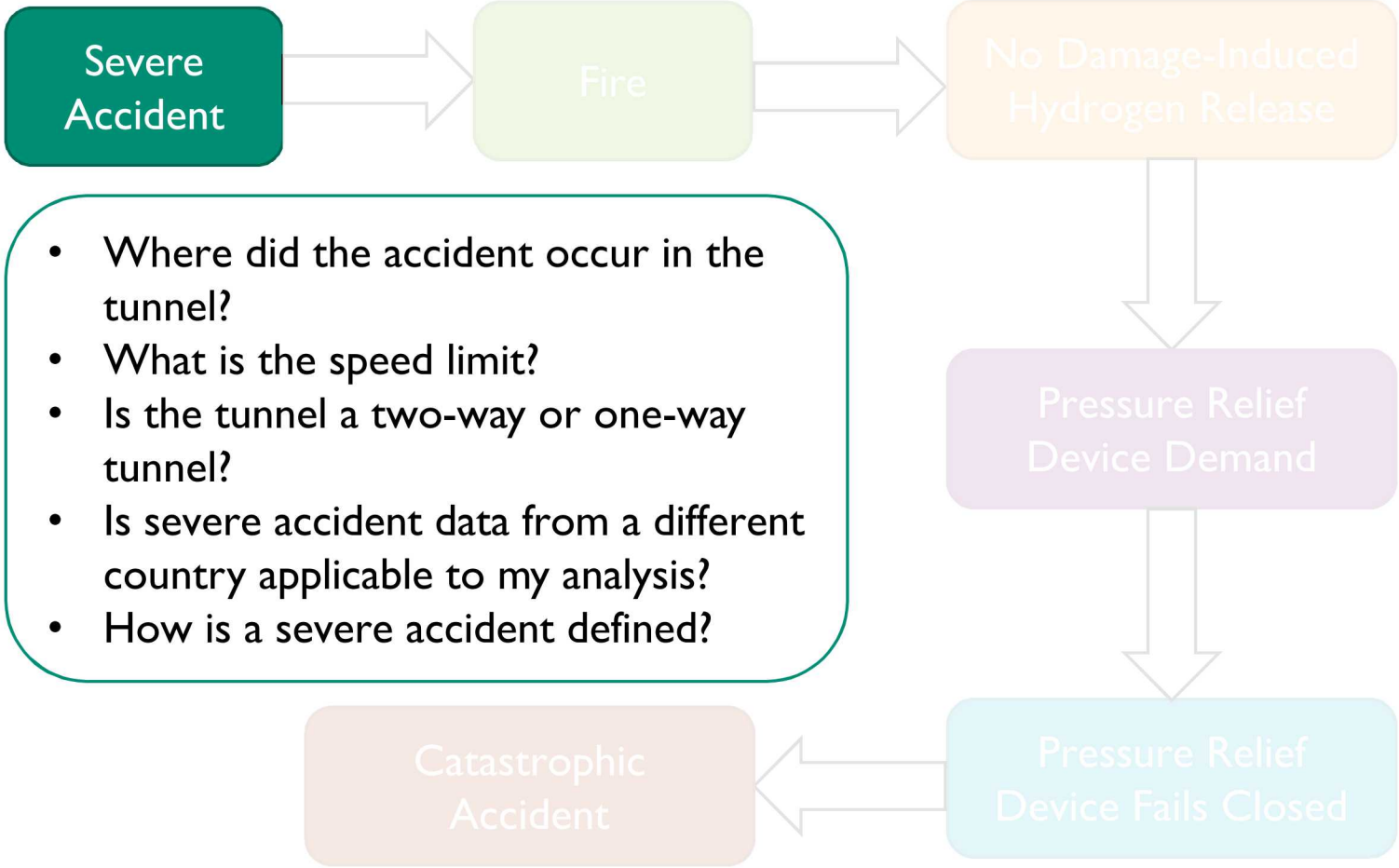


With $N = 10^4$ estimate ranges between 2E-15 and **2E-3**

What are the uncertainties?



What are the uncertainties?



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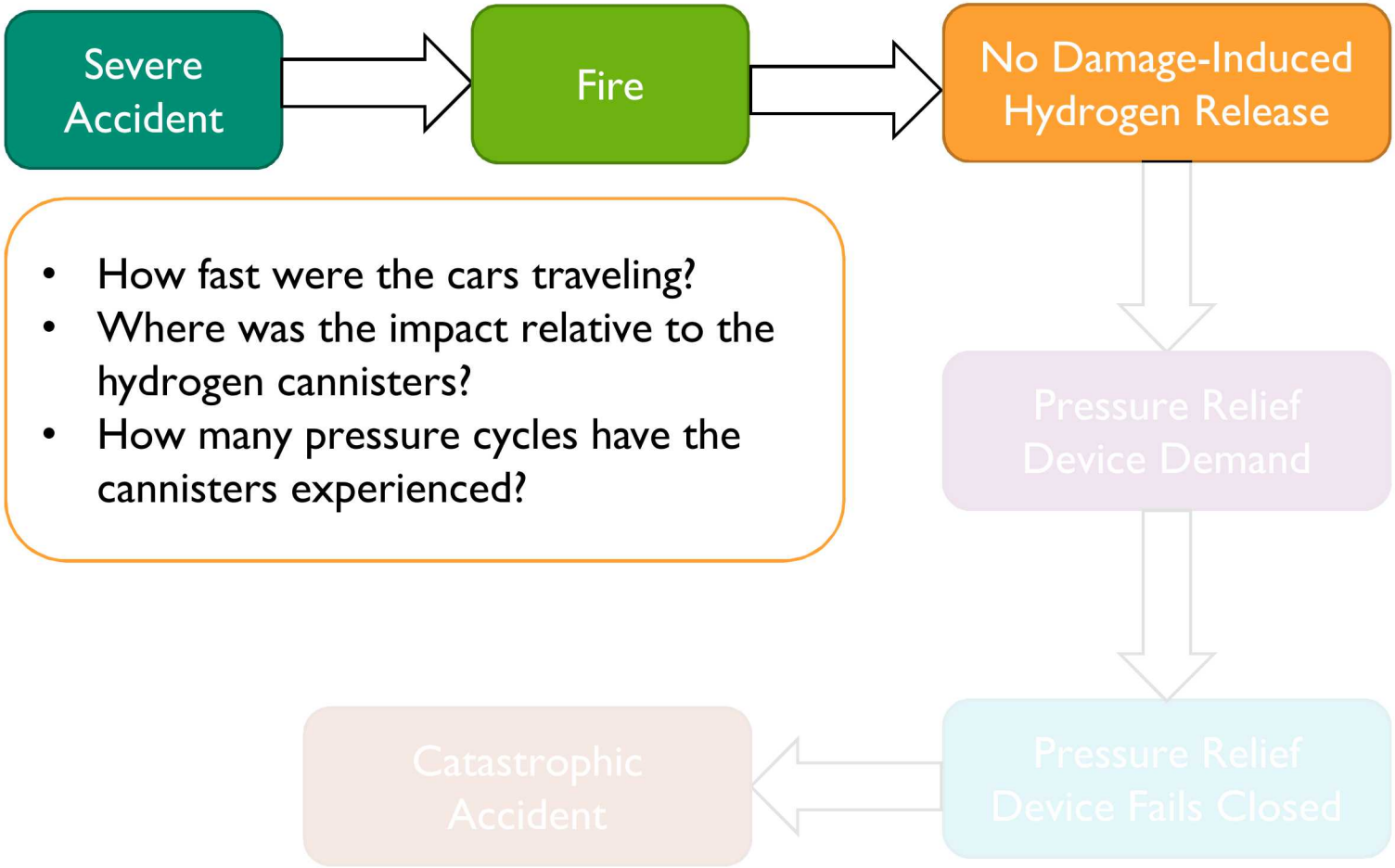
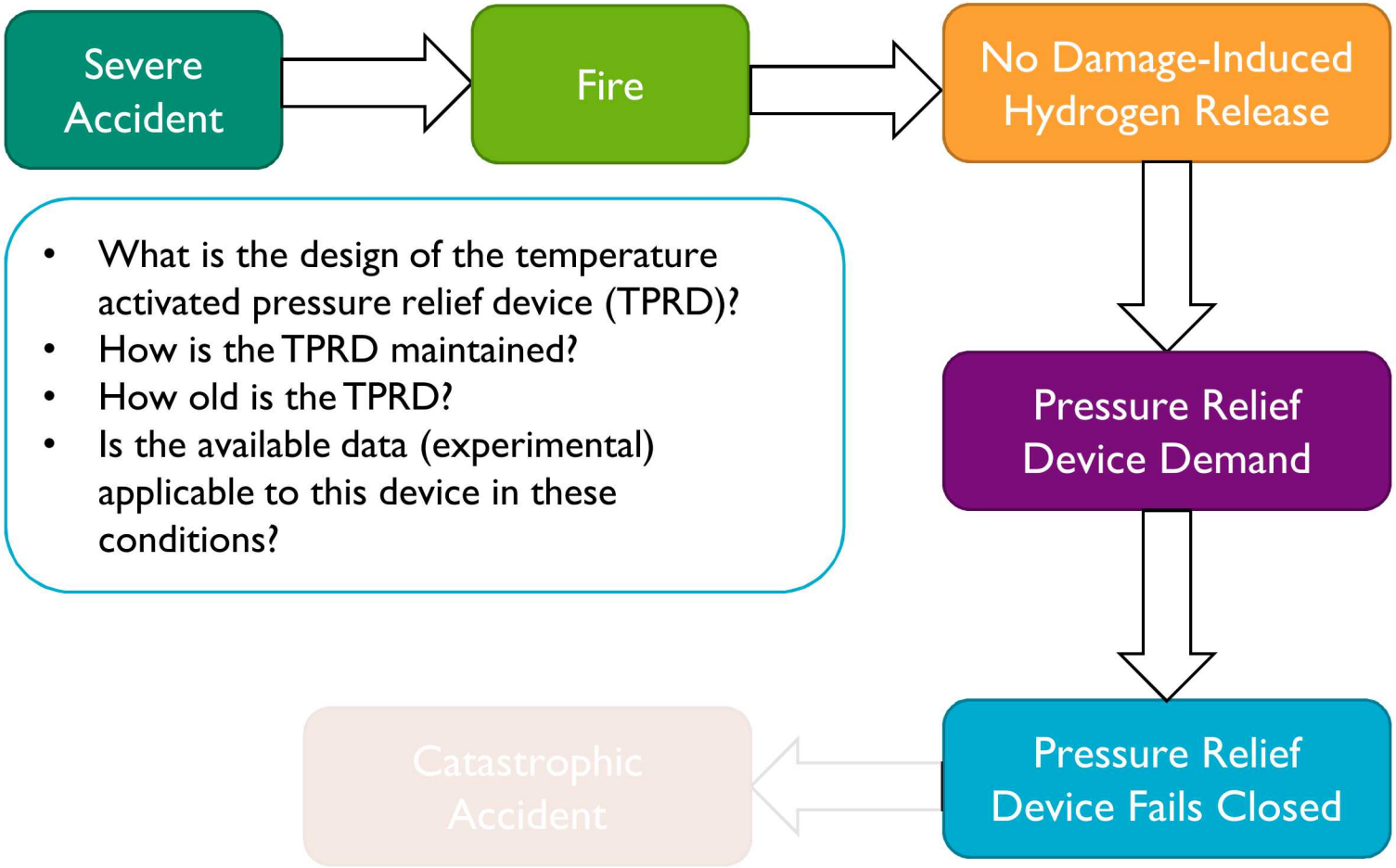


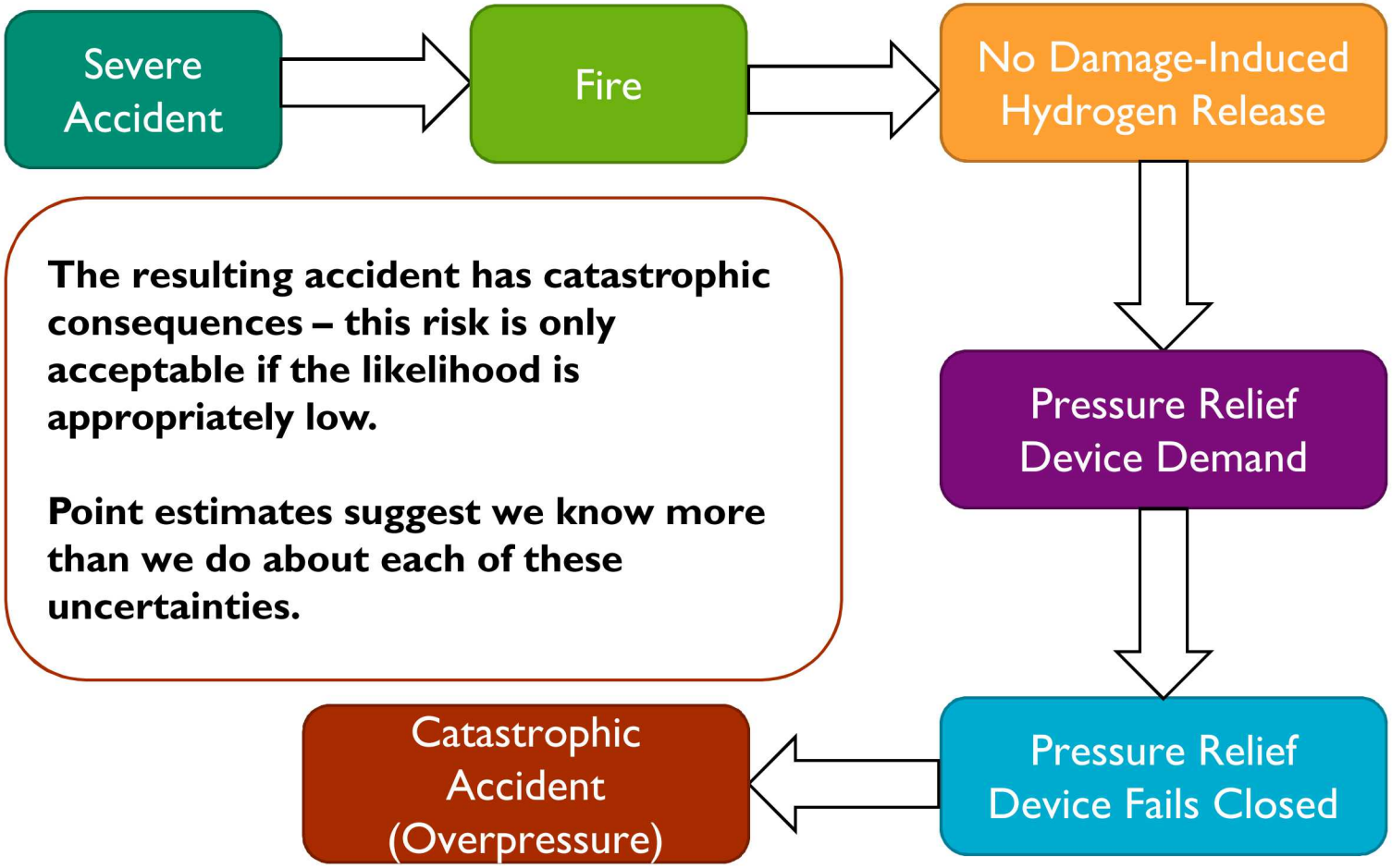
- How fast were the cars traveling?
- Where was the impact relative to the hydrogen cannisters?
- How many pressure cycles have the cannisters experienced?

What are the uncertainties?



- What is the design of the temperature activated pressure relief device (TPRD)?
- How is the TPRD maintained?
- How old is the TPRD?
- Is the available data (experimental) applicable to this device in these conditions?

What are the uncertainties?



The resulting accident has catastrophic consequences – this risk is only acceptable if the likelihood is appropriately low.

Point estimates suggest we know more than we do about each of these uncertainties.

How do we incorporate uncertainty?

Step 1. Collect data and/or expert knowledge

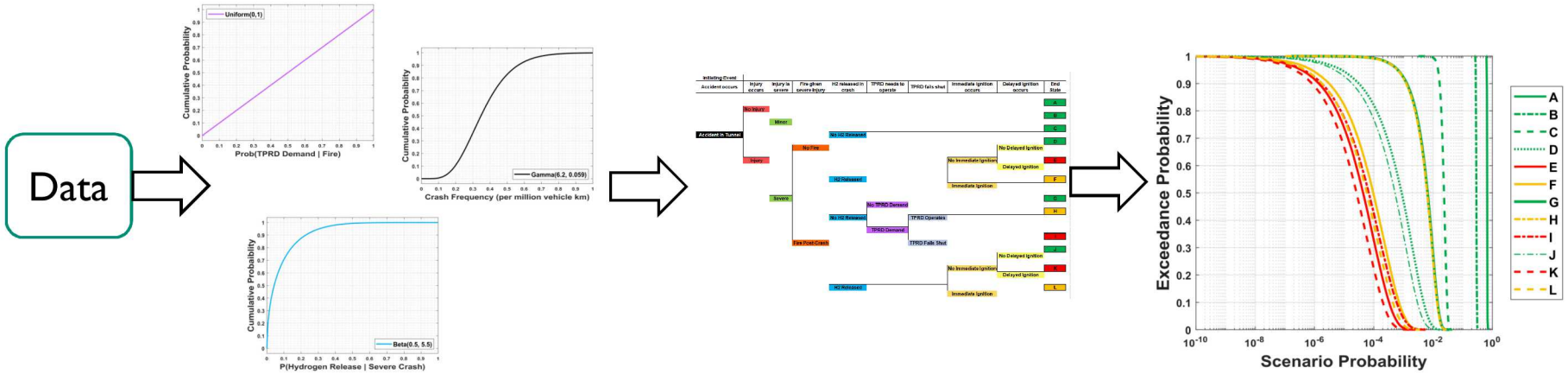
- e.g. experiments, historical data, models, subject matter experts

Step 2. Use data to derive uncertainty distributions around the probability of each event

- There are multiple correct ways to do this; use the most appropriate method for the quality and quantity of your data

Step 3. Propagate uncertainty through the likelihood calculation

Step 4. Present results with explicit identification of assumptions and limitations



Example – Derivation of uncertainty in probability of TPRD failure

Probability of temperature-activated pressure relief device failure, given demand for operation

- No operational data from accidents
- No experimental data from experiments designed to test this
- No modeling data or expert knowledge

Value used in literature = 6.04E-03

- Mechanical failure from reliability data
- Estimate is 1.384 failures per 1E6 hours ⇒ 1.38E-06 failure probability per hour
- Apply rule-of-thumb formula:
  - P(Failure per hour)*(test interval)/2 = P(Failure|Demand)
  - 1.38E-06*(365*24)/2 = 6.04E-03

What is wrong with this estimate?

- Reliability data may not reflect behavior in severe accident conditions
- Reliability data may reflect failure as leaks, rather than failure to relieve pressure
- The rule-of-thumb formula could give values >1, so this isn't appropriate for probability

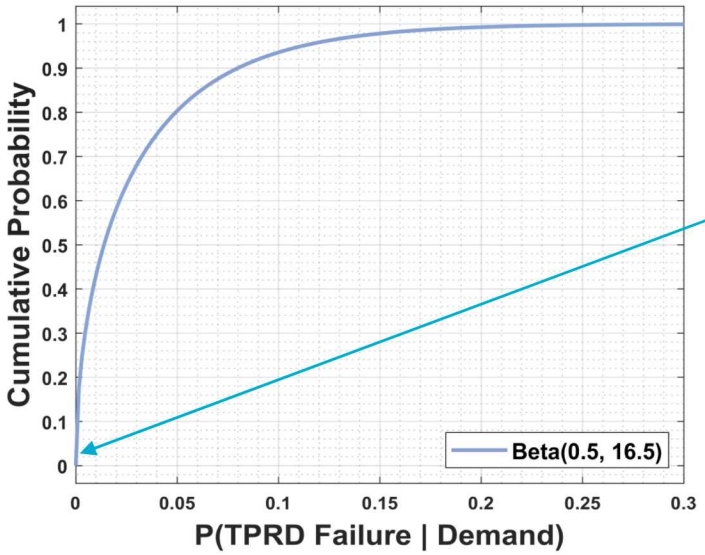
Example – Derivation of uncertainty in probability of TPRD failure

Step 1. Collect data

- Literature review for experiments on hydrogen cylinder burst in fire
  - All tests include TPRDs for safety reasons
  - All tests report whether the TPRD operated or not
  - 16 tests total, with 0 TPRD failures

Step 2. Derive uncertainty distribution around the probability of the event

- Use Bayesian with uninformed Beta prior to reflect lack-of-knowledge
- Update with 0 failures in 16 tests



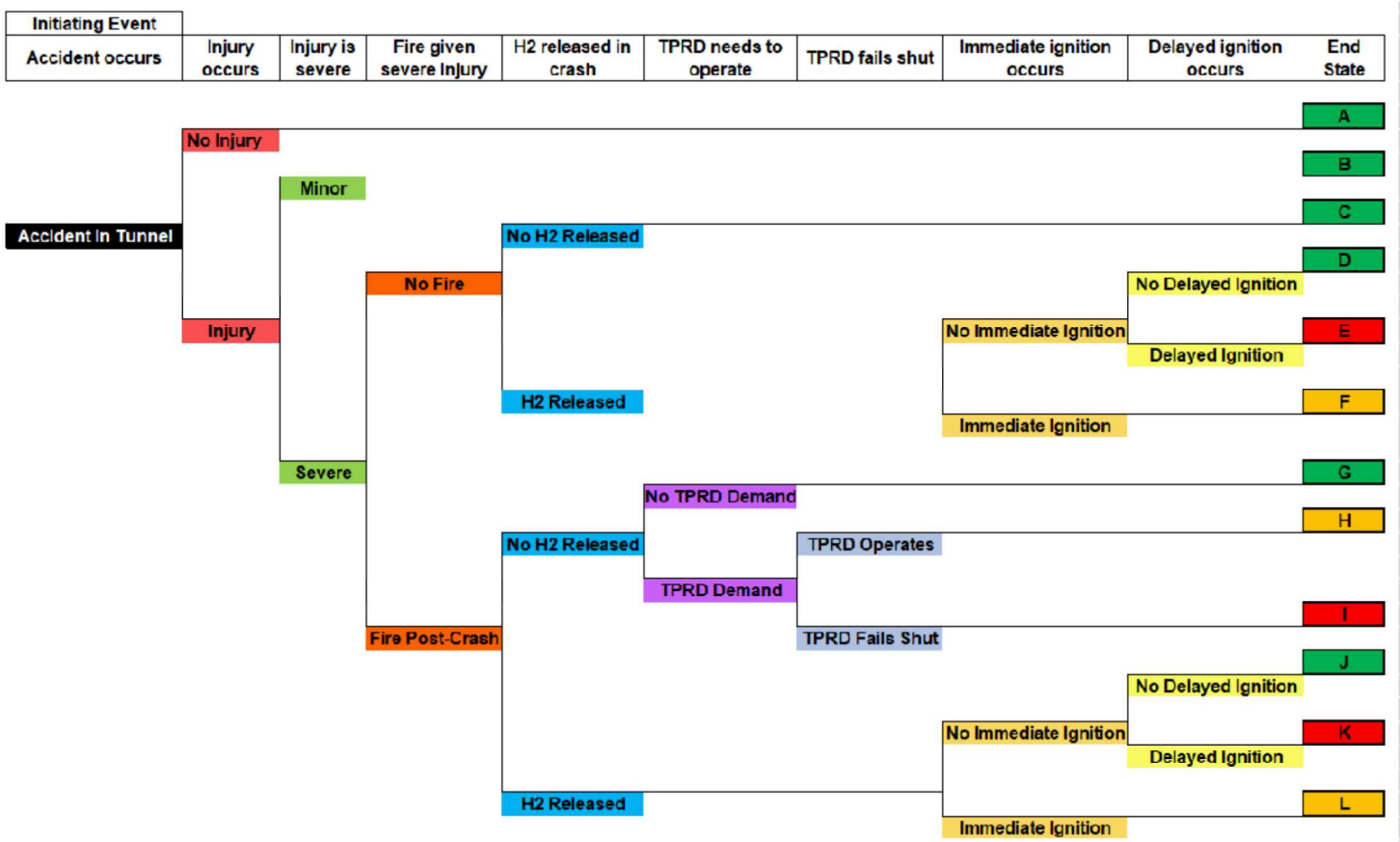
The literature estimate is down here. It claims to be conservative, but there is no clearly-applicable data with the power to assert this.

Our distribution includes the literature value but acknowledges the high uncertainty in our state-of-knowledge.

Uncertainty Propagation

Step 3. Propagate uncertainty through the likelihood calculation

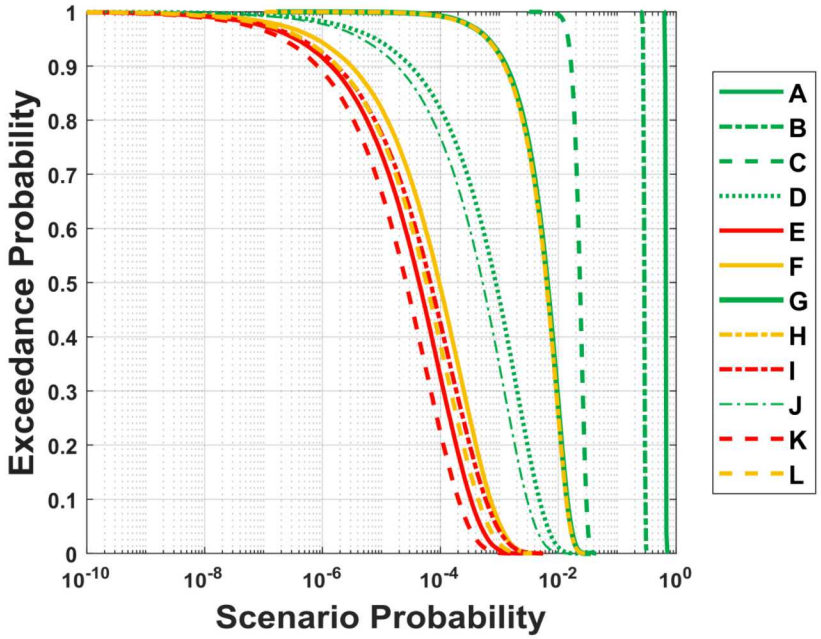
- We included an uncertainty distribution for every top event
- Number of top events is small, so simple random sampling was used

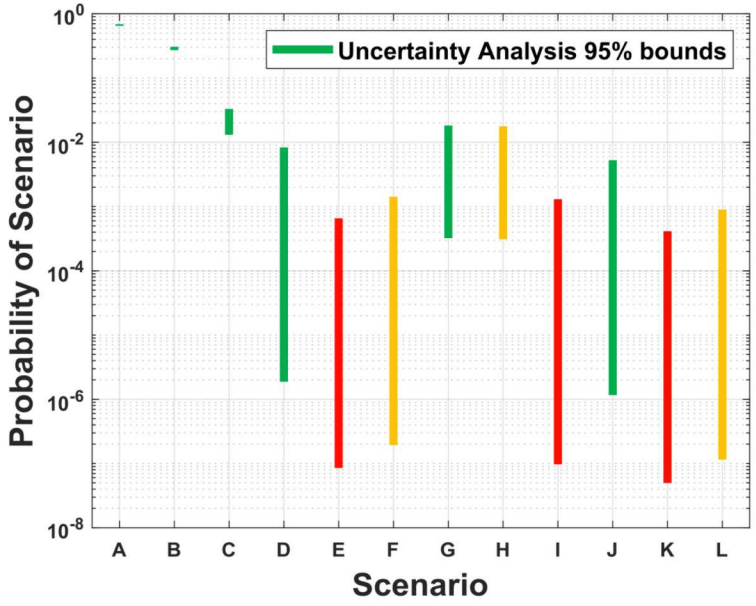


Uncertainty Characterization

Step 4. Present results with explicit identification of assumptions and limitations

- Distributional forms assumed for the uncertainty distributions
- Applicability/limitation in applicability of the data
- Impact of assumptions
  - e.g. Beta prior is a strong assumption about the distribution form, the choice of an uninformed prior may bias this distribution towards higher probabilities, and the data may have included TPRDs of different designs or fire configurations that are not consistent with the accidents we are modeling. Further study is needed to refine the uncertainty distribution.





Uncertainty Interpretation

Instead of thinking of this as a probability of a probability, think of it as characterizing where there is the most evidence for the probability.

We think the probability of this catastrophic accident is likely higher than 1E-6 but could be lower.

We think the probability of this catastrophic accident is lower than 2E-4, but it could be higher.

We are confident the probability is less than 1E-2.