INL/CON-18-52334-Revision-1

Coupling RAVEN to SAPHIRE for Performing Time Dependent Probabilistic Risk Assessment

Congjian Wang, Diego Mandelli, Andrea Alfonsi, Paul W Talbot, Stephen Ted Wood, James K Knudsen, Cristian Rabiti

June 2019

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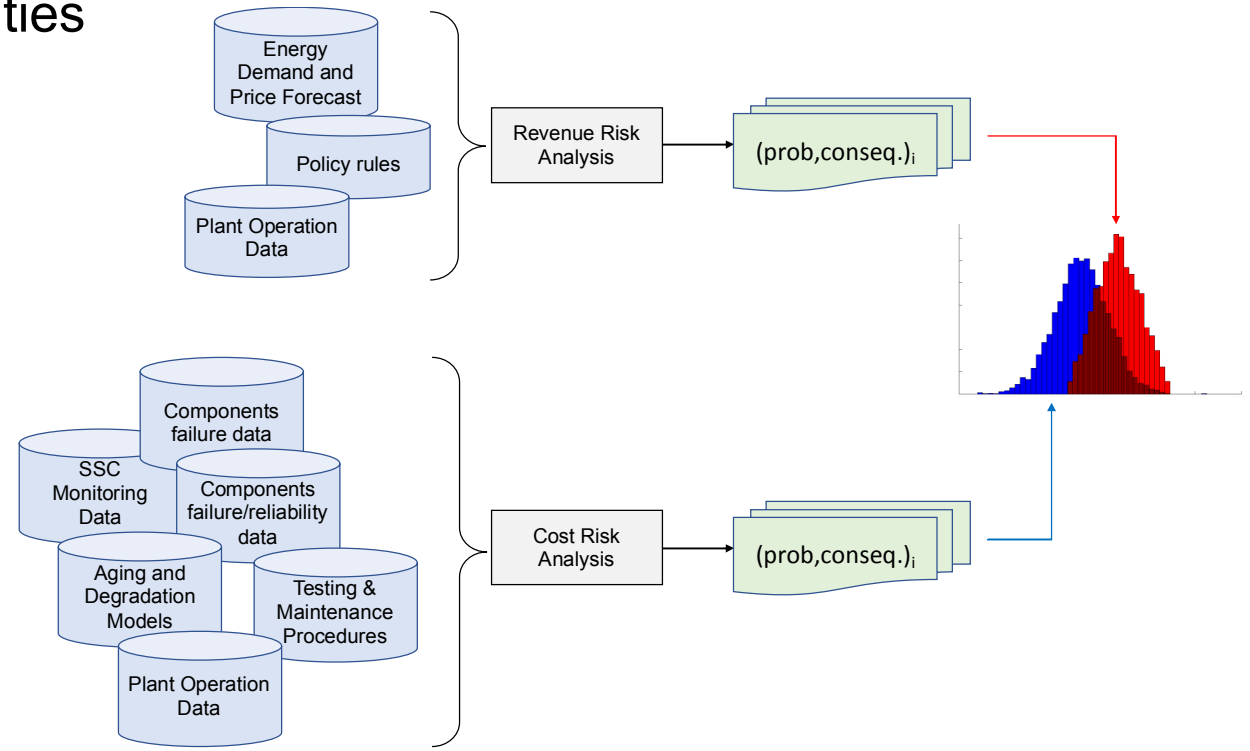
Presented by Congjian Wang

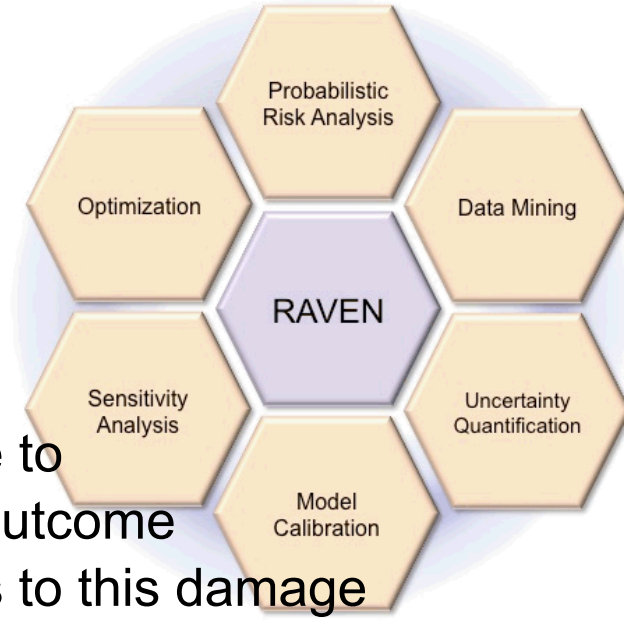
Background

- Cost Risk Analysis Framework (INL/EXT-19-51442)
  - Safety risk analysis: Event-Tree and Fault-Trees are employed to model accident progression
  - Cost risk analysis: estimates of plant cost drivers
  - Revenue risk analysis: estimates plant revenues and associated uncertainties



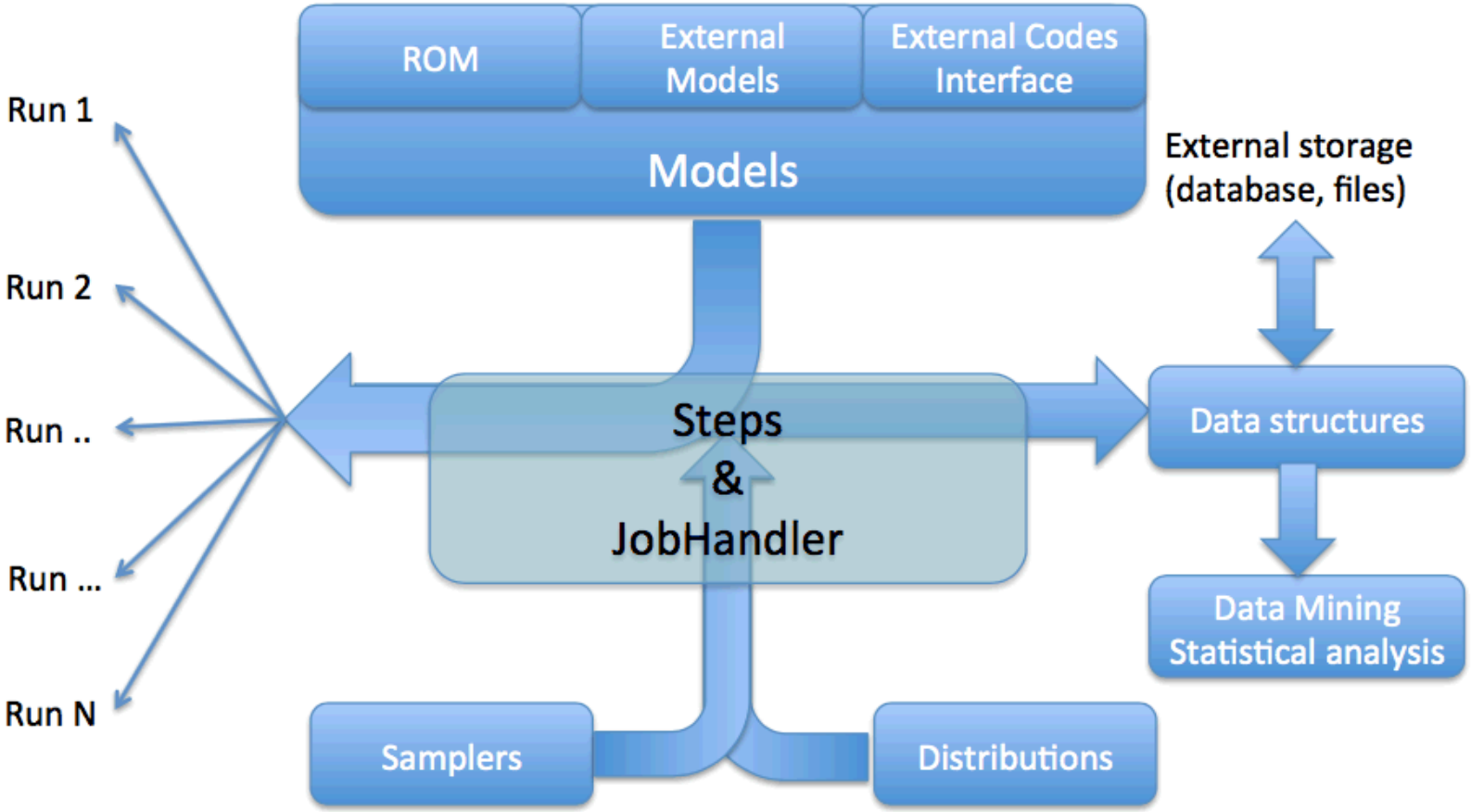
Background

- RAVEN: multi-purpose framework to enable Risk Informed Safety Margin Characterization (RISMC)
  - Evaluating risk (UQ)
  - Understanding risk (data mining)
  - Mitigating risk (optimization)

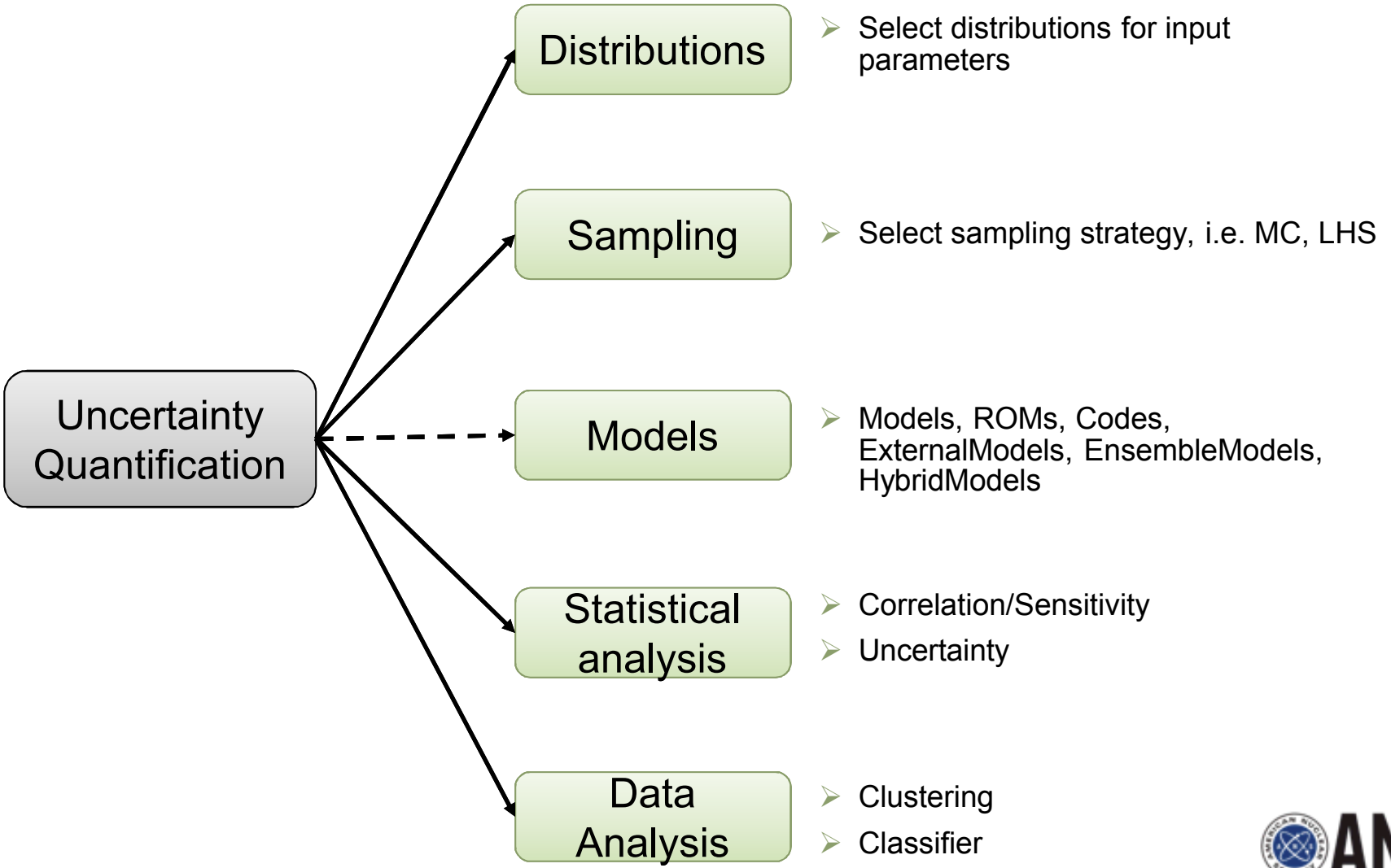


- SAPHIRE: perform complete PRA
  - Level 1: model a complex system's response to initiating events, quantify associated damage outcome frequencies, and identify important contributors to this damage
  - Level 2: analyze containment performance during a severe accident and quantify radioactivity releases
  - Level 3: quantify risk in terms of radioactivity release accidents to both the public and environment

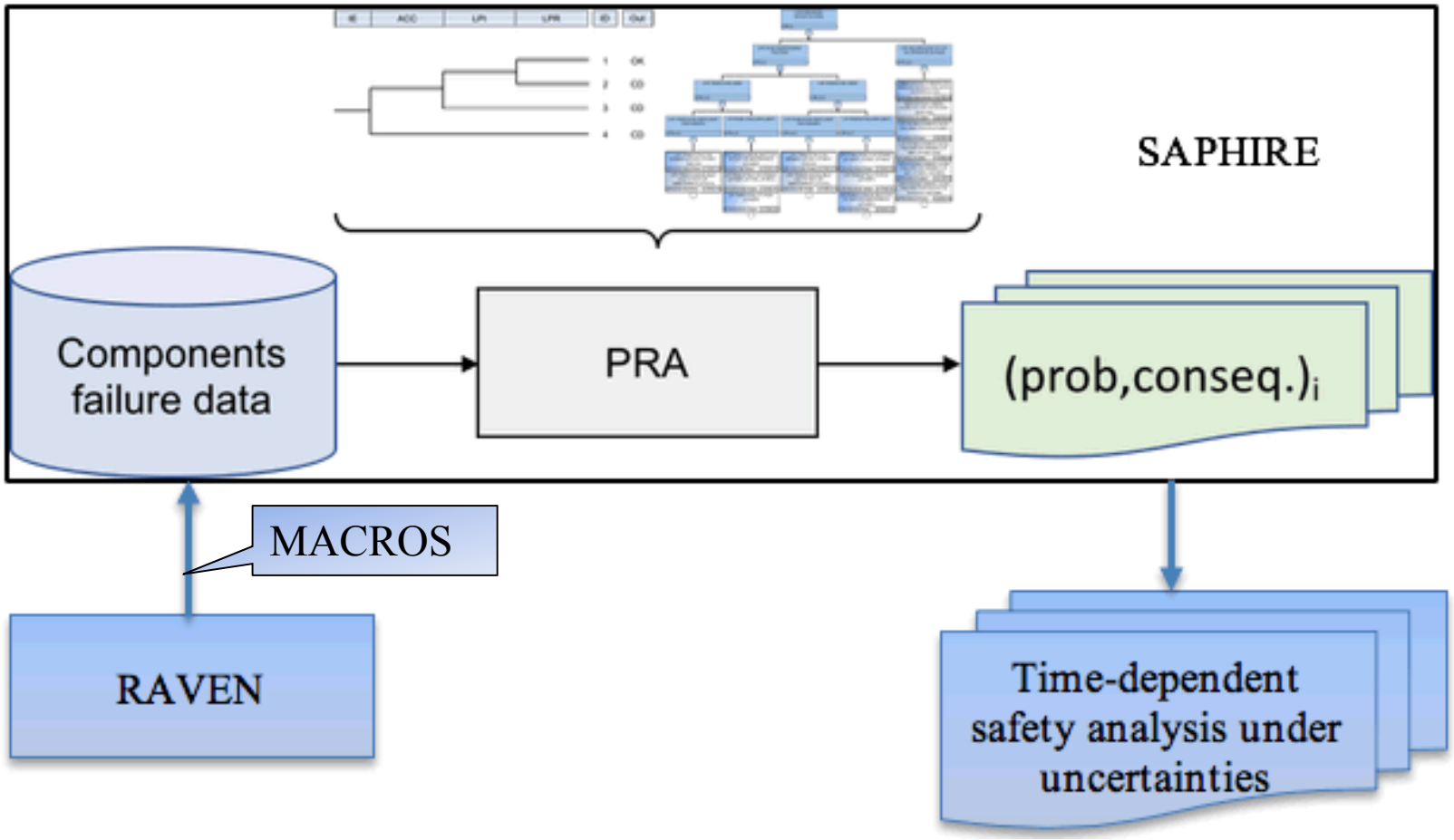
RAVEN Infrastructure



UQ Example: Capabilities vs. Needs

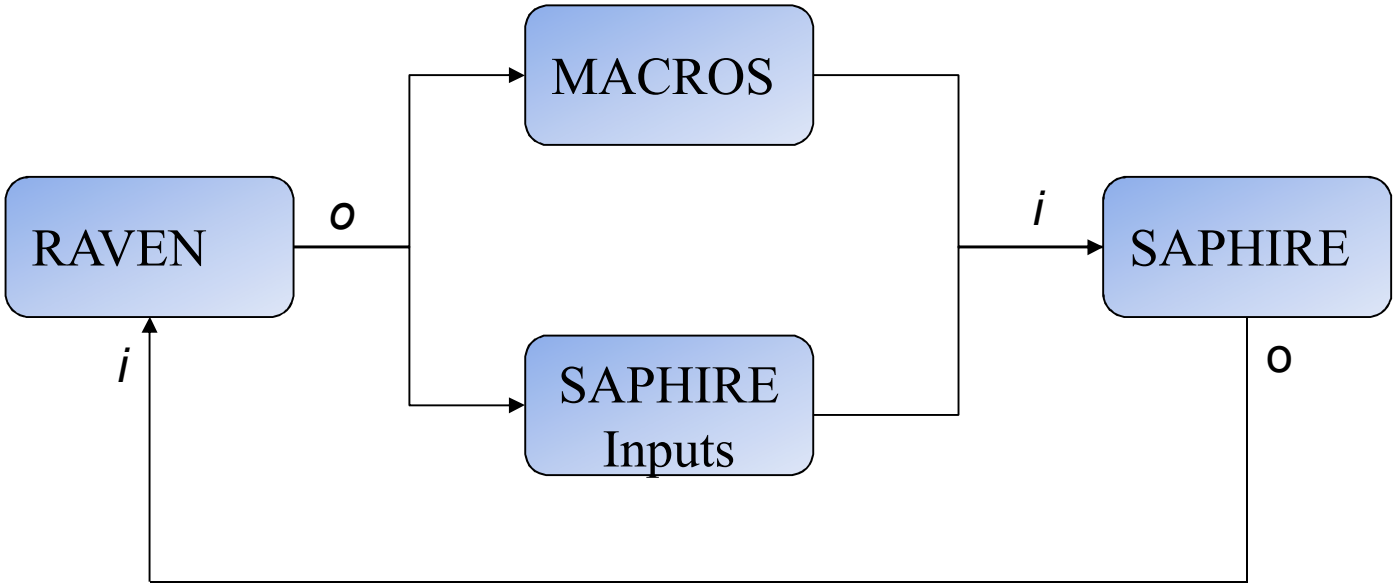


RAVEN-SAPHIRE Coupling



RAVEN-SAPHIRE Coupling

- MACROS in SAPHIRE
  - Automatically perform “analysis-menu” functions
  - Modify basic event data, fault tree logic and event tree logic
  - Using a standard text editor



- Perturbing the parameters in MACROS using “wild-cards”, i.e. ***$RAVEN-variableName$***

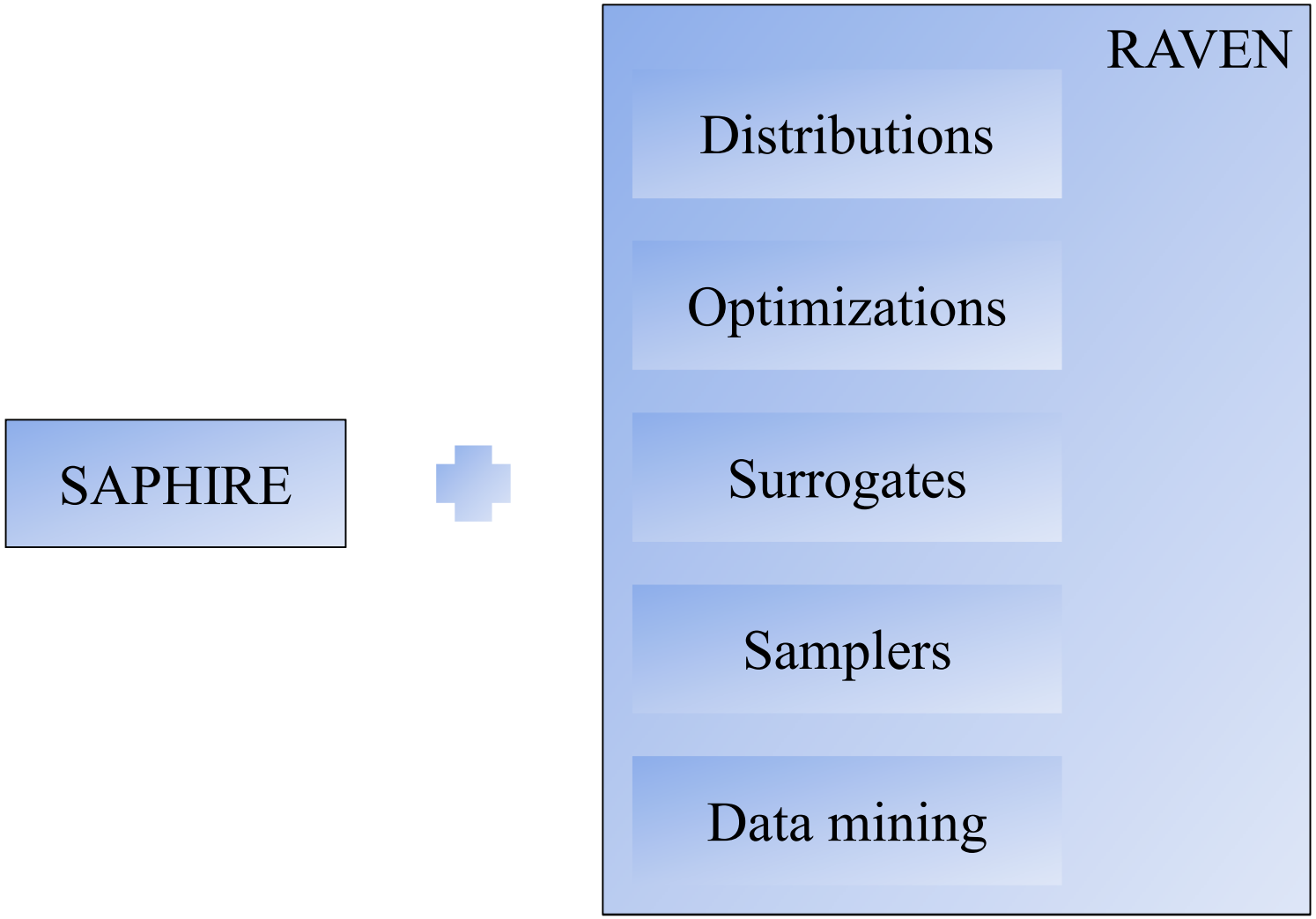
Example of MACROS' Perturbation

```
<change set>
  <unmark></unmark>
  <delete>
    <name>MOV-1-EVENTS</name>
  </delete>
  <add>
    <name>MOV-1-EVENTS</name>
    <description>Class change subset events C
      ↪ Set</description>
    <class>
      <event name>?-MOV-CC-1</event name>
      <calc type>1</calc type>
      <probability>5E-3</probability>
    </class>
  </add>
    <mark name>MOV-1-EVENTS</mark name>
    <generate></generate>
</change set>
```

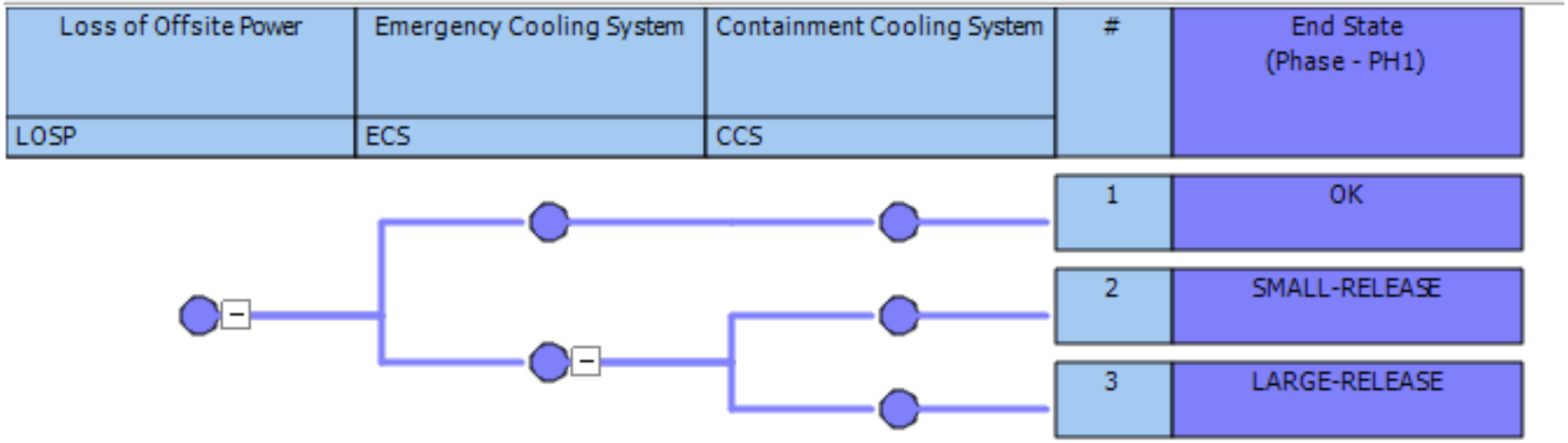
```
<MonteCarlo name="mcSaphire">
    <samplerInit>
        <limit>2</limit>
    </samplerInit>
    <variable name="allEventsPb">
        <distribution>allEvents</distribution>
    </variable>
    <variable name="mov1EventPb">
        <distribution>mov1Event</distribution>
    </variable>
    <variable name="single1Pb">
        <distribution>single1</distribution>
    </variable>
</MonteCarlo>
```

```
<class>
  <event name>?-MOV-CC-1</event name>
  <calc type>1</calc type>
  <probability>$RAVEN-mov1EventPb$</probability>
</class>
```

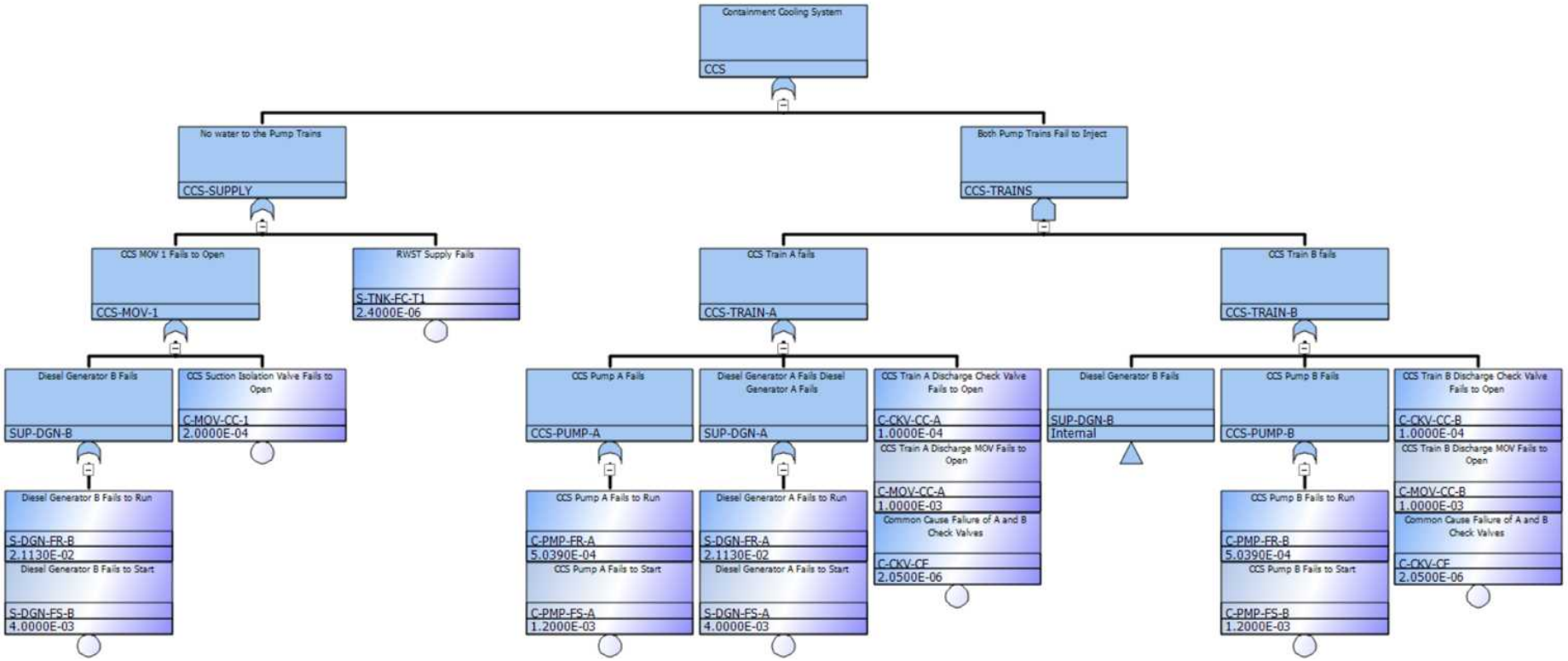
RAVEN-SAPHIRE Coupling



LOSP Event Tree Model



CCS/ECS Fault Tree Model



Failure Model Employed in ECS/CCS FTs

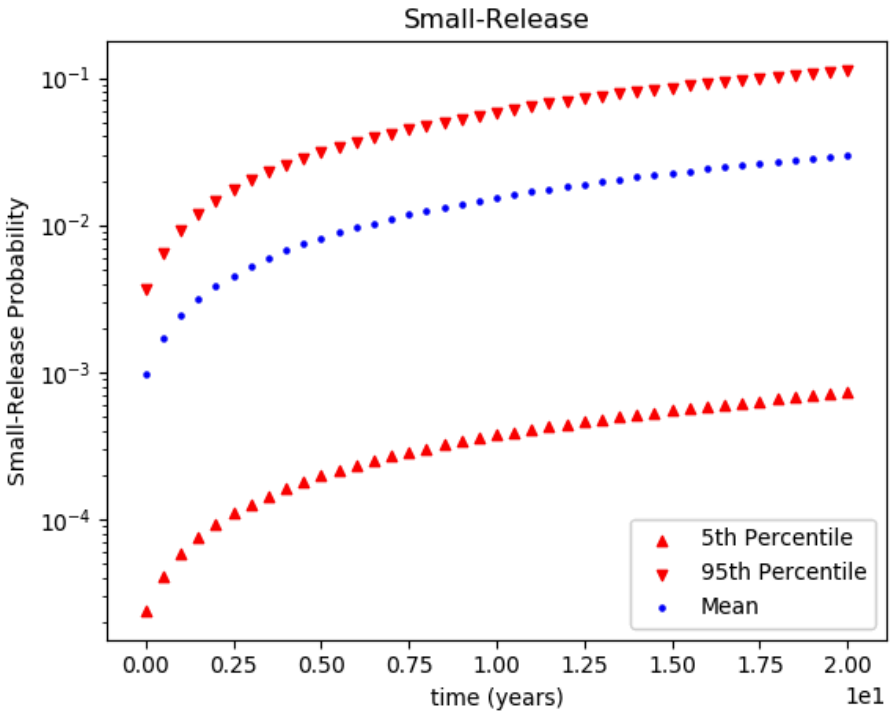
Calc. Type	Equation	Description
1	$P = p$	Mean probability
3	$P = 1 - \exp(-\lambda T_m)$	λ: mean failure rate, T_m: mission time. Failure probability of an operating component without repair.

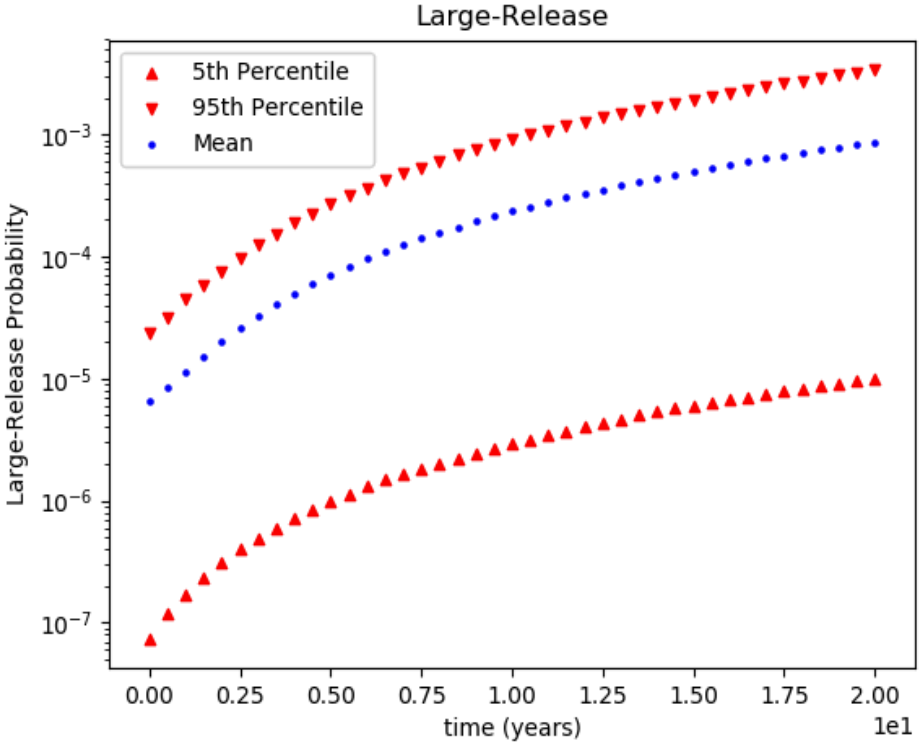
- Linear failure probability model: $P(t) = P_0[1 + b(t - t_0)]$
- Exponential failure rate model: $\lambda(t) = \lambda_0 \exp\big(b(t - t_0)\big)$

Failure Model Employed in ECS/CCS FTs

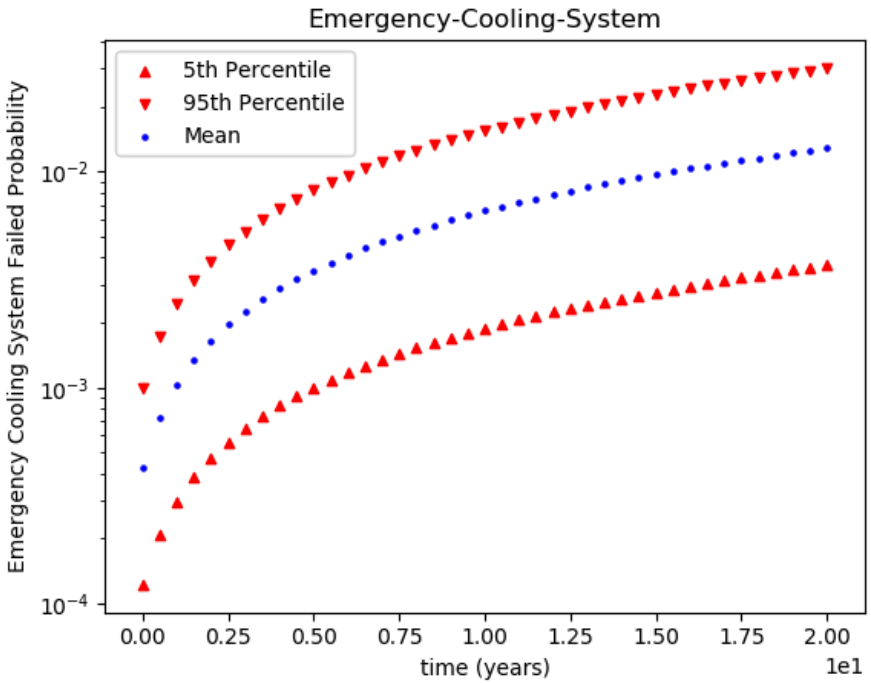
Basic Event	Calc. Type	Failure Probability/Rate	Description
CKV-CC-A	1	$P = 1.0E-05 + 1.45E-05 * (t - t_0)$	Train A discharge check valve fails to open
CKV-CC-B	1	$P = 1.0E-05 + 1.45E-05 * (t - t_0)$	Train B discharge check valve fails to open
MOV-CC-1	1	$P = 2.0E-05 + 2.9E-05 * (t - t_0)$	Suction isolation value fails to open
MOV-CC-A	1	$P = 1.0E-05 + 1.45E-05 * (t - t_0)$	Train A discharge MOV fails to open
MOV-CC-B	1	$P = 1.0E-05 + 1.45E-05 * (t - t_0)$	Train B discharge MOV fails to open
PMP-FR-A	3	$\lambda = 2.1E-06 * \exp(0.17(t - t_0))$	Pump A fails to run
PMP-FR-B	3	$\lambda = 2.1E-06 * \exp(0.17(t - t_0))$	Pump B fails to run
PMP-FS-A	1	$P = 1.2E-04 + 1.74E-04 * (t - t_0)$	Pump A fails to start
PMP-FS-B	1	$P = 1.2E-04 + 1.74E-04 * (t - t_0)$	Pump B fails to start
S-DGN-FR-A	3	$\lambda = 8.9E-05 * \exp(0.17(t - t_0))$	Diesel generator A fails to run
S-DGN-FR-B	3	$\lambda = 8.9E-05 * \exp(0.17(t - t_0))$	Diesel generator B fails to run
S-DGN-FS-A	1	$P = 4.0E-04 + 5.8E-04 * (t - t_0)$	Diesel generator A fails to start
S-DGN-FS-B	1	$P = 4.0E-04 + 5.8E-04 * (t - t_0)$	Diesel generator B fails to start

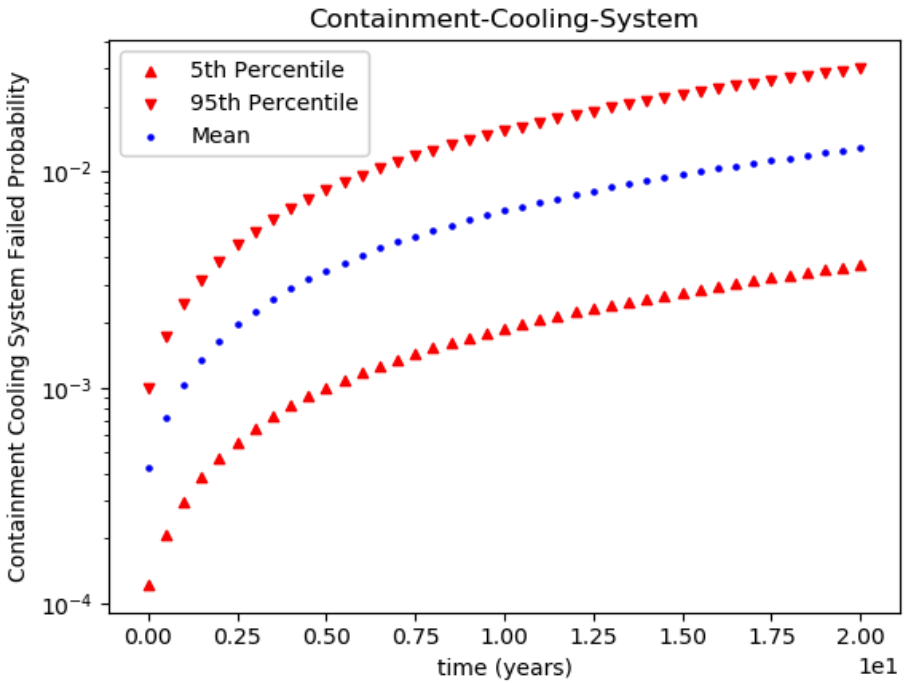
Time dependent uncertainty analysis of ET





Time dependent uncertainty analysis of FT CCS/ECS



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