NEPP ETW 2019

Model-Based Radiation Assurance for Satellites with Commercial Parts

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Acronyms and Abreviations

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CRÈME: Cosmic Ray Effects on Micro-Electronics Code
GSN: Goal Structuring Notation
JWST: James Webb Space Telescope
MBMA: Model-Based Mission Assurance
MBE: Model-Based Engineering
MOSFET: Metal Oxide Field Effect Transistor
MRQW: Microelectronics Reliability & Qualification Workshop
NASA: National Aeronautics and Space Administration
R&M: Reliability & Maintainabiltiy
R-GENTIC: Radiation GuidelinEsfor Notional Threat Identification and Classification
RESIM Radiation Effect System Impact Modeling
RHA: Radiation Hardness Assurance
SEAM: System Engineering and Assurance Modeling
SEB: Single Event Burnout
SiC: Silicon Carbide
STD: Standard
SysML: System Modeling Language

Radiation Assurance Approaches for Space Systems

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Conventional:

- Widespread use of radiation-hardened components
- Deep knowledge of components
- Several heavy-ion beam test campaigns
- Informed use of physics-based radiation modeling tools
- Relatively high budget and long-term development schedule
- Formal documentation of test procedures and results

"New, Commercial Space"

- Widespread, if not 100% use of COTS parts
- Little insight into components
- Minimal testing, possibly only proton testing of sub-systems
- Little use of radiation modeling tools
- Low budget, accelerated development schedule
- Little formal documentation or evidence of radiation behavior

Radiation Assurance for Space Systems

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What can we do early in the development of the project, other than formal modeling or ion-beam testing, to "buy down" risk of radiation-related failures?

Platform for Creation of a Radiation Assurance Case

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Useful radiation reliability assurance platform characteristics:

- Model-based approach=digital representation of objects
- Tolerant of uncertainty, various levels of model fidelity
- Flexible as new info/design changes become available
- Qualitative arguments about why the system will work
- Quantitative estimates for reliability and location of weak links
- Systematically covers known faults (not ad hoc)

System Engineering and Assurance Modeling (SEAM) Platform

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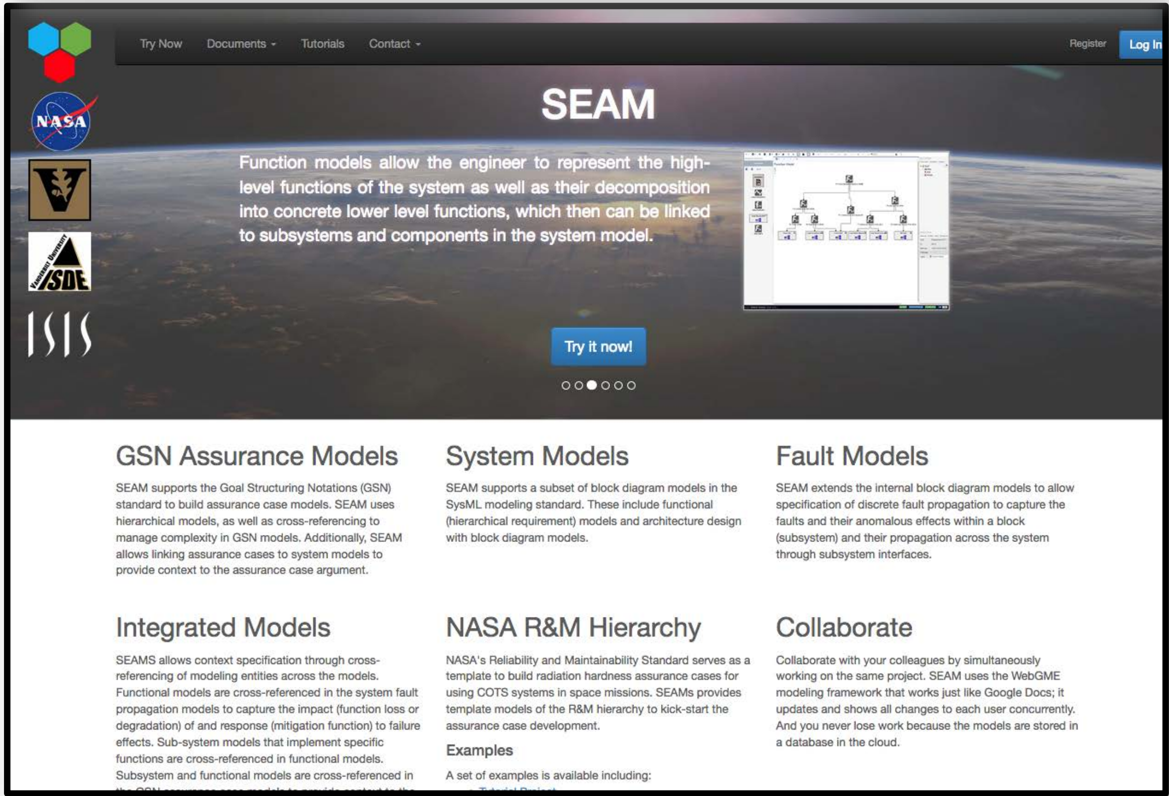
- Web-browser based
- Can access as guest or create account
- Creates system model diagrams and argument for radiation assurance case
- Maintained by Vanderbilt University
- Contains examples and tutorial information

https://modelbasedassurance.org/



Overall System Reliability Characterization Flow

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RESIM/Questa [1,2]
- Quantitative
- Based on rad data
- Mixed Signal Sim
- Functional models

SysML: Diagramatic
- System Architecture
- Part rad faults
- System functions
- Specifications

GSN: Text Based
- Specifications
- Environment info
- Goal/Strategy/Evidence
- Assurance Argument

System Waveforms
- Electrical +Rad sims
- Timing diagrams
- Probability distributions

Bayesian Nets
- Identify a function
- Create BN graph
- Export to BN Tool

Fault Trees
- Tied to system functions
- Create FT structure
- Export to FT Eval tools

SEAM

[1] A. F. Witulski, et al, RADECS, Sept. 2018.
[2] A. F. Witulski, et al, Trans. Nucl. Sci., August, 2019.

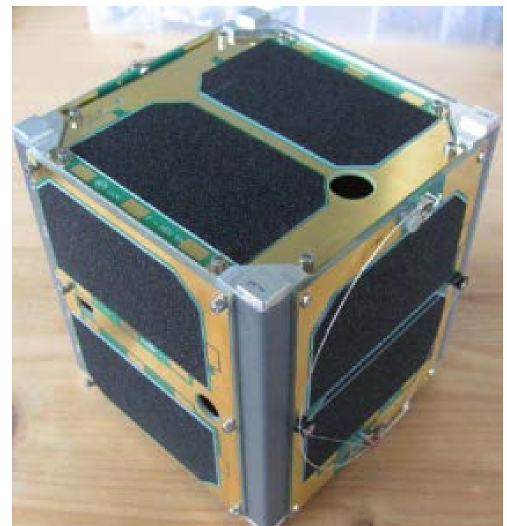
Systems Engineering Assurance and Modeling (SEAM)

Program History

- FY16: Started as collaboration of NASA OSMA, HQ, NEPP
  - Work on Goal Structuring Notation Safety Cases
  - Single events on SRAM CubeSat application
- FY17: collaboration of NASA OSMA, HQ, NEPP
  - Added SysML and Bayesian Nets (BN) to platform
  - JPL sponsors application to C&DH board
- FY18: NASA OSMA, HQ, NEPP, JPL
  - Coverage Checks, Start work on Requirements, Compatibility with Magic Draw, Fault Trees
- FY19: NASA OSMA, HQ, NEPP, JPL
  - Requirements, Fault Trees
  - Initial import of radiation modeling tools
  - Application of SEAM to development lifecycle

Radiation Reliability Assessment of CubeSat SRAM Experiment Board

- **Assessment completed on REM**
  - 28nm SRAM SEU experiment
- **Reasons for integrated modeling**
  1. Use commercial off-the-shelf (COTS) parts
  2. System mitigation of SEL
  3. System mitigation of SEFI on microcontroller



Courtesy of AMSAT

System-level RHA:
Block Diagram of 28nm SRAM SEU Experiment

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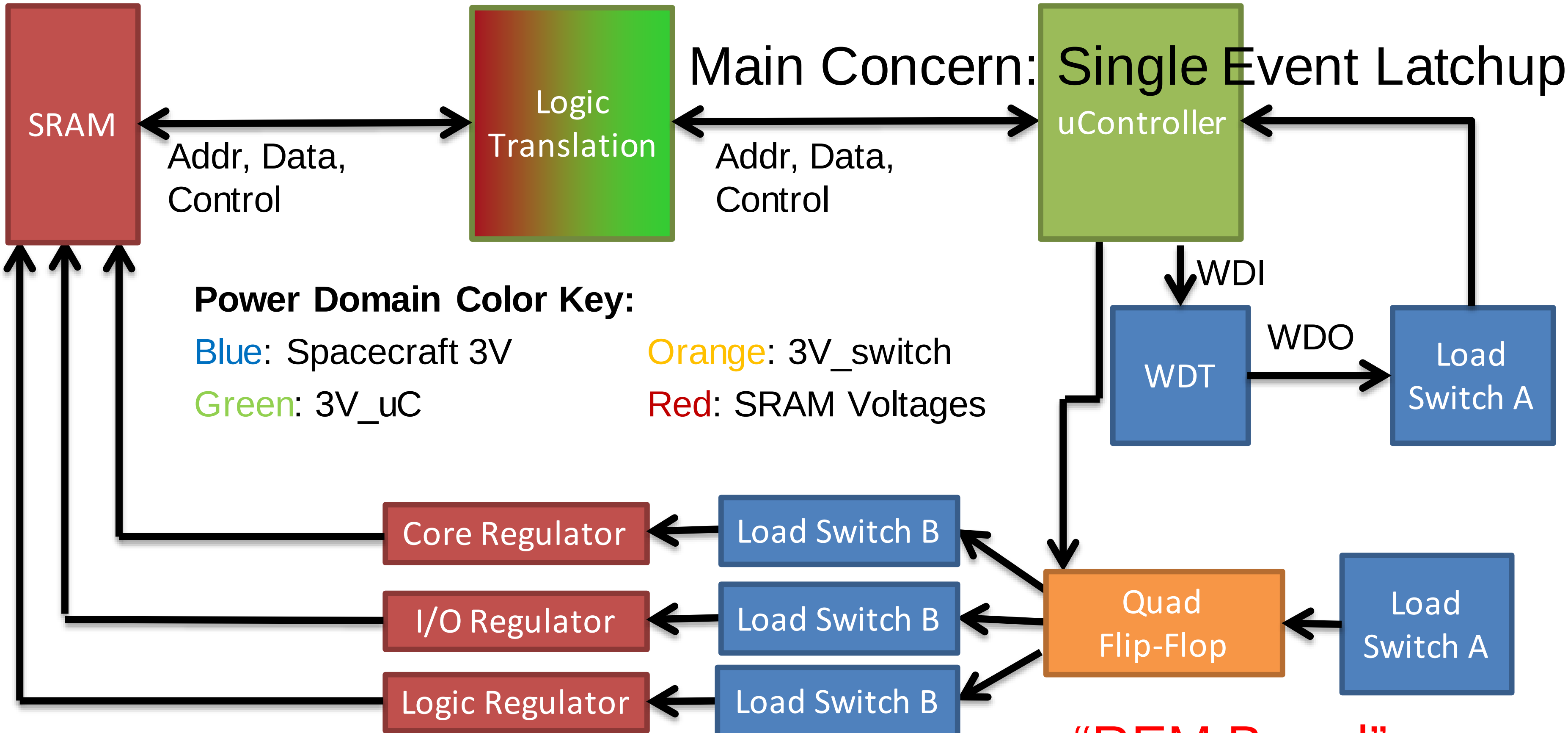
Main Concern: Single Event Latchup



"REM Board"

Functional Model: Count Upsets in SRAM

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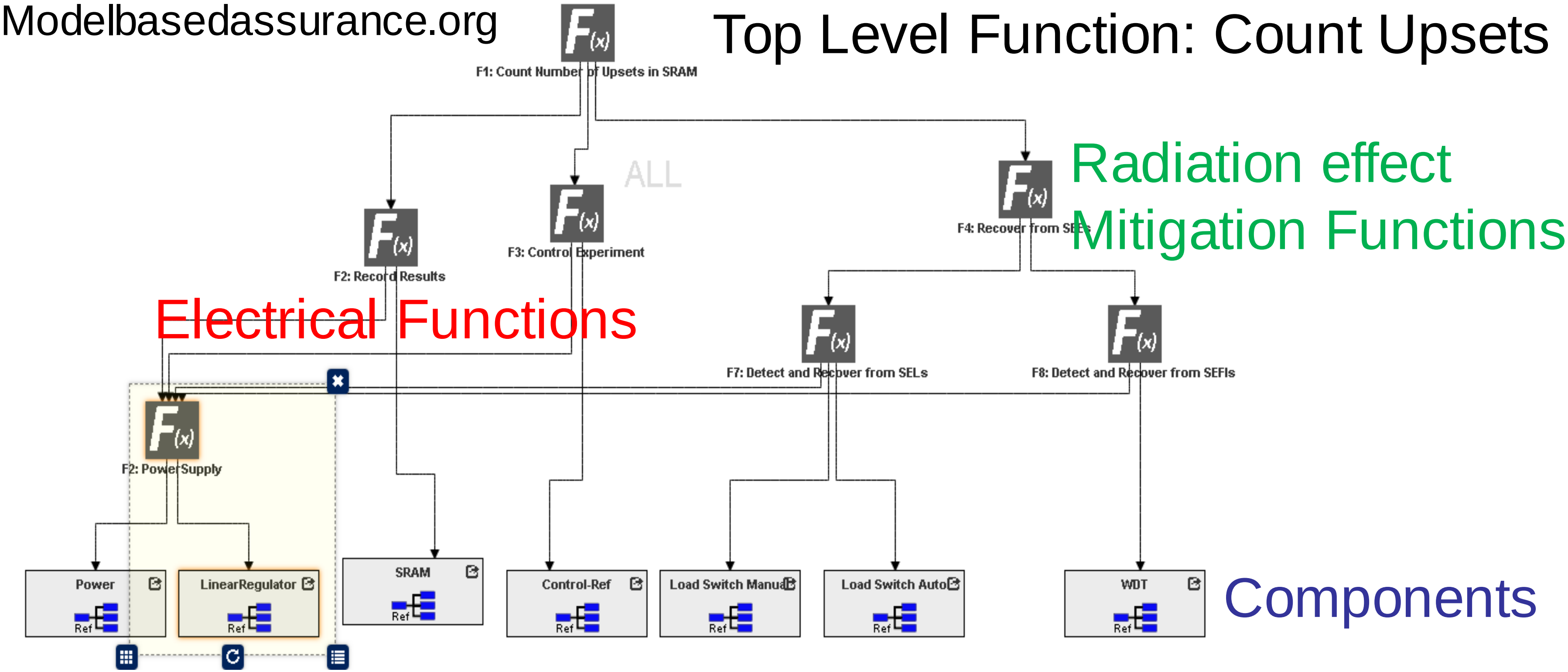

Functional models associate functions with components

Architectural Model of REM Board

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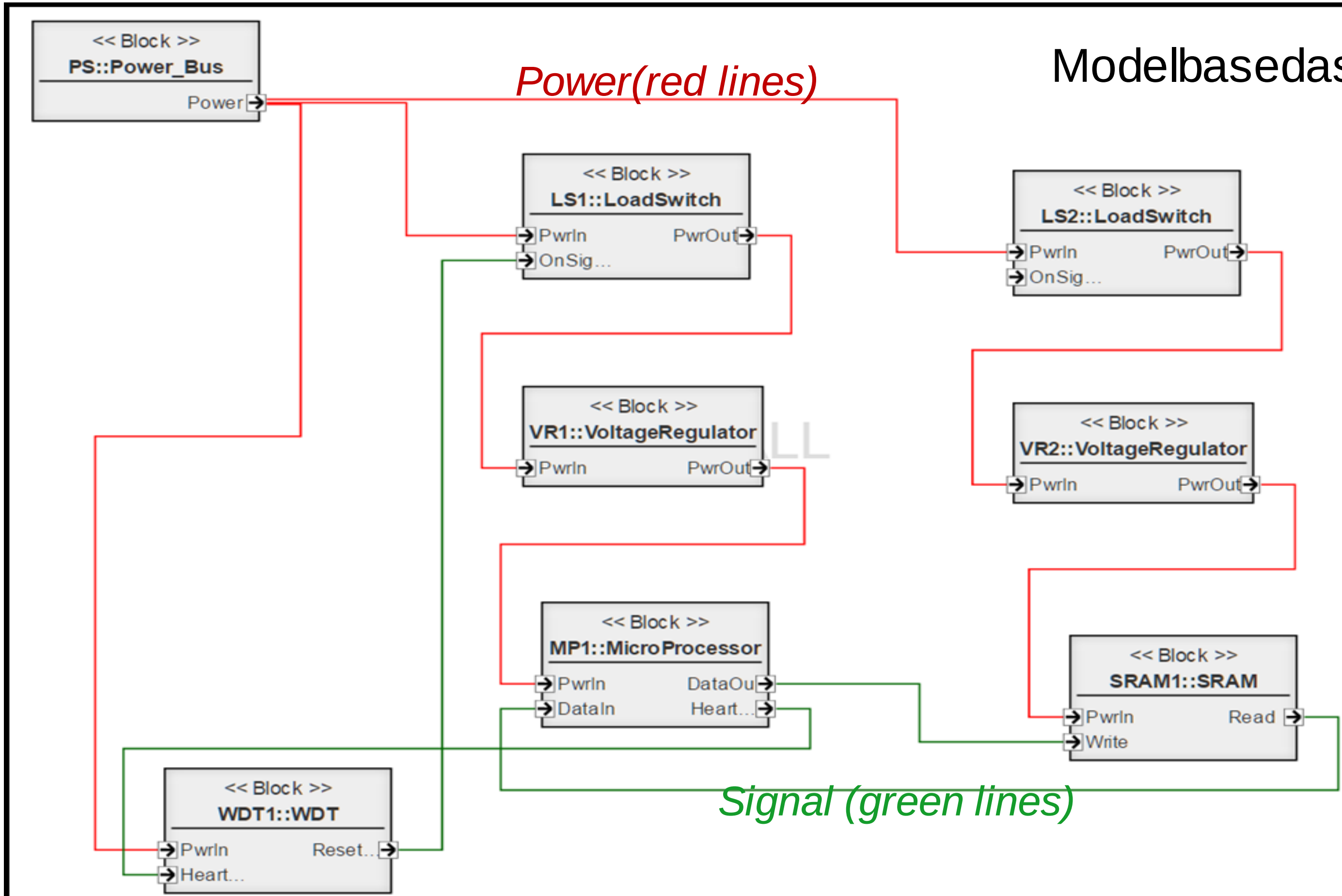

Architectural Models capture the structure and interconnection of the system and fault propagation

Component Fault Propagation Model

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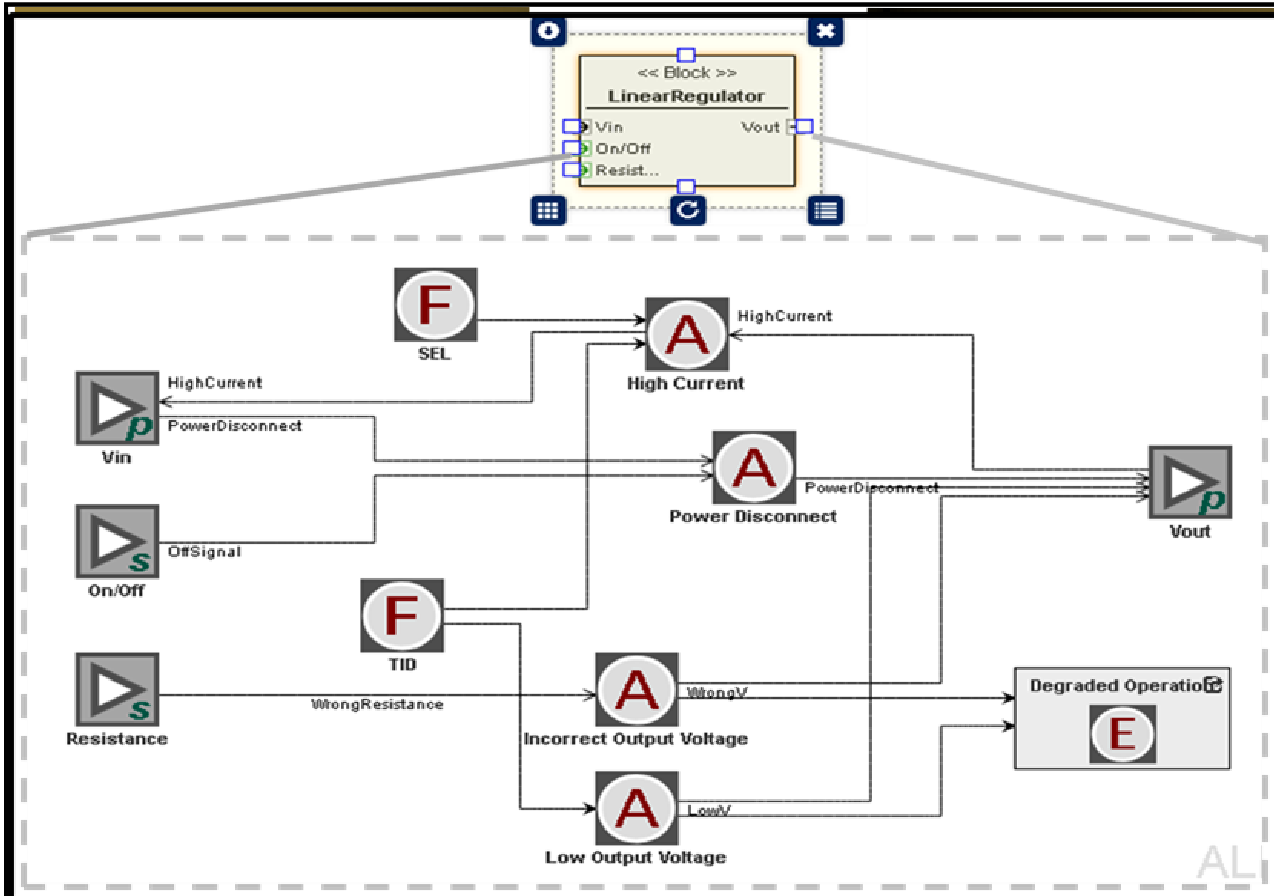

Fault Propagation Models show how fault effects originate in components and propagate from the component through the structure of the system

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Component Fault Propagation Model: Fault

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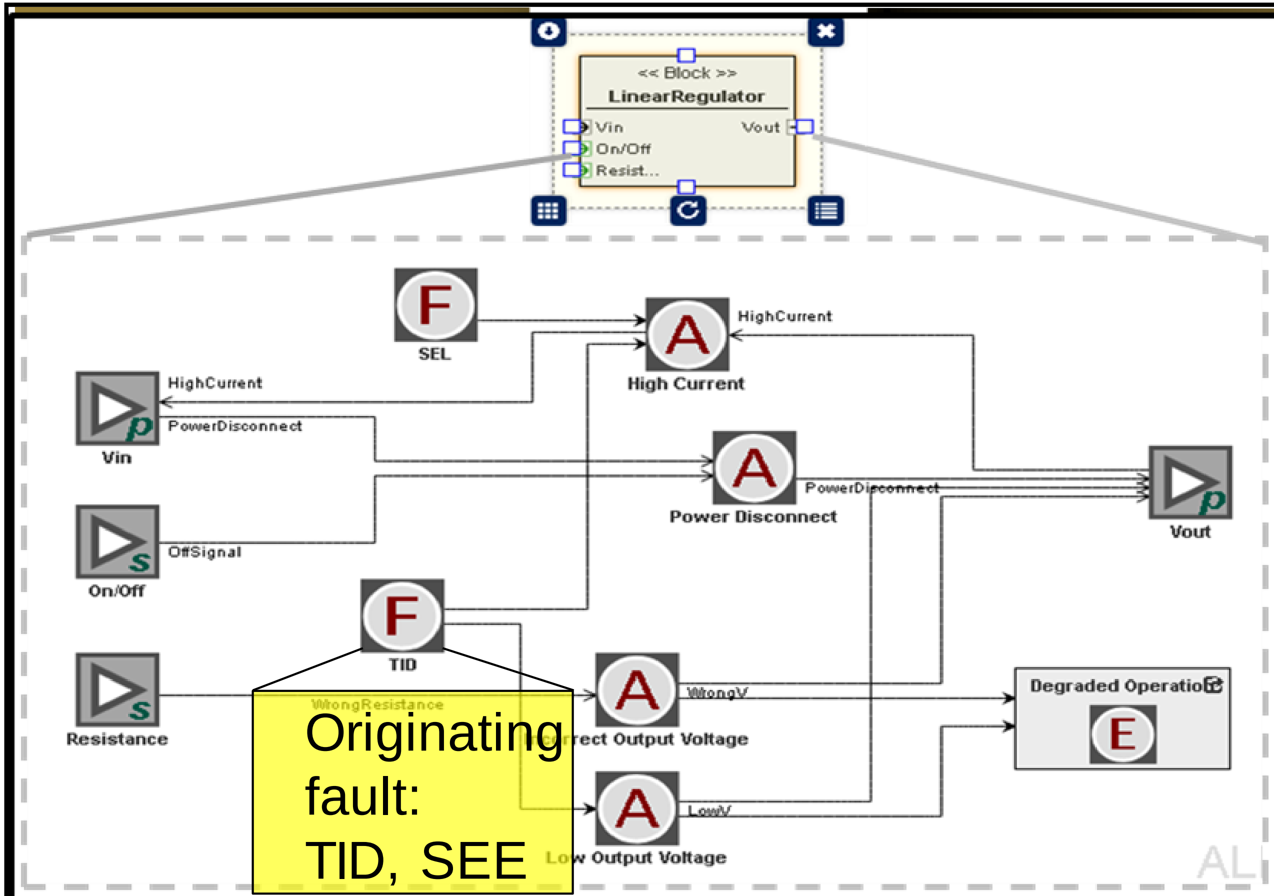

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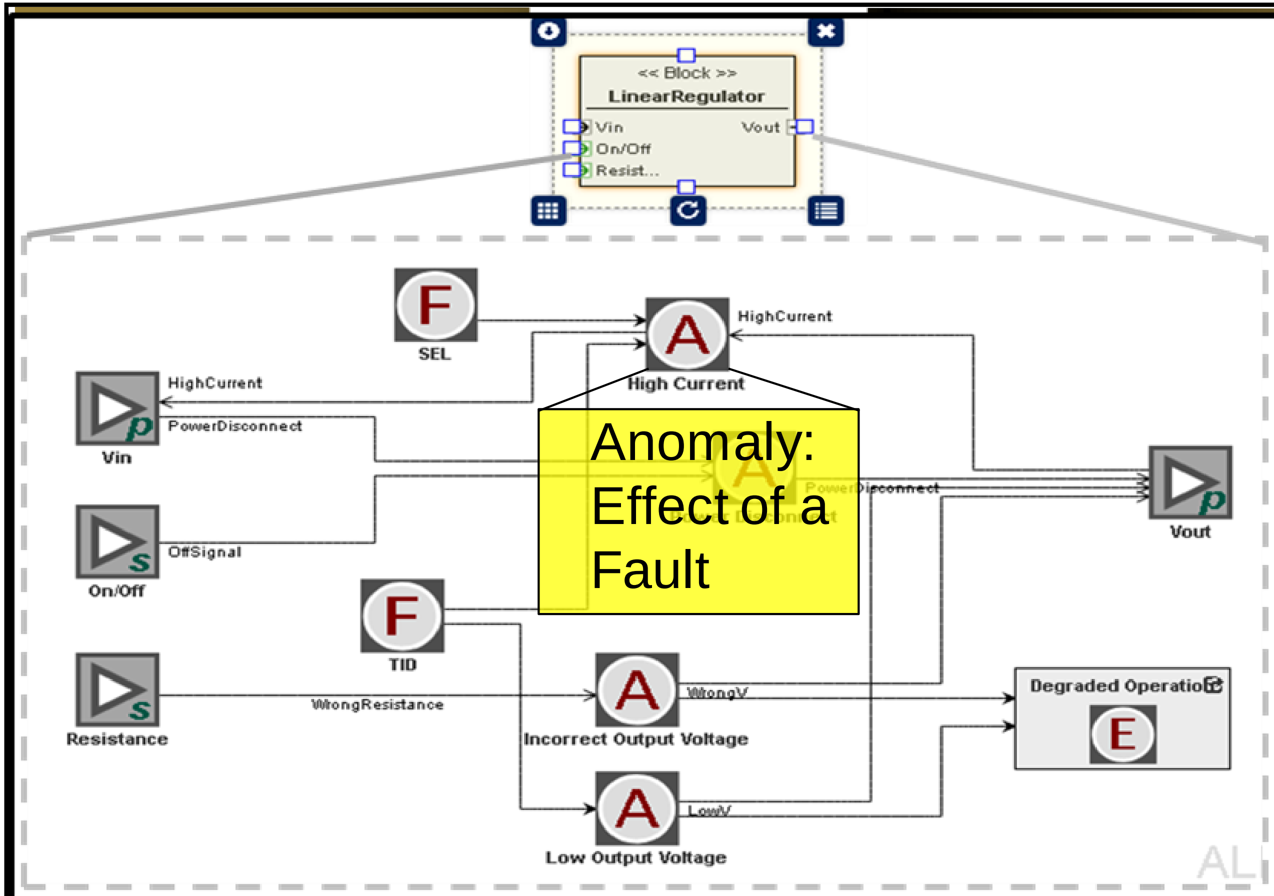
Component Fault Propagation Model: Anomaly



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Component Fault Propagation Model: Port

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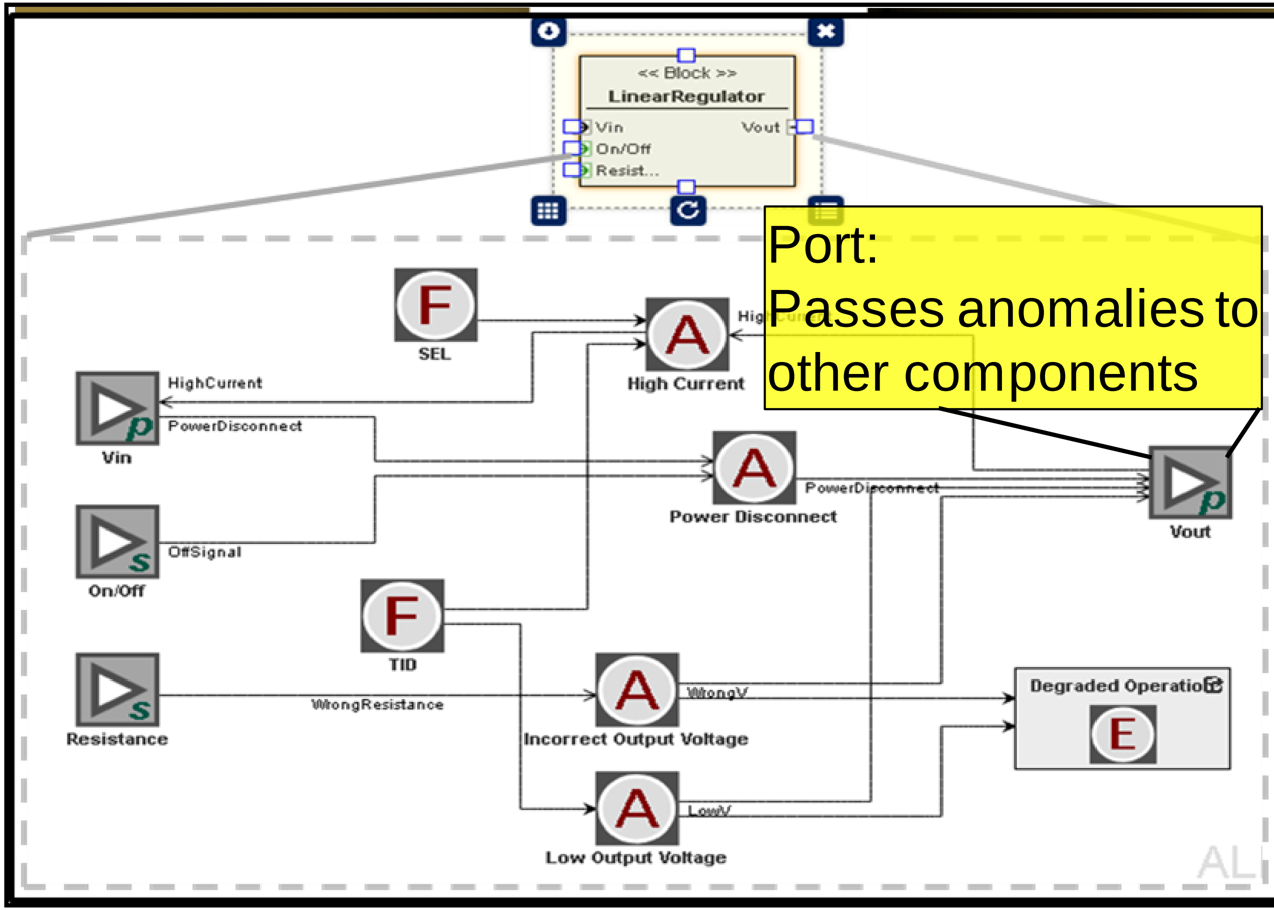

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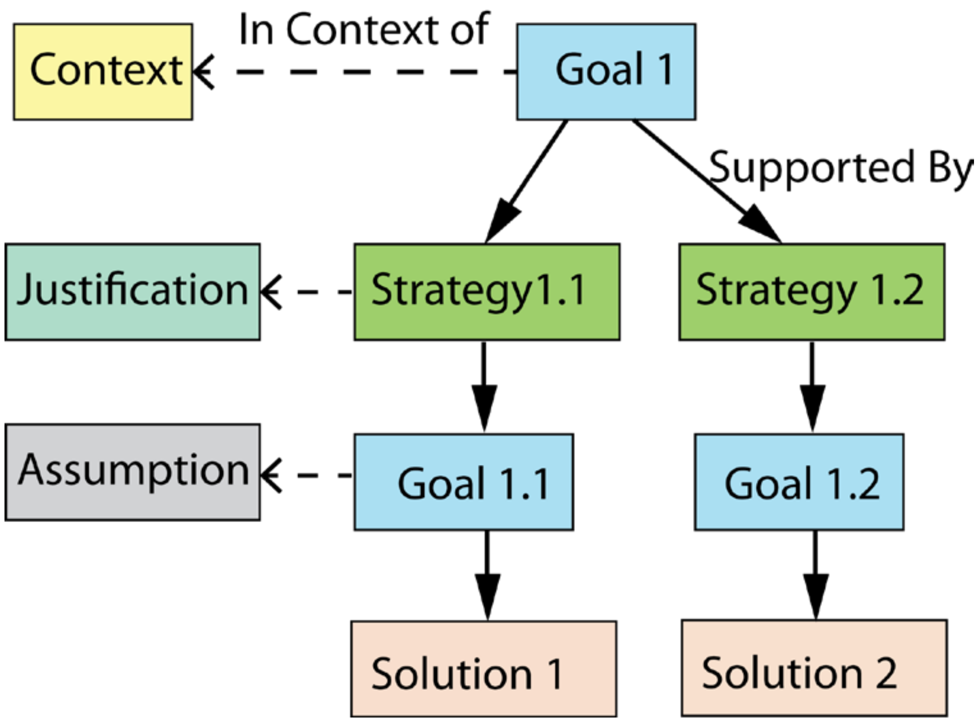
Goal Structuring Notation (GSN)



Colors/Shapes Denote Function

[1] GSN Community Standard Version 1 2011

Goal=Claim
Strategy=Inference
Solution=Evidence
Context=Background
Justification=Rationale
Assumption=Unsub-stantiated Claim

Benefits of GSN

Makes assumptions explicit
Connects assurance case to models of system
Shows how argument is supported by evidence
Context shows spacecraft environment and requirements

GSN Assurance REM SEU Experiment Board

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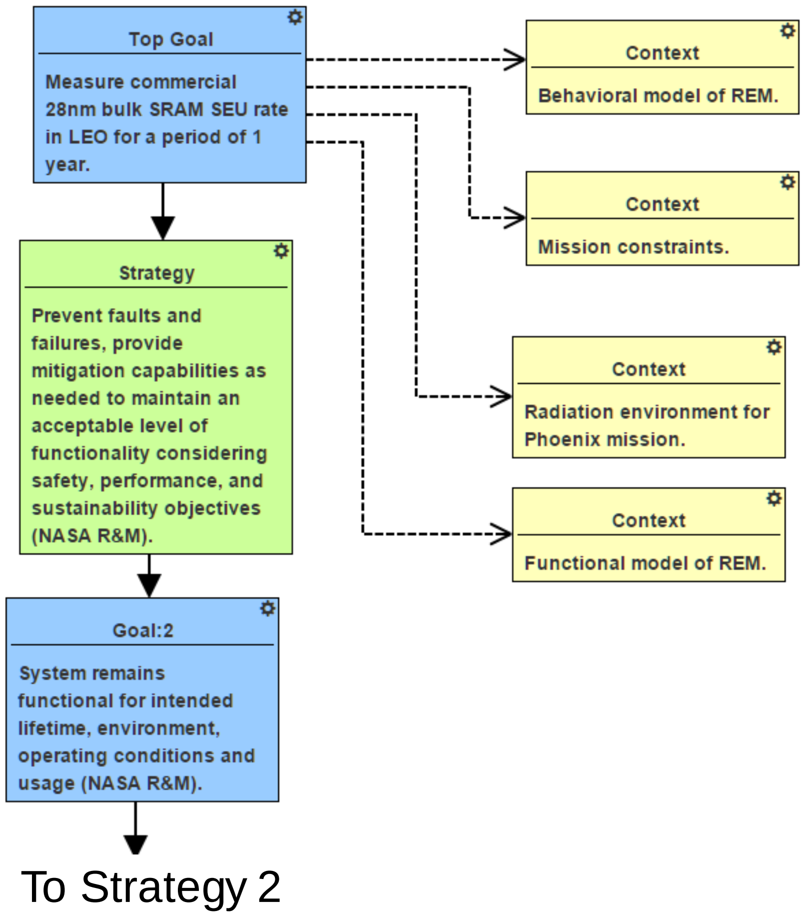

- Top Goal states overall objective
- Mission constraints can be radiation environment, performance requirements, cost constraints, etc.
- Top-level goals and strategies track NASA R&M template

Mission Assurance over the Development Lifecycle

- Create radiation assurance case early in the development cycle-find radiation problems earlier
- ”Time-Varying” Radiation Assurance Case
- *R. A. Austin*, R. D. Schrimpf, A. F. Witulski, N. Mahadevan, G. Karsai, B. D. Sierawski, and R. A. Reed, “Capturing and Modeling Radiation Hardness Assurance throughout the Project Lifecycle,” 27th Annual Single Events Symposium, La Jolla, CA, 2019.
- Interaction of requirements, component knowledge, and system design information

The Parts Engineer

- **Starting point: Single-event Burnout Requirement**
- **End work product: The approved part list**
- **Information needed: Mission orbit and lifetime (can change), parts currently in the system (can change), how the parts are used in the system (can change)**
  - How can I keep up to date with system changes?
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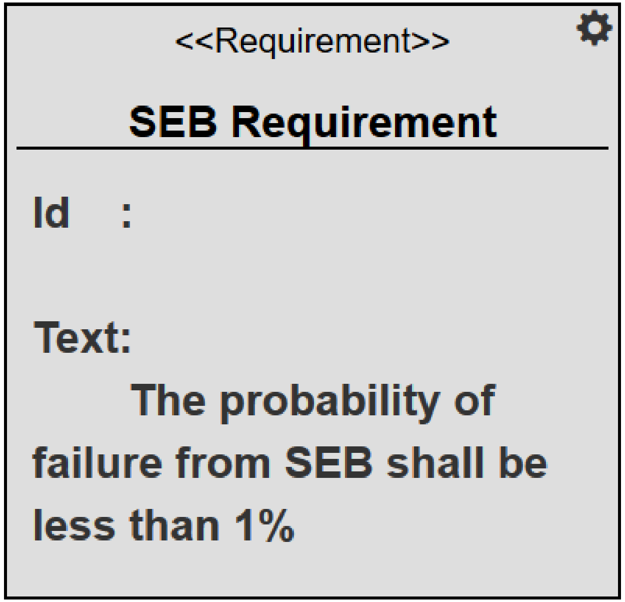

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Microcontroller	Passed	
SiC power MOSFET	Passed with comments	Probability of failure of 2% at derating of 50% with current shielding

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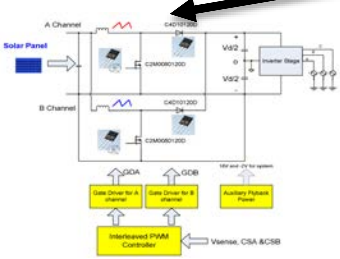
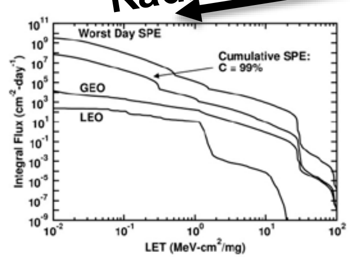
System Design

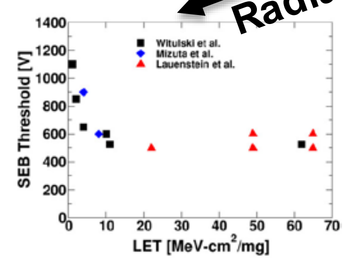
Radiation Environment

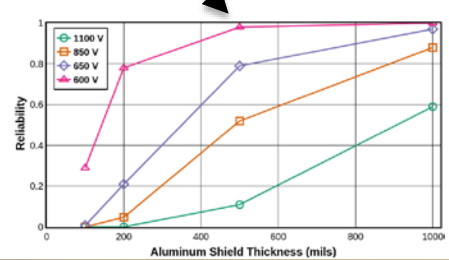
Radiation Test

Reliability Calculation









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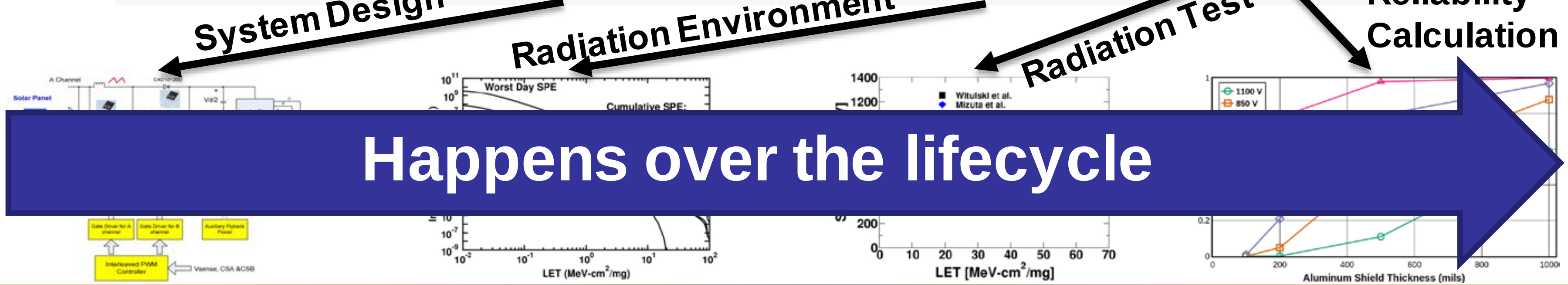

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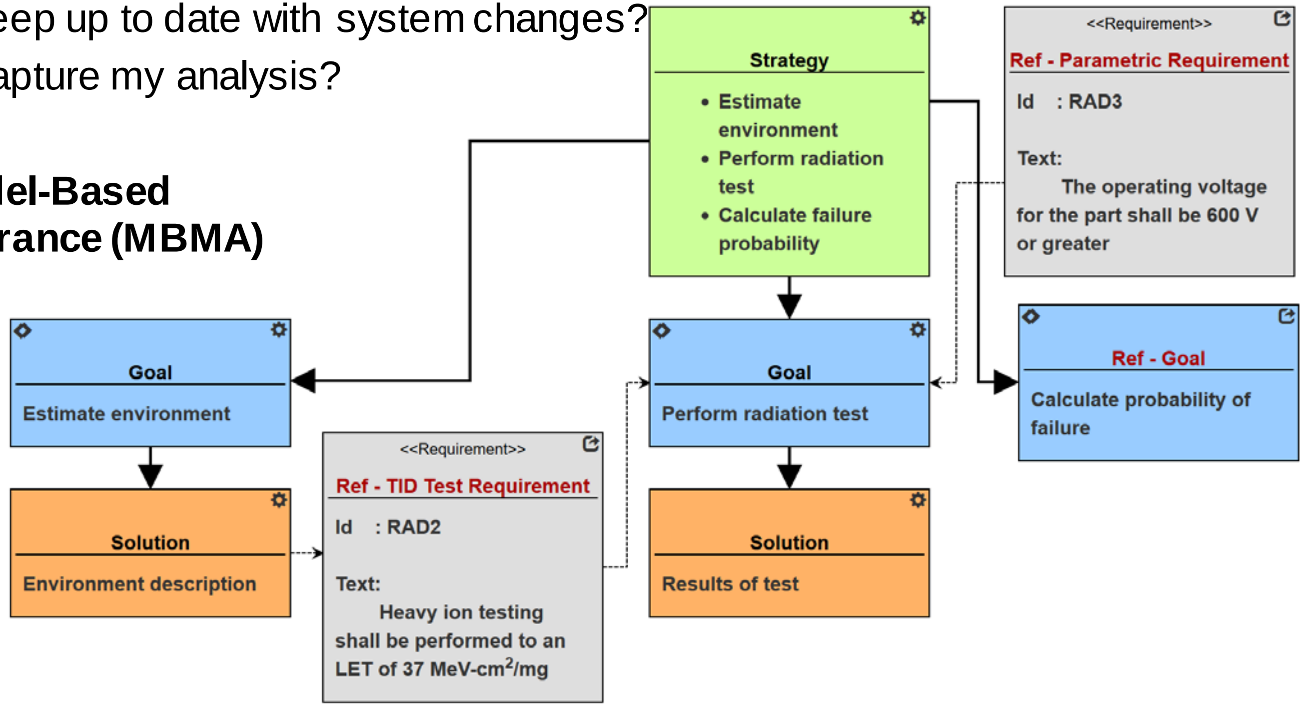
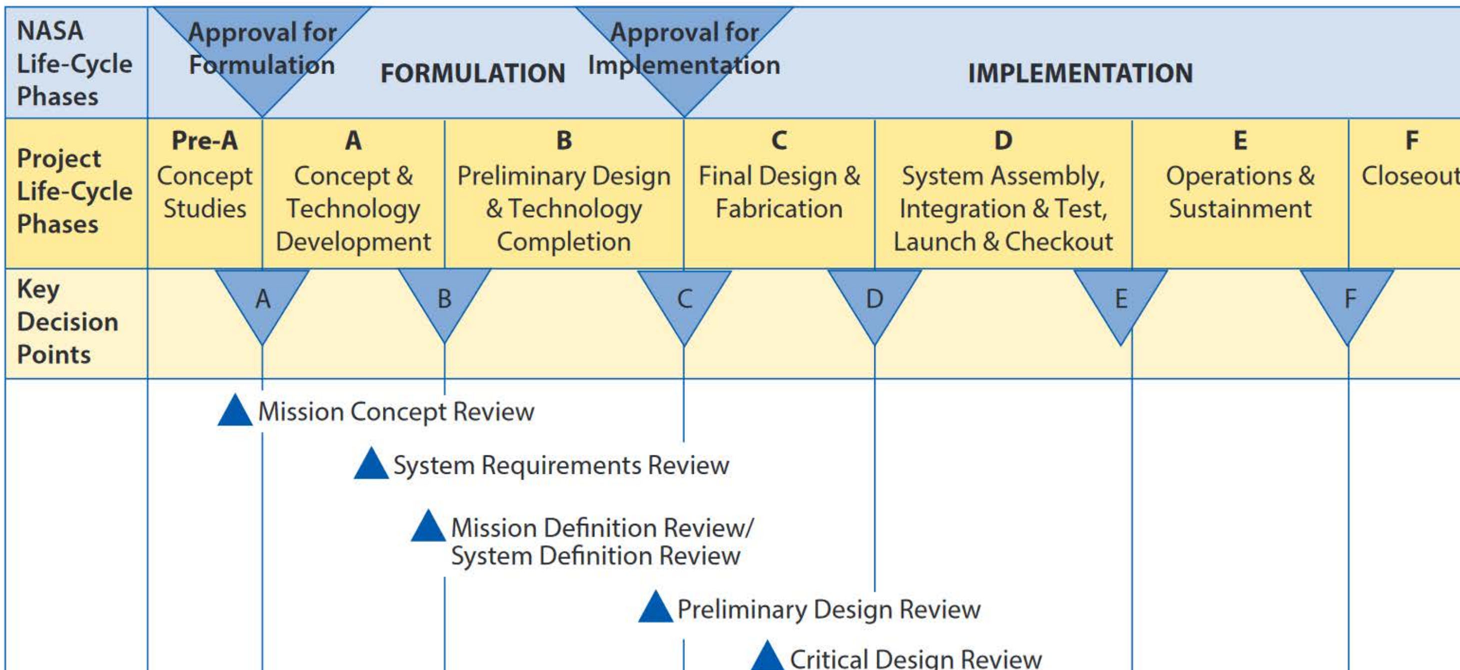
- **Solution: Model-Based Mission Assurance (MBMA)**



NASA Project Lifecycle Phases

- **The reliability tests and analysis required to verify the requirement take place during several life-cycle phases**
  - In addition, the analysis requires the system to mature and will have to be re-evaluated if the system or mission changes



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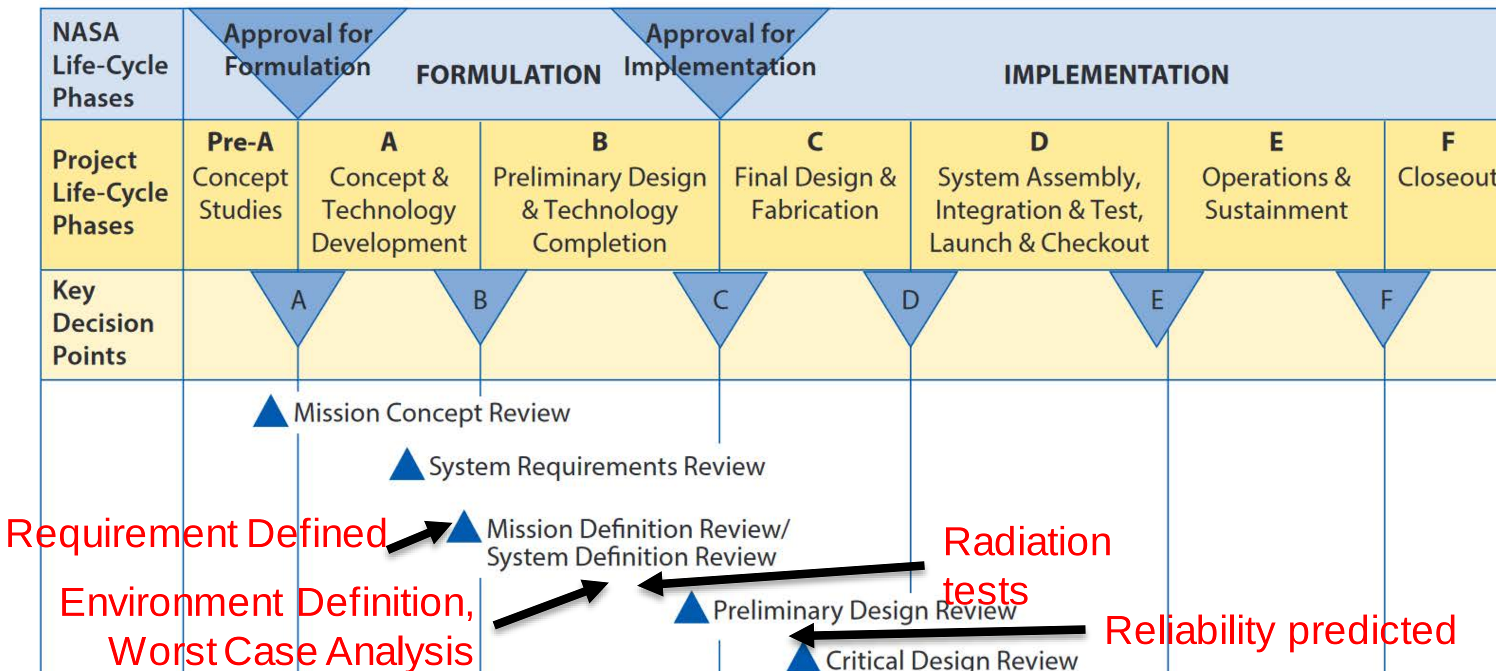
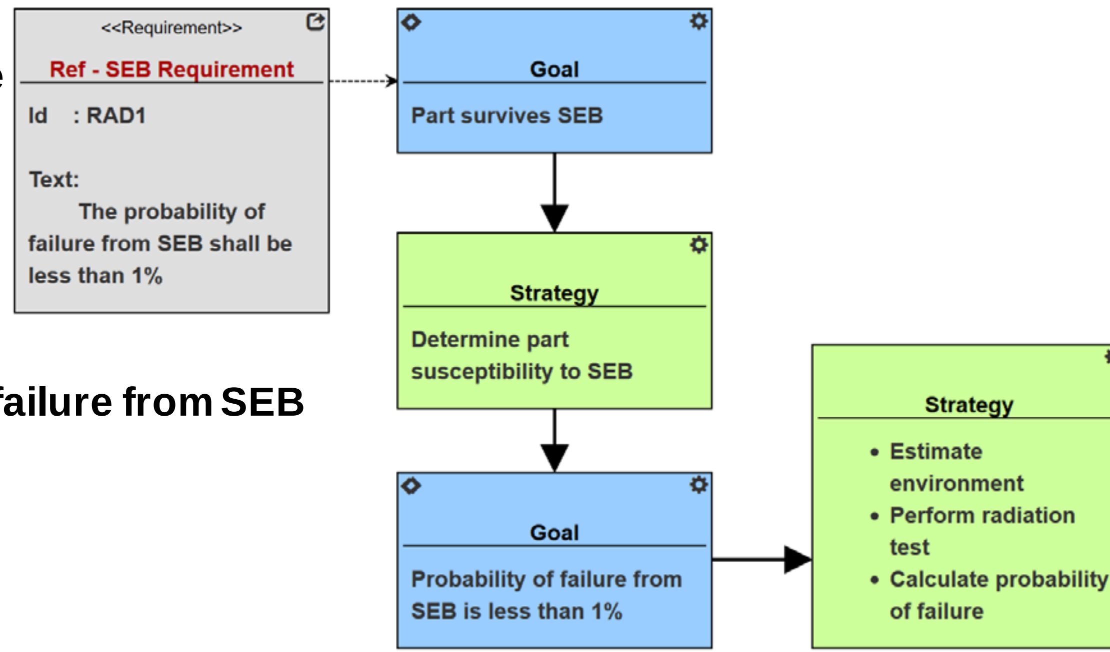


Today's Example: Single Event Burnout Requirement

Project Life-Cycle Phases	Pre-A Concept Studies	A Concept & Technology Development	B Preliminary Design & Technology Completion	C Final Design & Fabrication	D System Assembly, Integration & Test, Launch & Checkout	E Operations & Sustainment	F Closeout

Requirement Defined

- **Beginning of Phase B: GSN template for part assurance**
  - Generic goals generated from part assurance templates
  - Framework for planning RHA activities



- **Requirement: The probability of failure from SEB shall be less than 1%**

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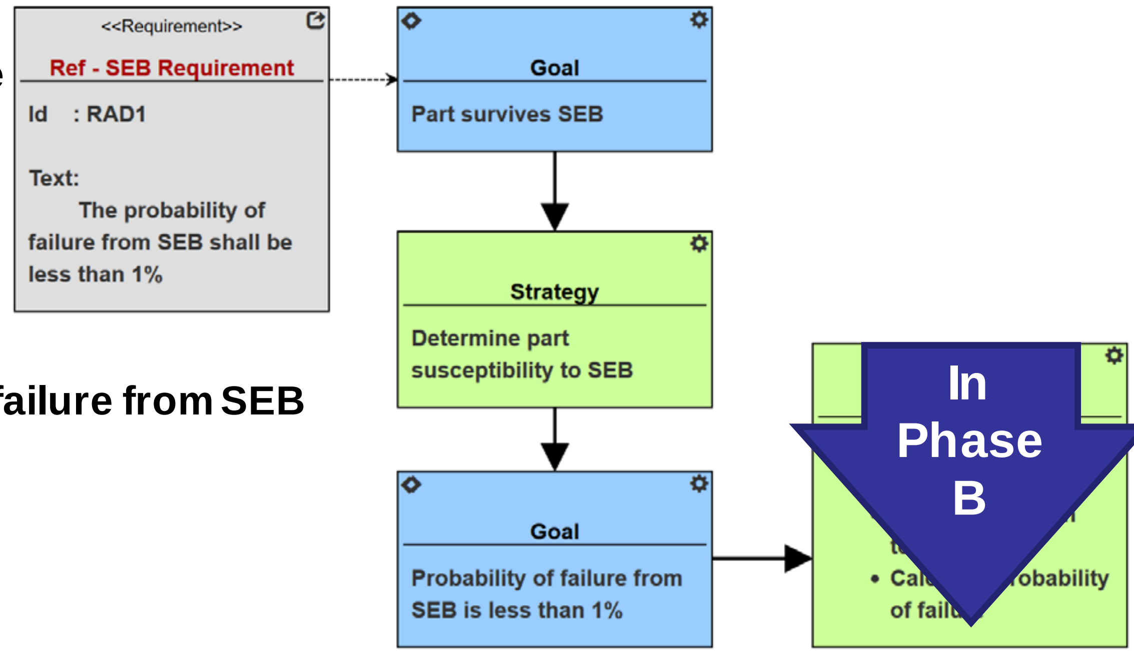

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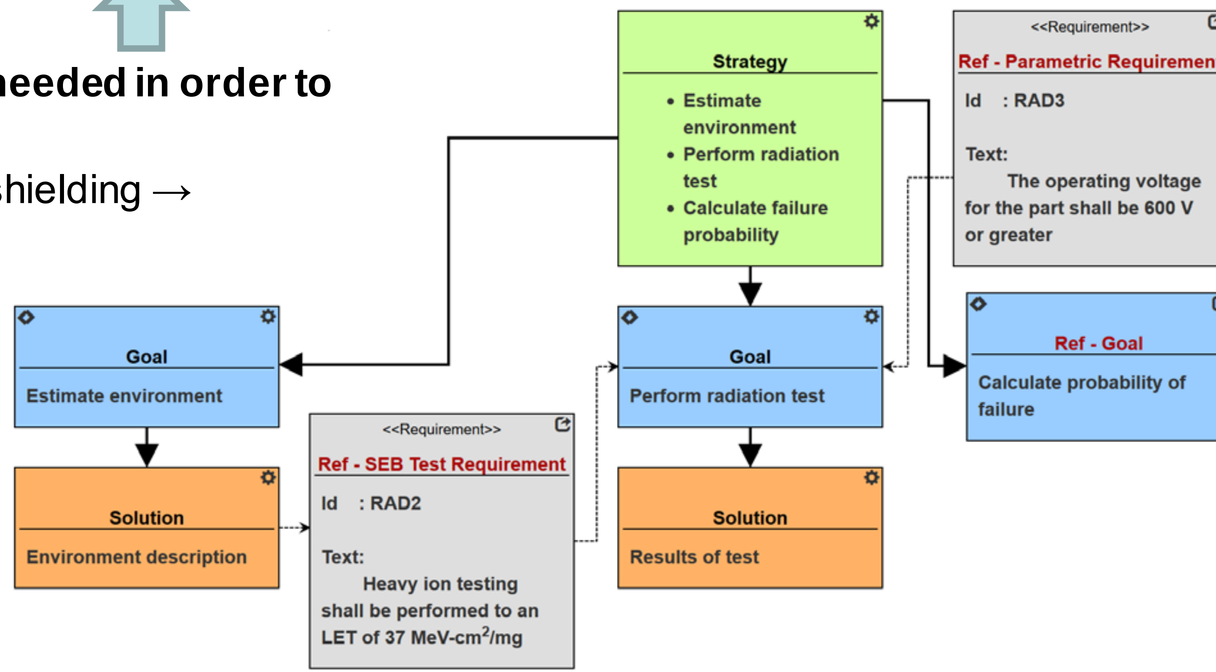

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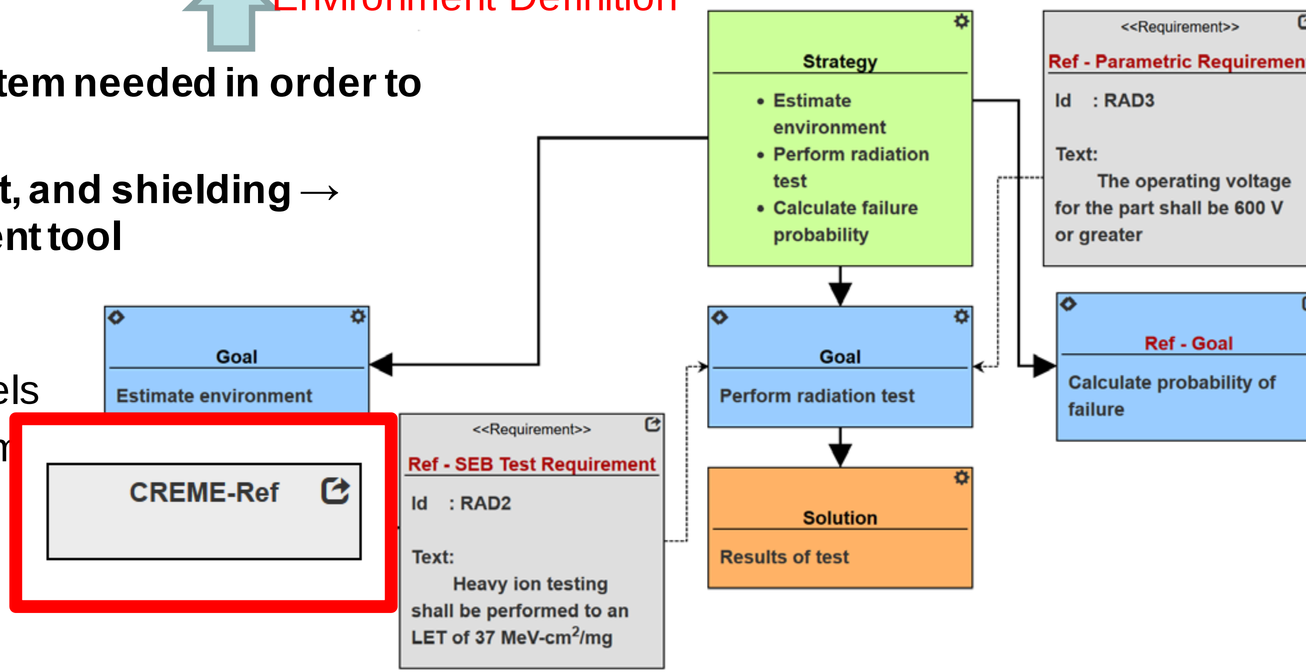

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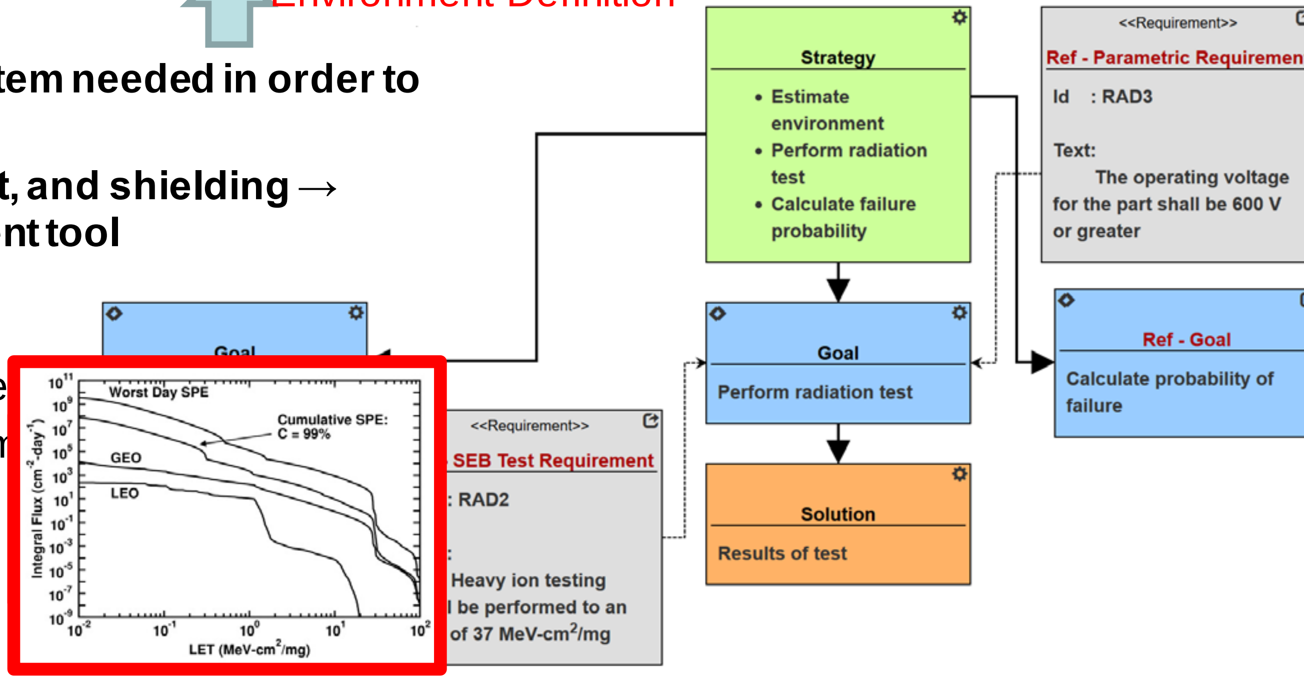

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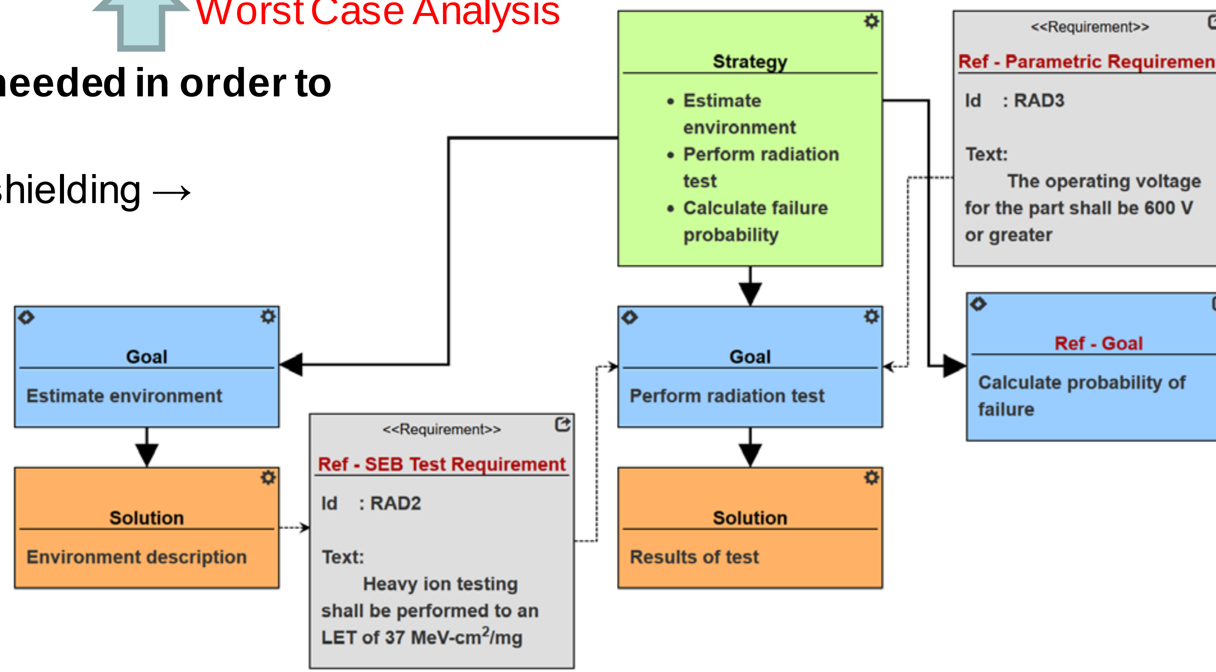

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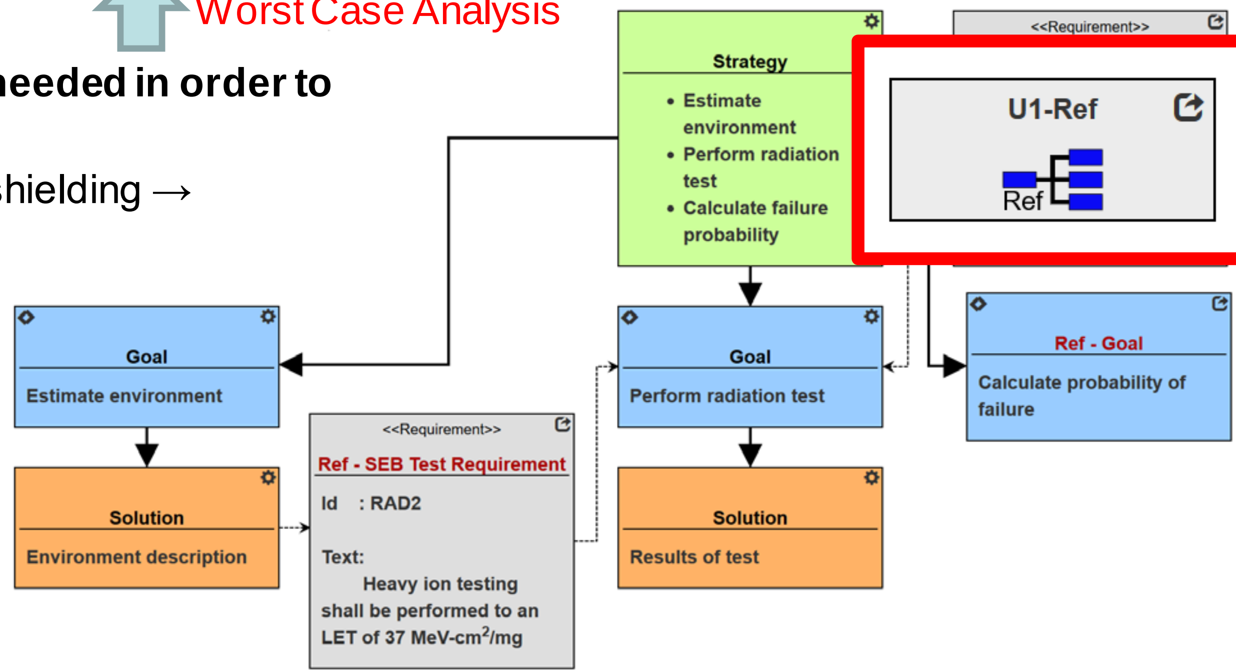

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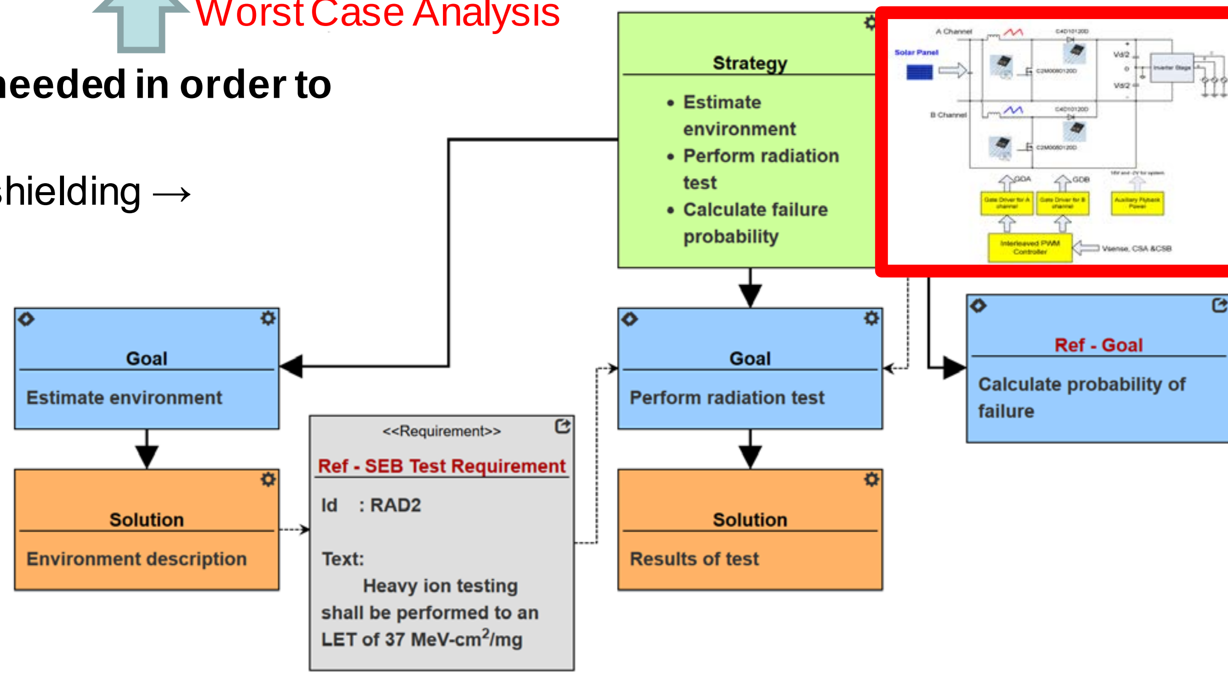

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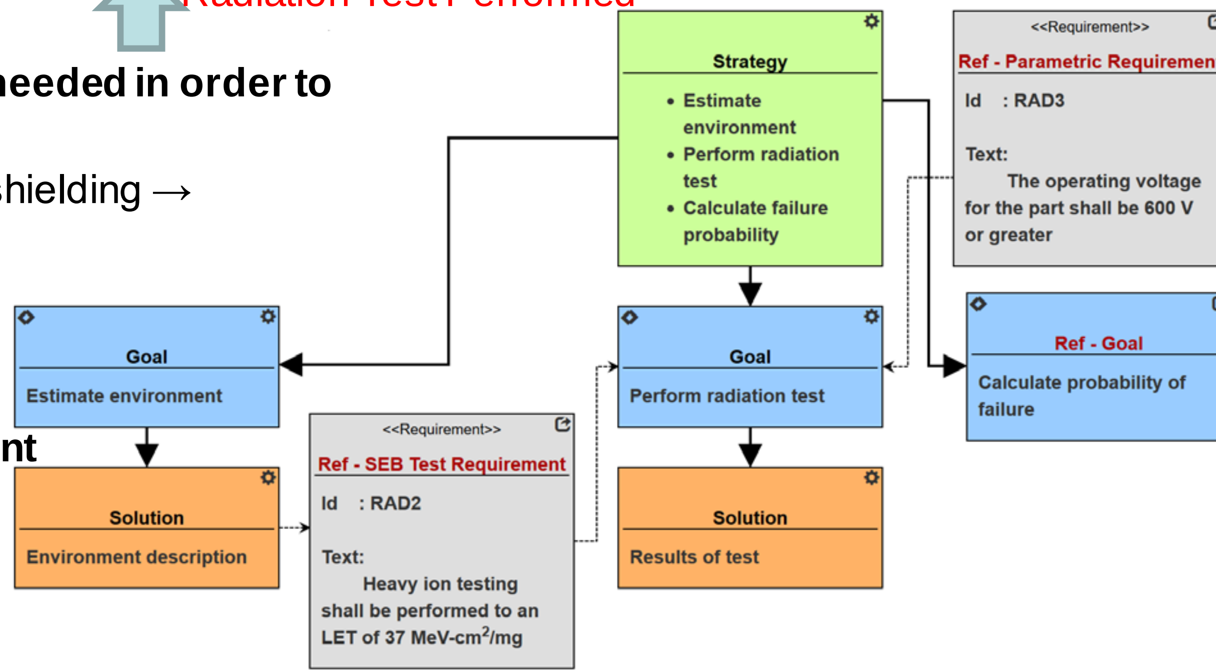

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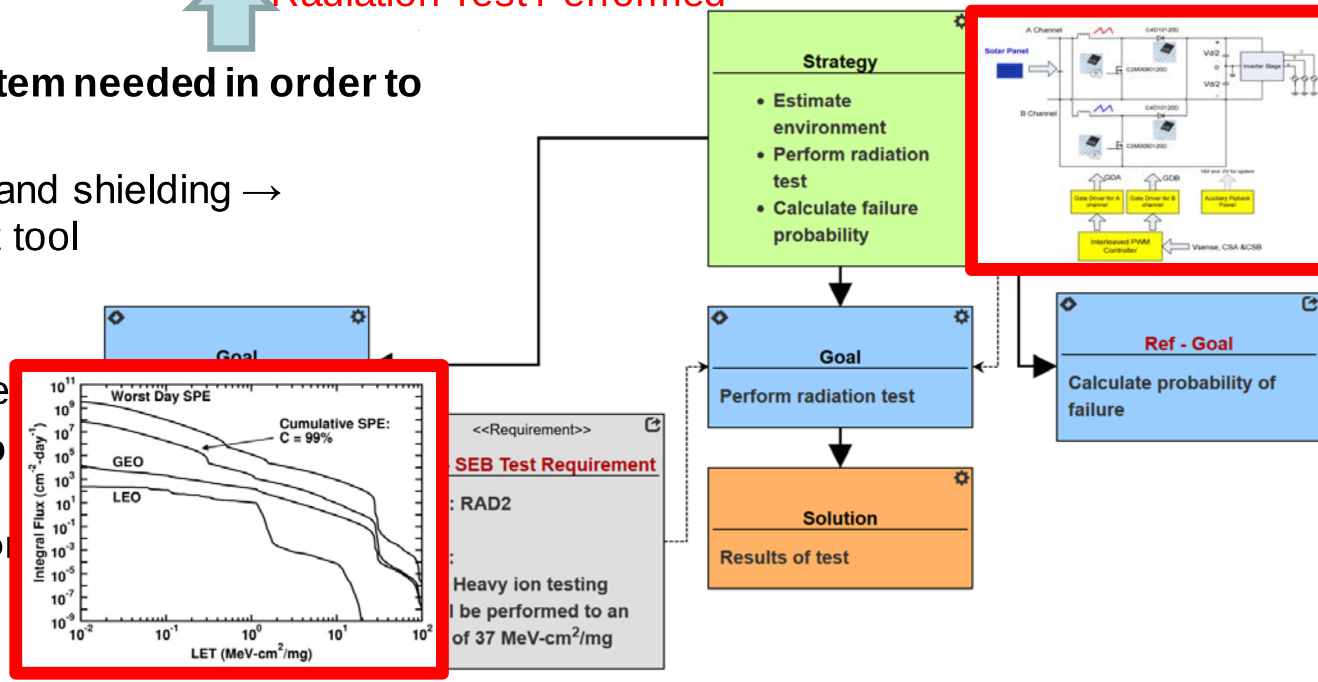

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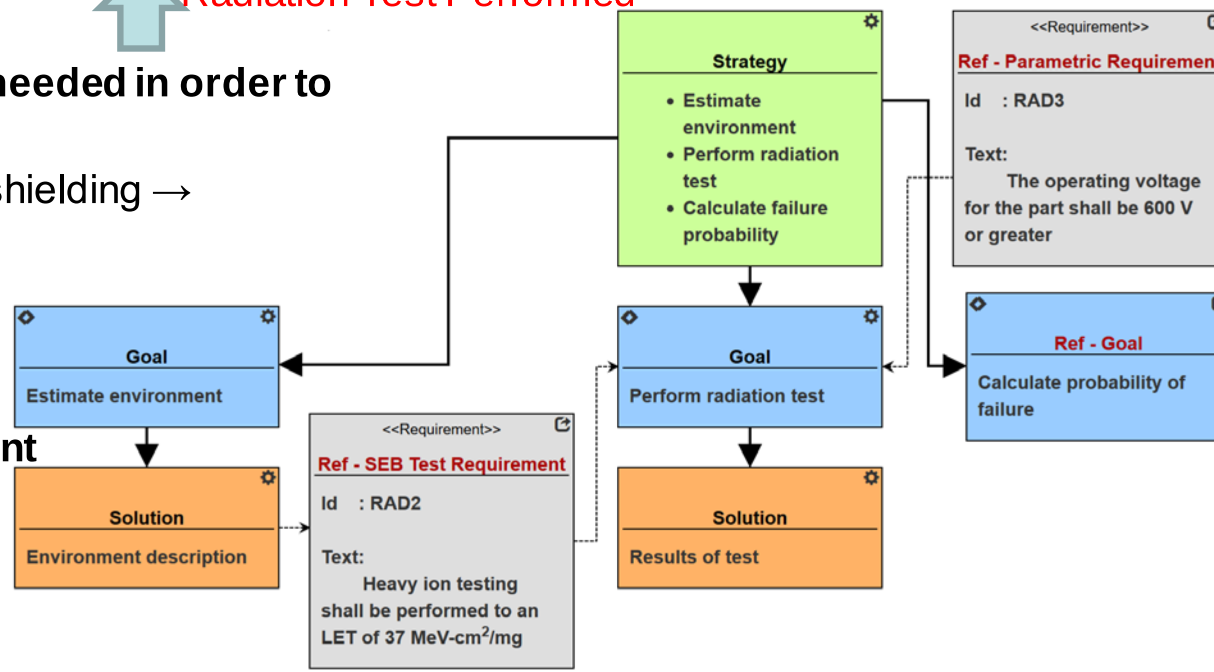

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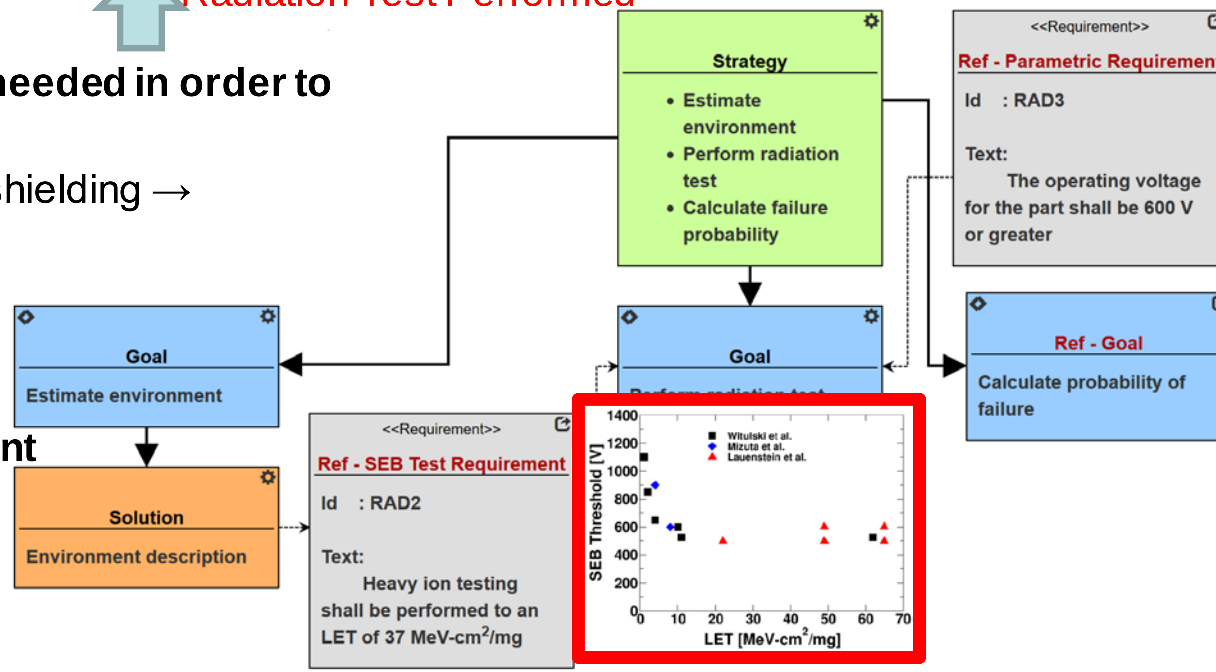

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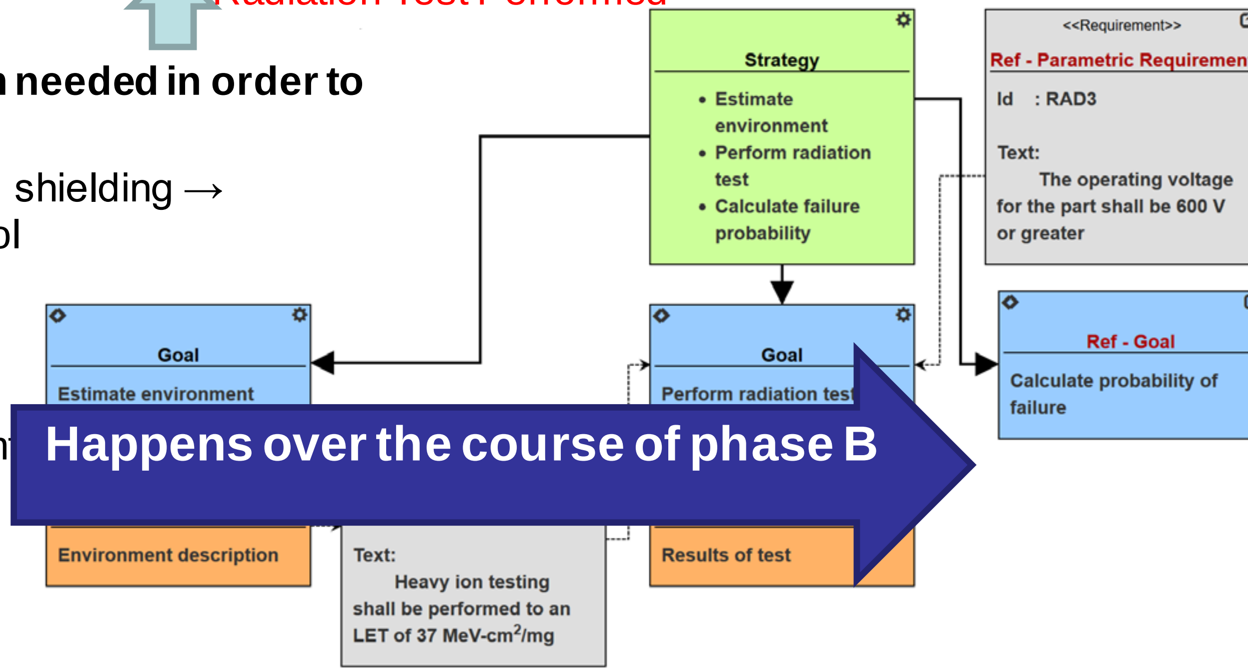

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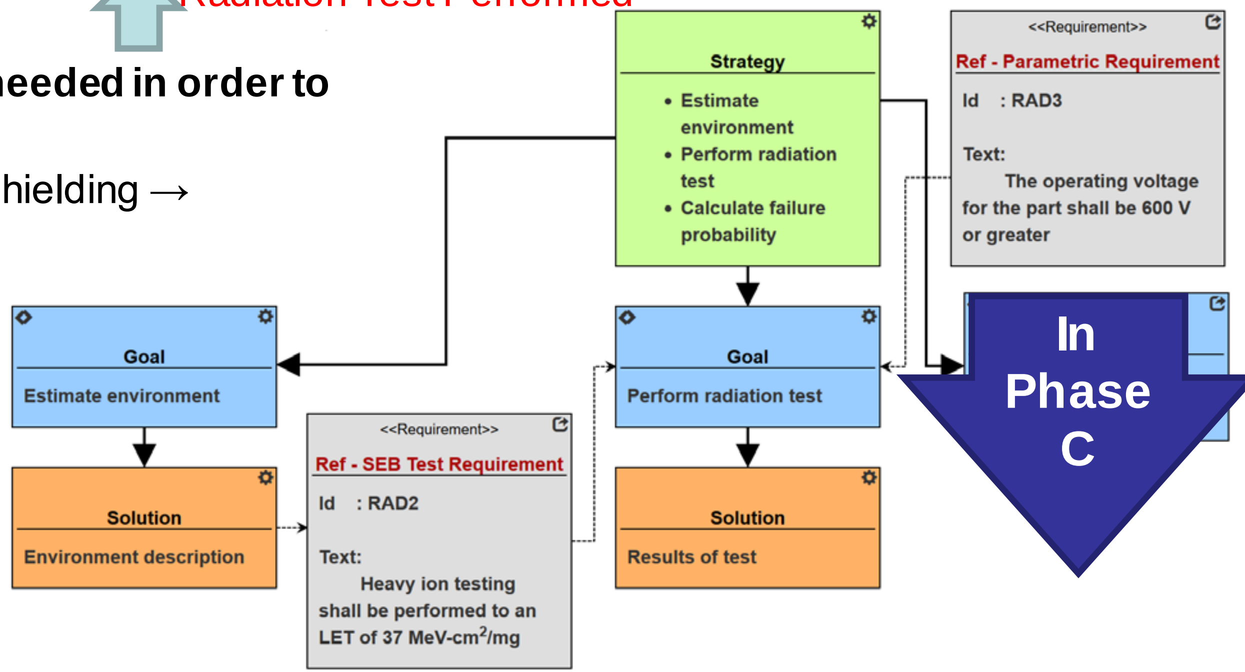
  - Part use in system → Inputs to determine parametric failure levels
  - Outputs from environment tool and part failure analysis → Inputs for radiation test

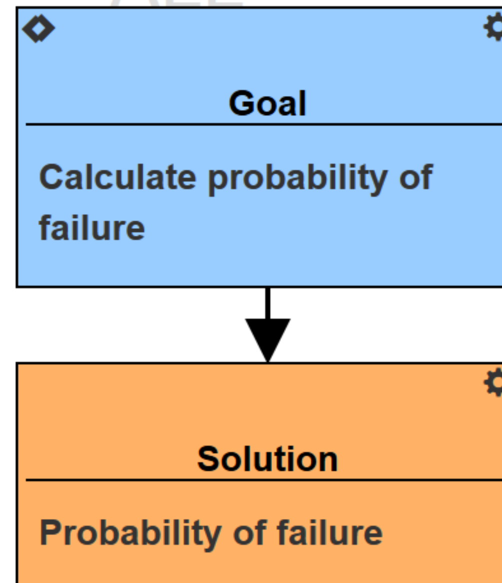


Today’s Example: Single Event Burnout Requirement

Project Life-Cycle Phases	Pre-A Concept Studies	A Concept & Technology Development	B Preliminary Design & Technology Completion	C Final Design & Fabrication	D System Assembly, Integration & Test, Launch & Checkout	E Operations & Sustainment	F Closeout

Reliability Predicted

- **Requirement: Mission shall meet a reliability level**
- **End of Phase C**
  - Probability calculation
  - Assuming nothing changed about the system from Phase B



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Reliability Predicted

- **Requirement: Mission shall meet a reliability level**
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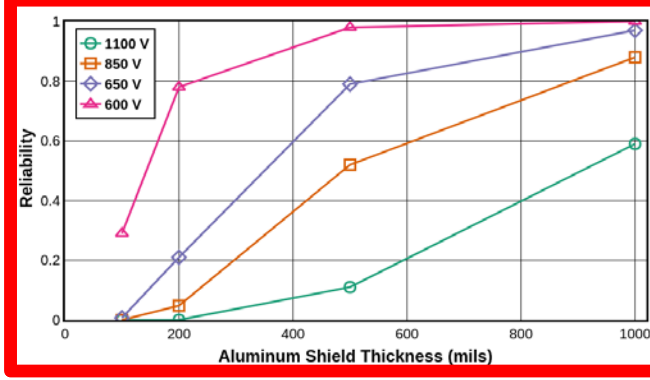
  - Probability calculation
  - Assuming nothing changed about the system from Phase B
- **Reliability calculation attached to solution**

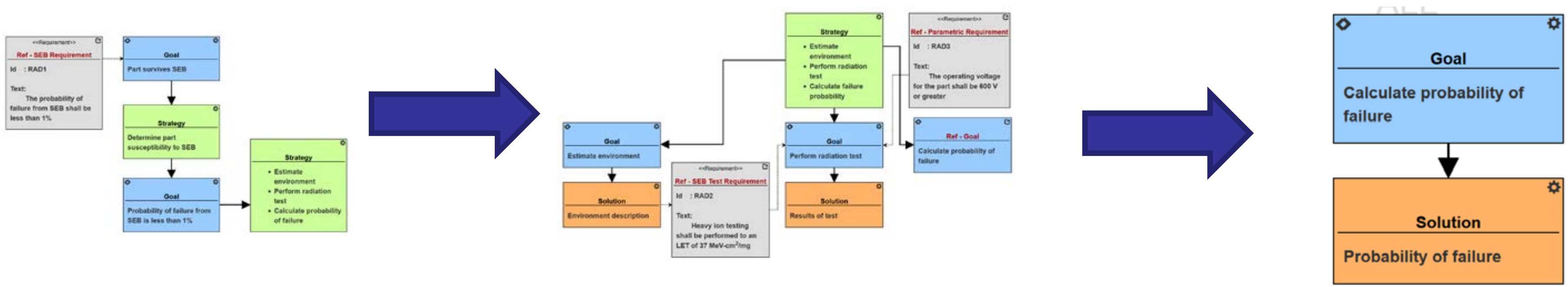
Goal

Calculate probability of failure



Conclusions

- **MBMA is a function of time**
  - Captures the evolution of mission assurance as the system is developed
- **MBMA enables concurrent engineering of reliability and design engineering**
  - Argument structure show how a requirement is verified and how it is derived
- **MBMA enables intelligent mission-specific requirements**
  - Illustrates the creation of reliability requirements as more about the mission is known



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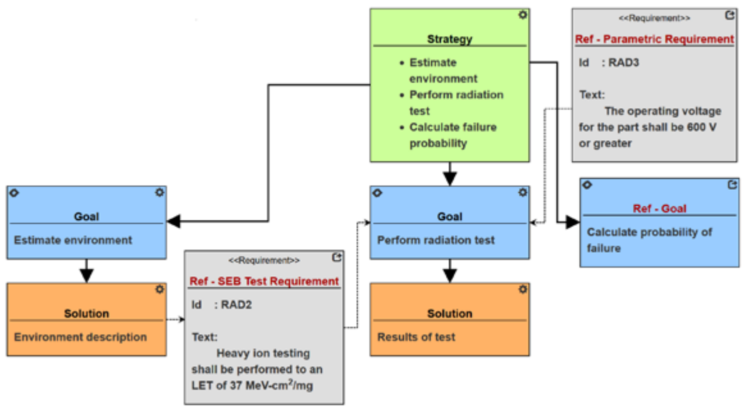

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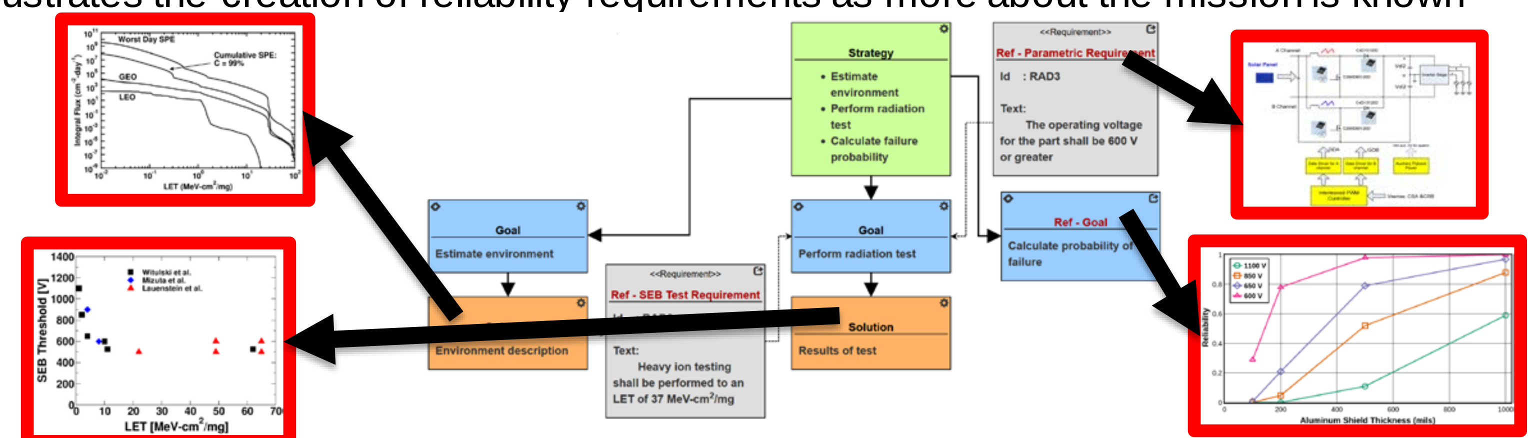

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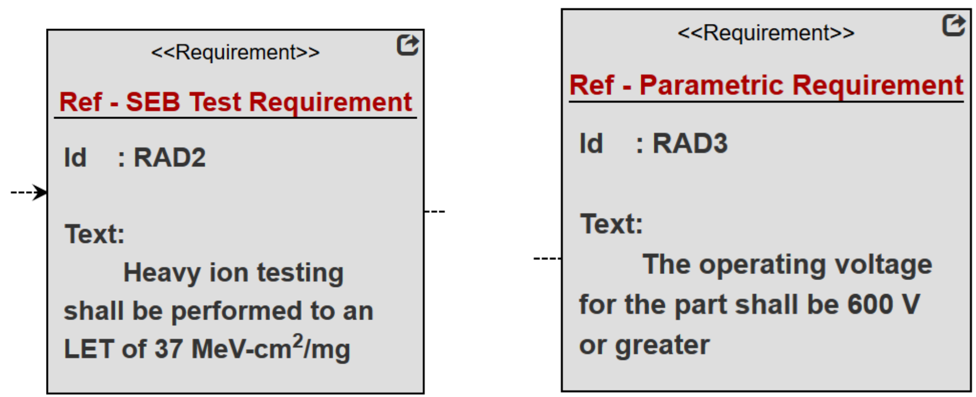

Fault Tree Generation Capability Added to SEAM

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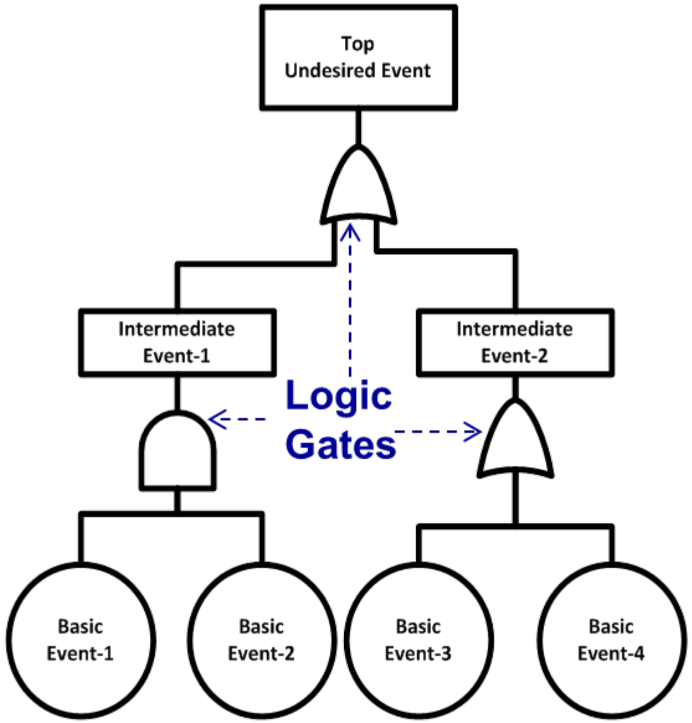
- **Fault tree captures logical relationships between events**
- **Inputs are probabilities of events**
- **System information in SEAM SysML model can be used to generate fault trees for various system functions**
- **Fault tree structure can be exported in standard format to other reliability tools**



Example: Fault Tree for Temperature Control Loop of a Command and Data-Handling Board

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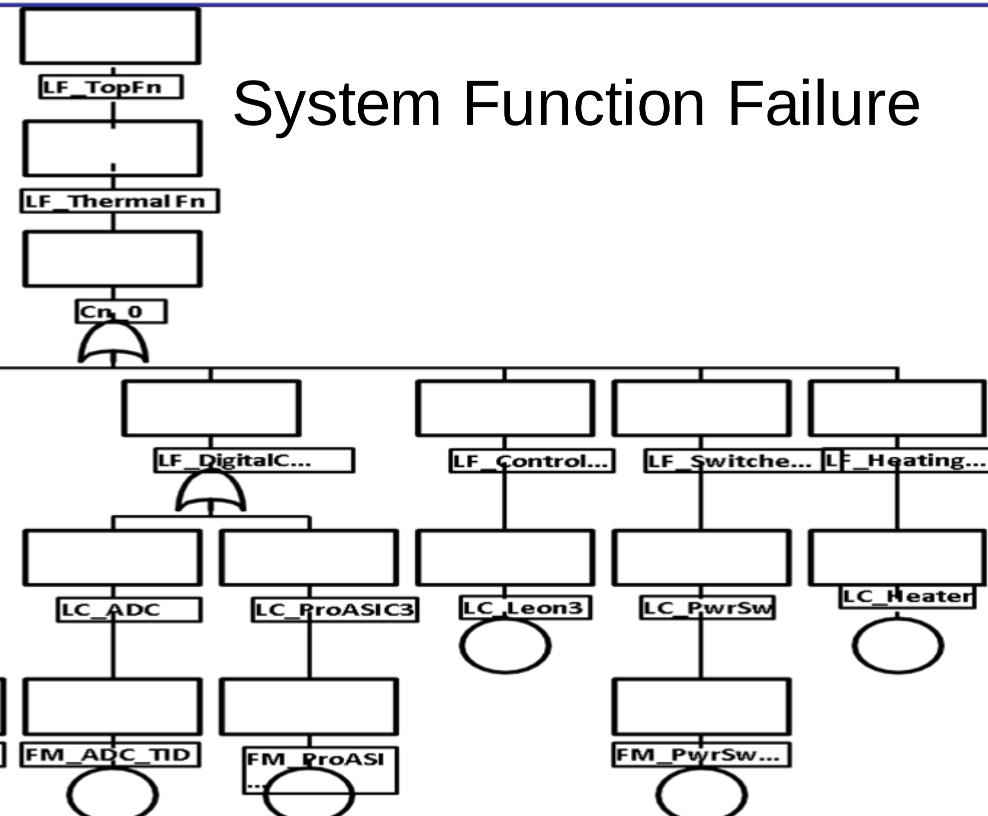
Generated from Functional & Architectural Model in SEAM

System Function Failure



Component failure modes

Activities for SEAM Development in Coming Year

- Promote visibility and adoption of SEAM, e.g., University Nanosat program at AFRL, S3VI at NASA, AAQ at Auburn, NASA MBx community
- Lower the barriers to learning and using SEAM-identify required prior knowledge and skills and make that information explicit
- Develop more libraries and templates of common spacecraft components, functions, assurance arguments

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