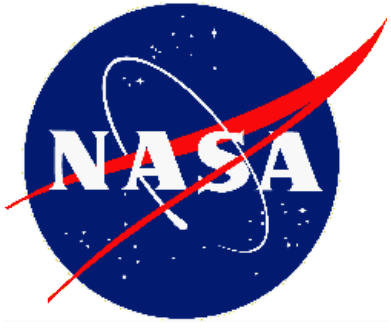


Inclusion of Radiation Effects in the NASA Reliability & Maintainability Standard

R. A. Austin, B. D. Sierawski, J. M. Trippe, K. L. Ryder, J. M. Petrin, A. L. Sternberg, R. A. Reed, A. F. Witulski, N. Mahadevan, G. Karsai, R. D. Schrimpf, K. M. Warren, R. A. Weller
Vanderbilt University, NASA Grant #NNX15AV48G
K. A. LaBel, J. W. Evans, F. J. Groen
NASA

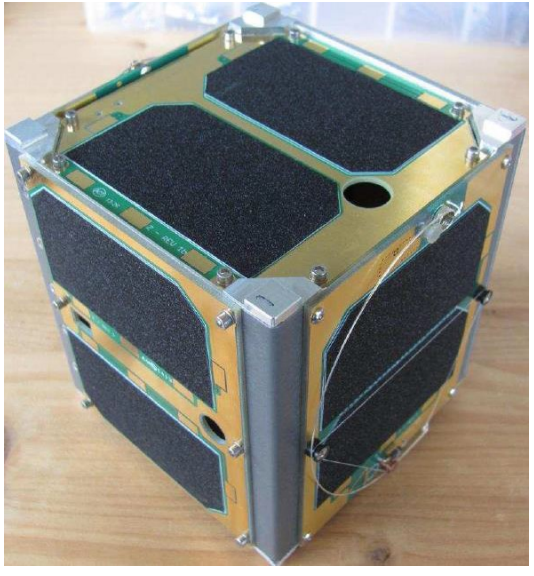
26th Annual
Single Event Effects (SEE) Symposium

Acronyms and Abbreviations

- AMSAT: Radio Amateur Satellite Corporation
- BN: Bayesian Network
- COTS: Commercial Off-the-Shelf
- GSN: Goal Structuring Notation
- IUCF: Indiana University Cyclotron Facility
- LEO: Low Earth Orbit
- NASA: National Aeronautics and Space Administration
- R&M: Reliability and Maintainability
- REM: Experiment Board
- RHA: Radiation Hardness Assurance
- SEE: Single-Event Effects
- SEFI: Single-Event Functional Interrupt
- SEL: Single Event Latch-up
- SEU: Single-Event Upset
- SRAM: Static Random Access Memory
- SysML: System Modeling Language
- TID: Total Ionizing Dose
- VUC: Controller Board
- VUMC: Vanderbilt University Medical Center
- WDT: Watchdog Timer
- WDI: WDT Input
- WDO: WDT Output

Motivation: CubeSats

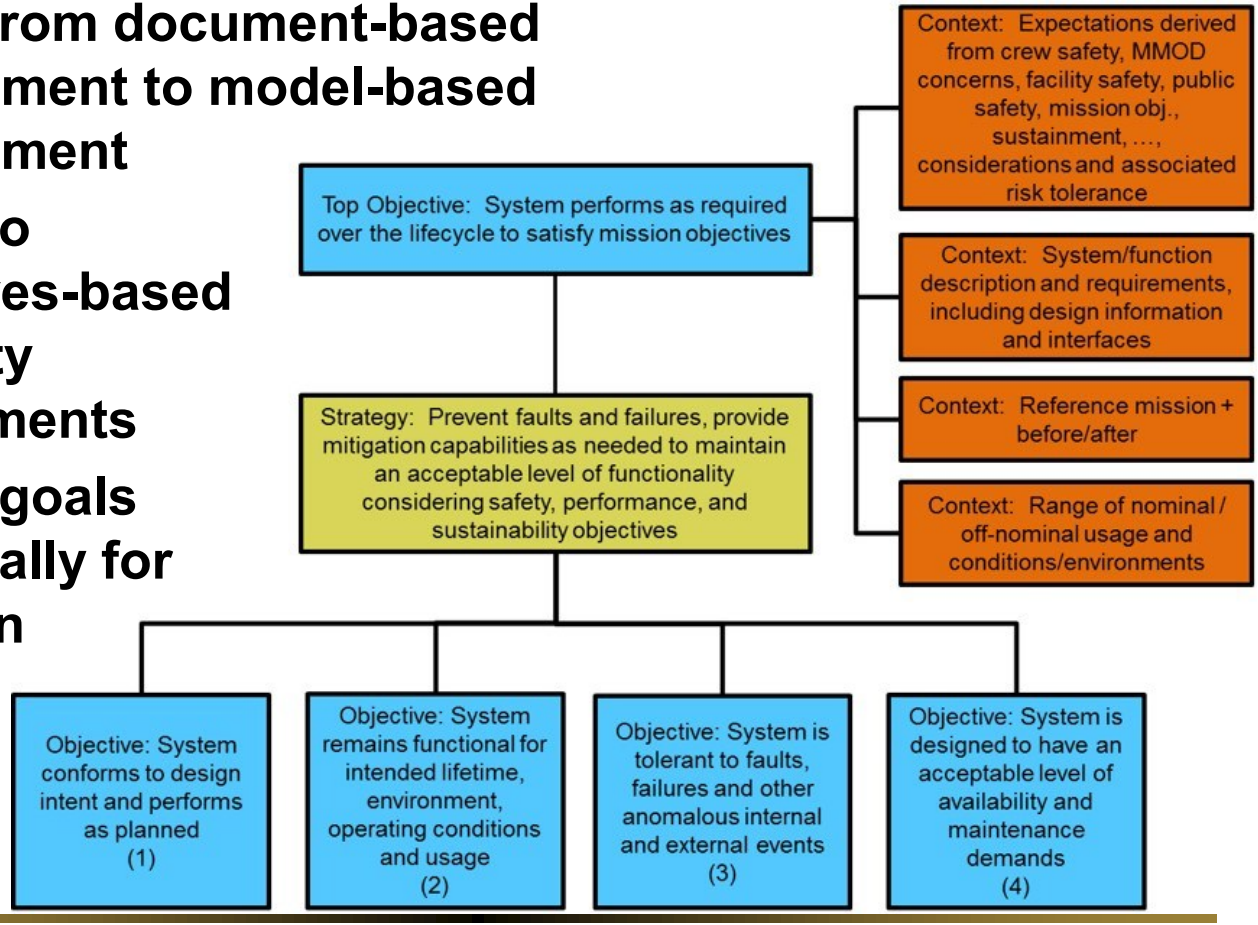
- **CubeSats: Platform for affordable, quick-turn spaceflight**
  - Volume, mass, and power constraints
  - Use of rad-hard parts prohibitive
- **Traditional Radiation Hardness Assurance (RHA)**
  - System reliability based on parts reliability
- **Commercial off-the-shelf (COTS) RHA**
  - System reliability based on system mitigation of part faults and failures



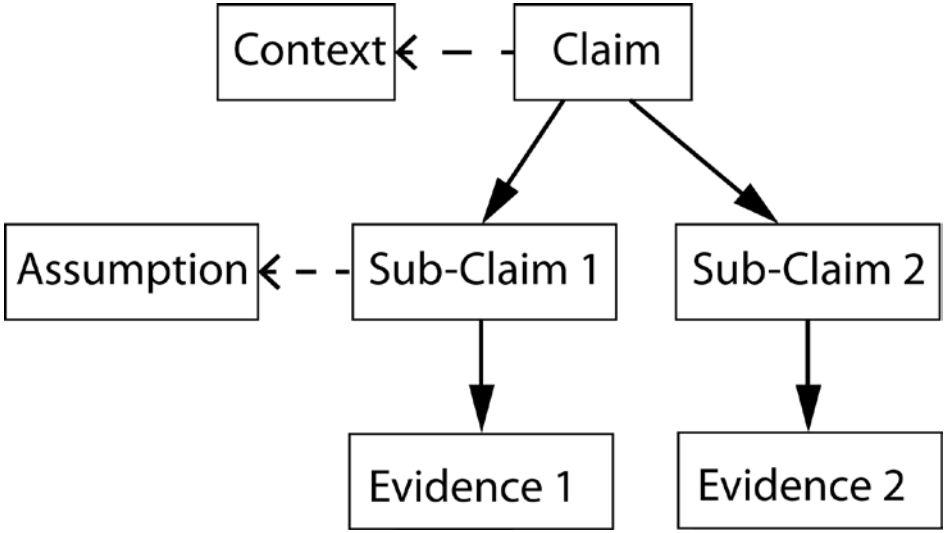
AO-85 Engineering Prototype (AMSAT)

Motivation: NASA Reliability & Maintainability (R&M) Hierarchy

- Moves from document-based development to model-based development
- Moves to objectives-based reliability requirements
- Adding goals specifically for radiation effects



Graphical Assurance Cases

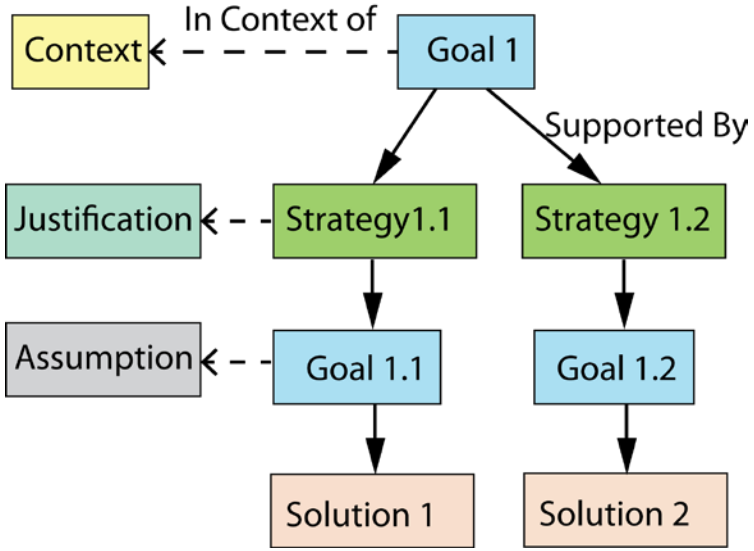


Argument: "A connected series of claims intended to support an overall claim." [1]

Assurance Case: "A reasoned and compelling argument, supported by a body of evidence, that a system, service or organization will operate as intended for a defined application in a defined environment." [1]

[1] GSN Community Standard Version 1 2011

Goal Structuring Notation (GSN)



Colors/Shapes
Denote Function

GSN is a visual representation of a hierarchy of claims [1]

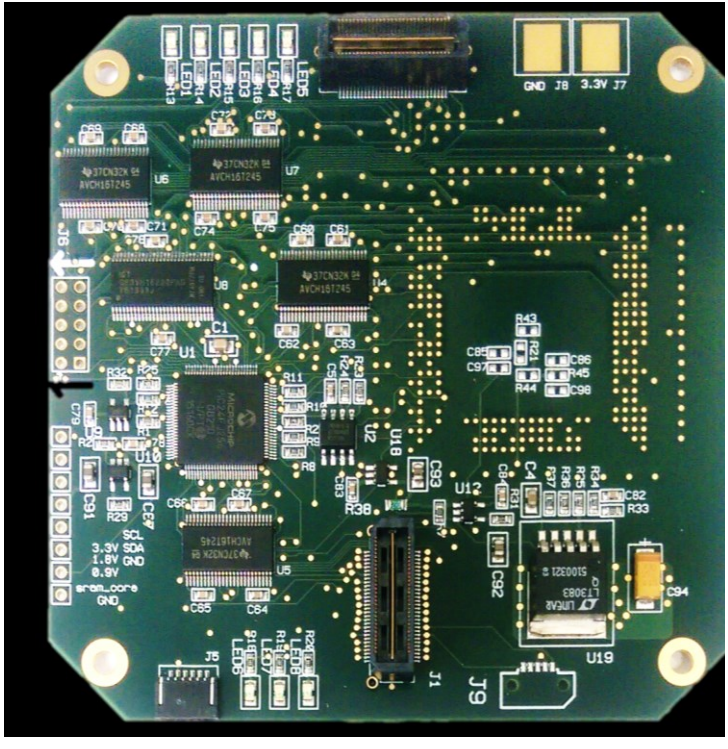
University of York U.K.

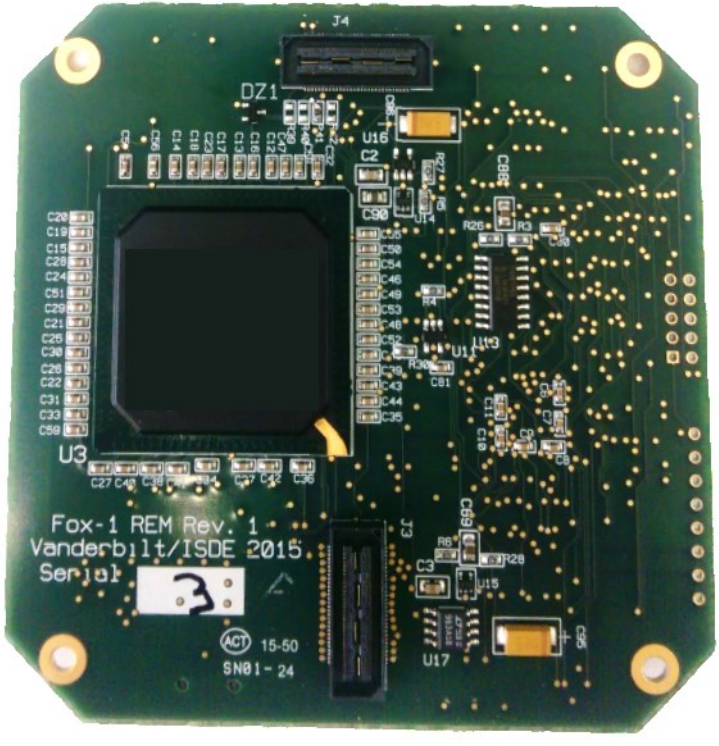
Goal=Claim
Strategy=Inference
Solution=Evidence
Context=Background
Justification=Rationale
Assumption=Unsubstantiated Claim

[1] GSN Community Standard Version 1 2011

CubeSat Experiment

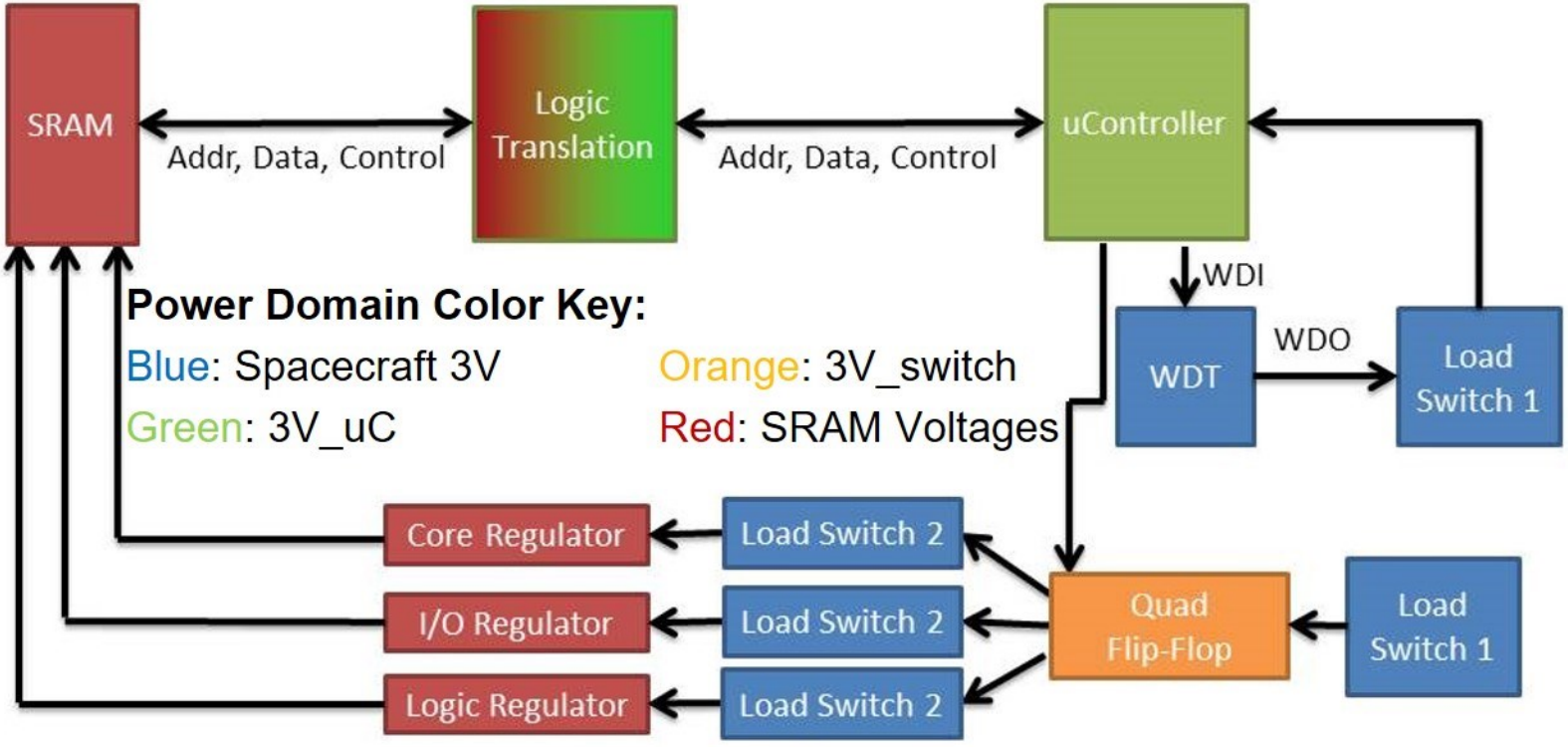
Mission Objective: Record the number of SEUs in 28nm bulk SRAM in LEO for a period of 1 year.





CubeSat Experiment Block Diagram

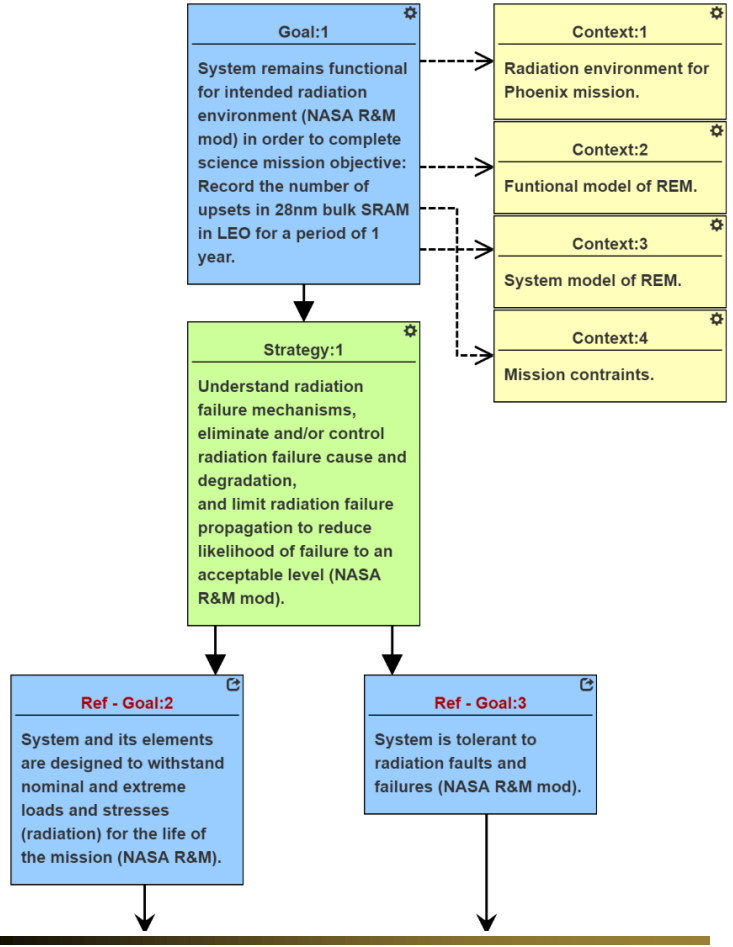
Mission Objective: Record the number of SEUs in 28nm bulk SRAM in LEO for a period of 1 year.



CubeSat Experiment Top Level GSN Model

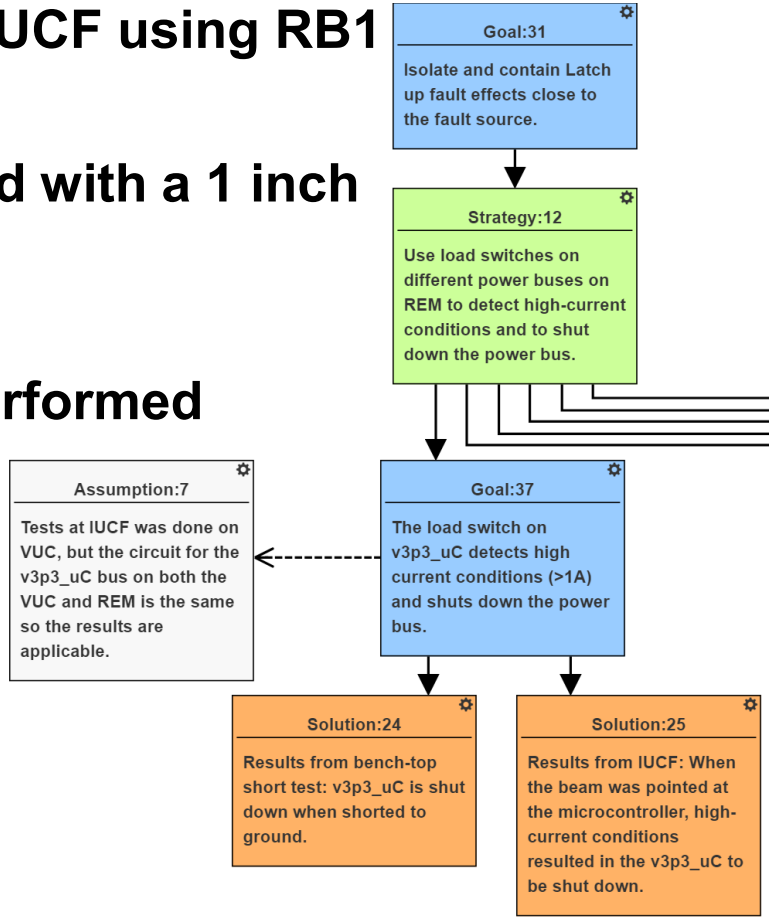
- **Top level goal: Based on top level goal of R&M hierarchy, adds specific science mission objective**

- **Sub-goals: Use both part-level radiation tolerance and system-level radiation tolerance to achieve top level goal**



CubeSat Experiment GSN Model for System-Level Mitigation Test Results

- **Proton test performed at IUCF using RB1**
- **Component test performed with a 1 inch square collimator**
- **System level tests also performed**
  - Showed that the board recovers from SEL and SEFI



CubeSat Experiment GSN Model for Part-Level Mitigation Test Results

Goal:6

COTS parts pass TID requirement at 20 krads(SiO2).

Goal:15

Load Switch B(FPF2164) passes TID mission requirement: Supply current is <100uA and ON and FLAGB functions still work.

Goal:14

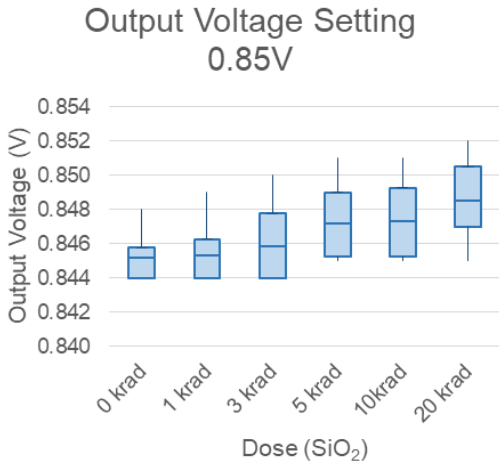
Variable regulator passes TID mission requirement: Supply current <50uA and offset voltage -5mV<Vout-Vset<5mV for Vset = 0.5V and 0.85V.

Solution:4

Results from VUMC: No noticeable changes for supply current and chip functionality for FPF2007 up to 40 krads(SiO2).

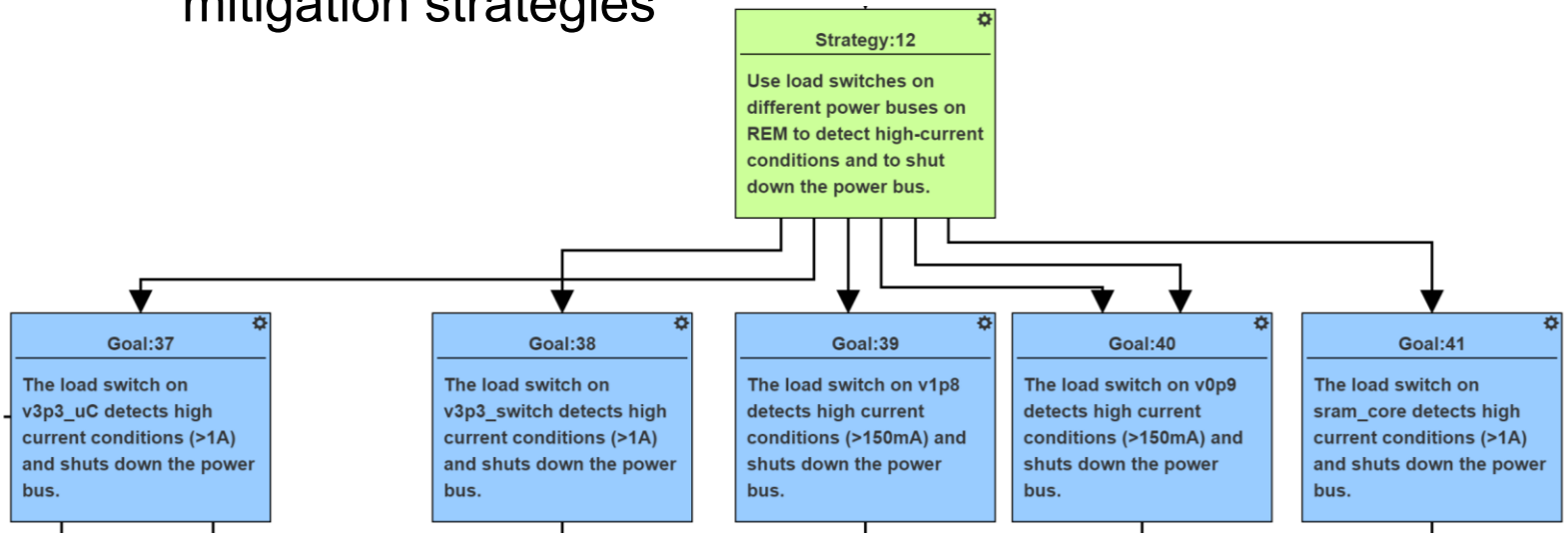
Solution:3

Results from VUMC: No noticeable changes at 20 krads(SiO2).



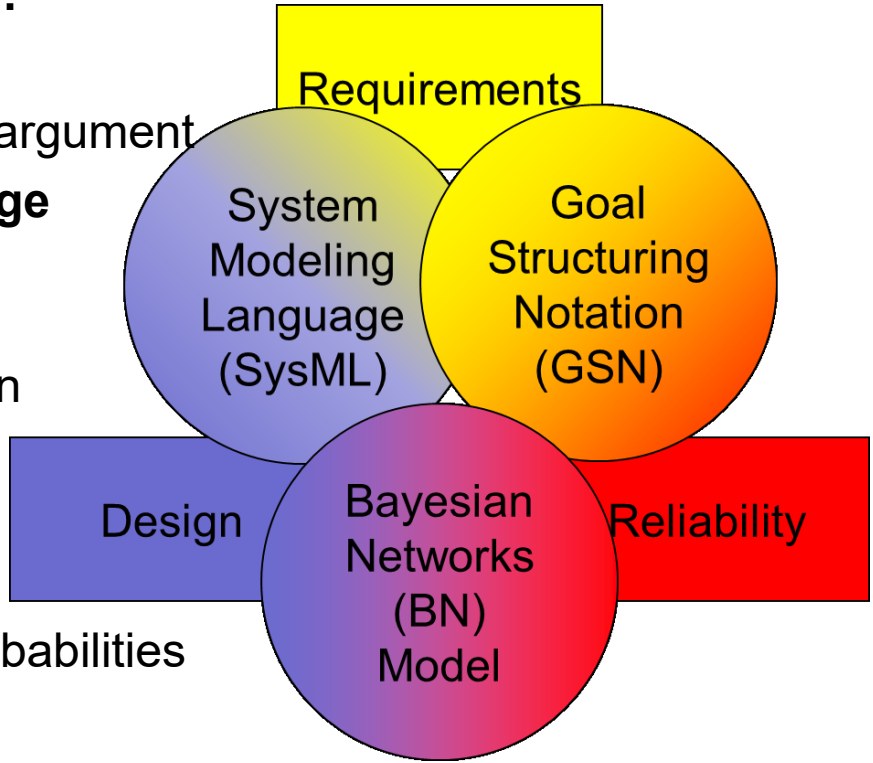
CubeSat Experiment Design Changes from use of GSN

- **Missing load switched identified**
  - Discovered during creation of argument for the system mitigation of latch-up events
- **Influenced future experiment board designs**
  - Addition of system level telemetry to evaluate mitigation strategies

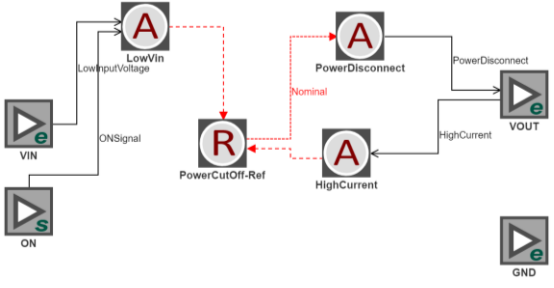
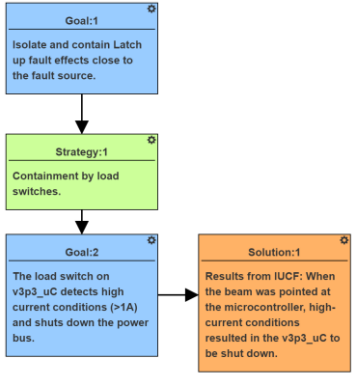
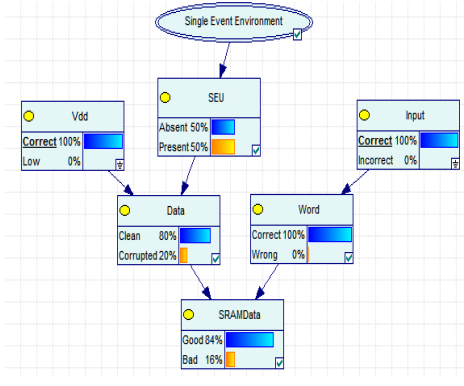


Integrated System Design for Radiation Environments

- **Goal Structuring Notation:**
  - R&M Template
  - Visual representation of argument
- **System Modeling Language (SysML):**
  - Specification of systems through standard notation
- **Bayesian Network (BN)**
  - Nodes describe probabilities of states
  - Calculate conditional probabilities from observations



Overview of Modeling Languages Used

SysML+Fault Modeling	GSN	BN Model
• Extends SysML with fault propagation models • "[F]aults" cause "[A]nomalies", potentially triggering "[R]esponses"	• Arguments show mitigation measures to address faults and anomalies	• Captures probabilities that faults result in anomalies
		

Integrated System Design for Radiation Environments

- **R&M Hierarchy (using the GSN modeling language) provides the connection between Requirements and Reliability**
- **Developing models between**
  - Design and Requirements and adding fault propagation
  - Design and Reliability
- **Applying to same CubeSat experiment board**
  - Considerations for the use of COTS and related mitigation strategies