revised version with Sandra Dawsons changes

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Larry Reinhart joined the Jet Propulsion Laboratory in 1982 and shortly after, in 1985, become involved in space nuclear power system launch approval activities for the Galileo and Ulysses missions to be launched on the Shuttle. He currently manages integration of launch vehicle databooks which support space nuclear power system launch approval for future missions to Mars and the outer planets, and development of associated accident scenarios and probabilities, accident environments and environment testing, and reentry/breakup analyses. He was the recipient of the Exceptional Achievement Award from NASA for his contribution to the Cassini nuclear safety launch approval effort. He received his PhD in Mechanical Engineering from the University of Massachusetts, Amherst.

Abstract

This paper provides an overview of the U. S. space nuclear power system launch approval process as defined by the two separate requirements of the National Environmental Policy Act (NEPA) and Presidential Directive/National Security Council Memorandum No. 25 (PD/NSC - 25). The general content of the launch vehicle databook developed by NASA which supports this approval process is described. Finally, the evolution in the development of a key component of this data, the definition of accident scenarios and their probability of occurrence, is traced from the simple analyses/engineering judgment used for the Galileo mission to the probabilistic risk assessment methods currently employed.

Overview of U.S. Space Nuclear Power System Launch Approval Requirements/Processes, Supporting Launch Vehicle Databooks and Probabilistic Risk Assessment Methods

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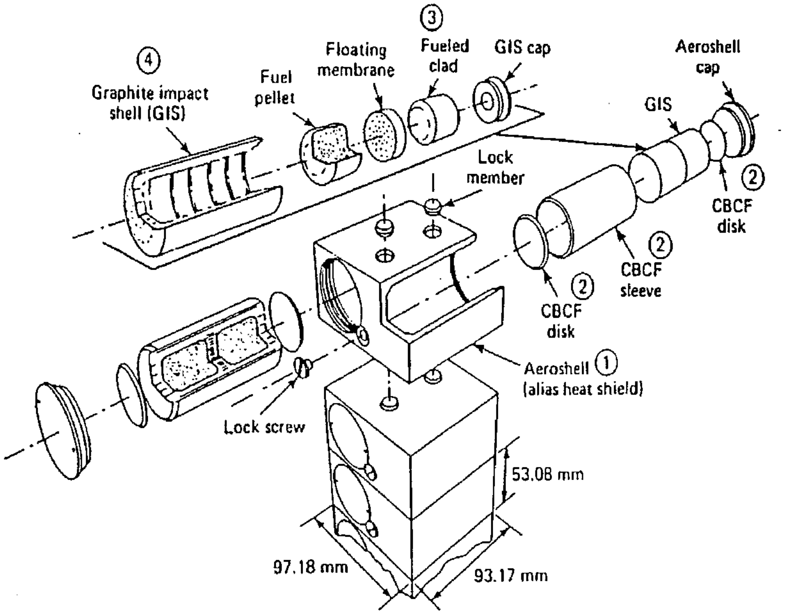
Content

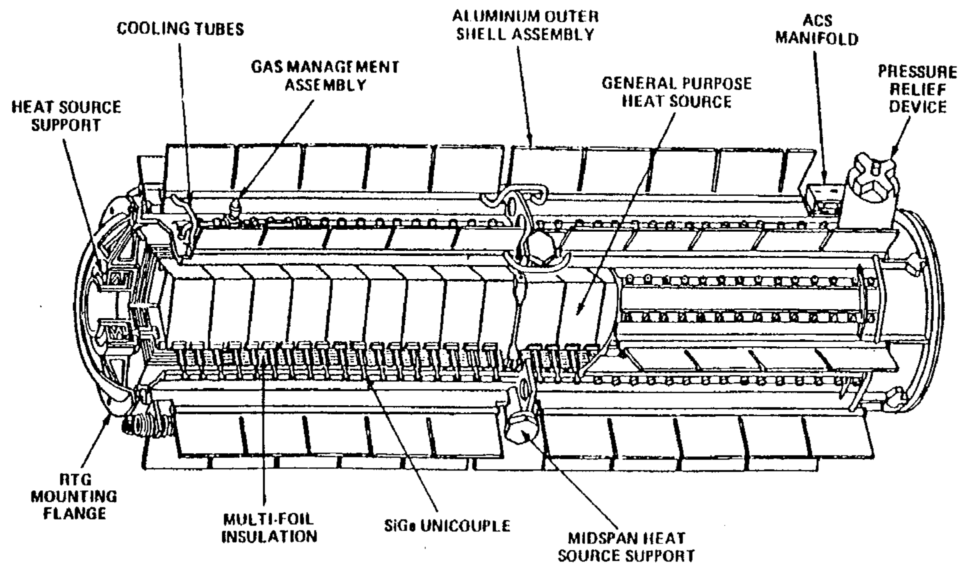
- Space Nuclear Power System (NPS) Launch Approval Requirements/Processes
  - National Environmental Policy Act (NEPA)
  - Presidential Directive/National Security Council Memorandum No. 25 (PD/NSC – 25)
- Launch Vehicle Databook
  - Overview/Focus
  - Historical Development of Accident Scenarios and Probabilities
  - The Current Probabilistic Risk Assessment Methodology

JPL Space NPS Launch Approval

- Required for Missions Using Space Nuclear Power System (NPS), e.g., Radioisotope Thermoelectric Generators (RTGs) and Radioisotope Heater Units (RHUs)
- Addresses Two Separate Requirements/Processes
  - National Environmental Policy Act (NEPA) – Ensures consideration of potential environmental impacts of proposed actions and reasonable alternatives
  - Presidential Directive/National Security Council Memorandum No. 25 (PD/NSC-25) – Ensures informed decision-making at the Presidential level before launching NPS

JPL GPHS & RTG

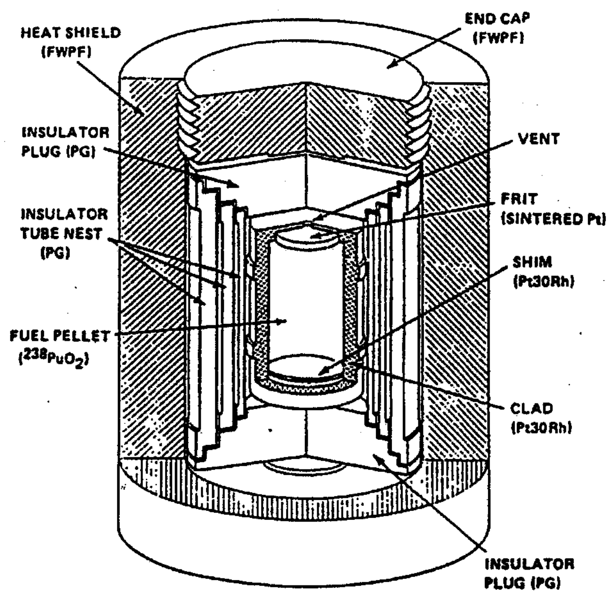


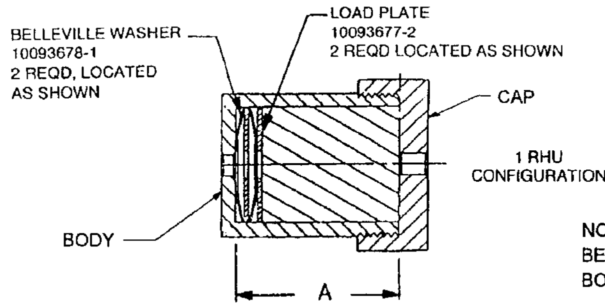


General Purpose Heat Source
- 3.7 x 3.8 x 2.1 in.
- 4 plutonium dioxide fuel pellets
- 250 watts thermal

Radioisotope Thermoelectric Generator
- 44.9 in. long x 16.6 in. diameter
- 18 GPHS modules
- 10.7 kg plutonium dioxide fuel
- 285 watts electric

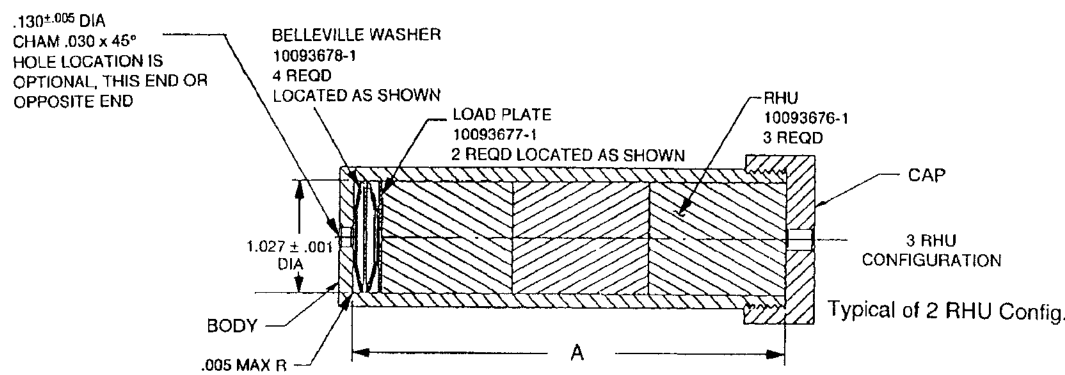
JPL RHU





Configuration	Dimension A (in.)
1 RHU	1.446 ± 0.003
2 RHU	2.704 ± 0.003
3 RHU	3.962 ± 0.003

NOTES:
BELLEVILLE WASHER - BERRILIUM COPPER
BODY, CAP - 6061 Al Aly (Typ.)



Radioisotope Heater Unit

- 32 mm long x 26 mm diameter
- FWPF – Fine Weave Pierced Fabric

Typical RHU Assembly

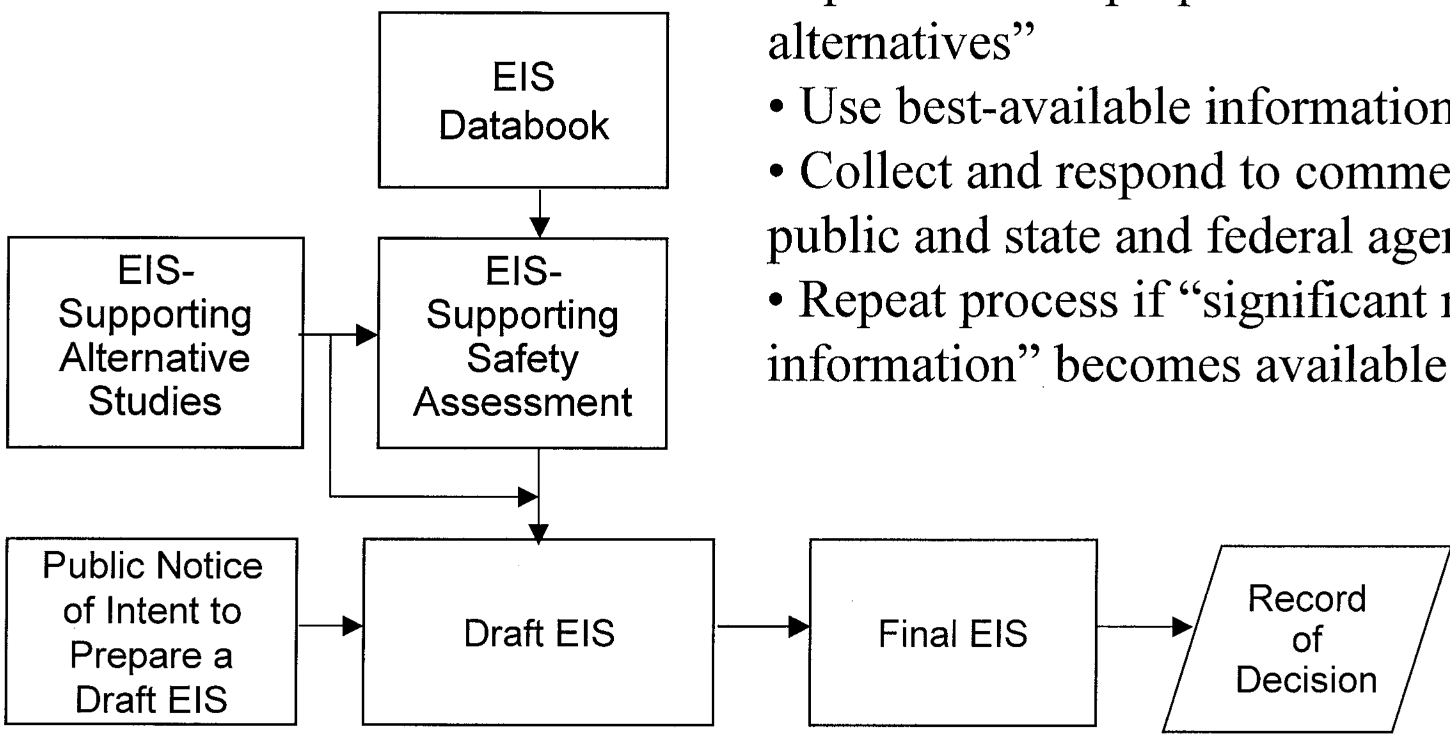
NEPA

- Completed Early in the Development Phase
- Focuses on Proposed Baseline Plan and Reasonable Alternatives
- Radiological Safety Assessment Based on Best Available Information, e.g., Accident Scenarios, Probabilities, and Environments
- Decision to Proceed Made by NASA Associate Administrator for Space Science

NEPA Process

Requirements:

- Complete an Environmental Impact Statement (EIS) early in the Program (e.g., prior to CDR)
- Objectively assess potential environmental impacts of the “proposed action” and alternatives”
- Use best-available information
- Collect and respond to comments from the public and state and federal agencies
- Repeat process if “significant new information” becomes available



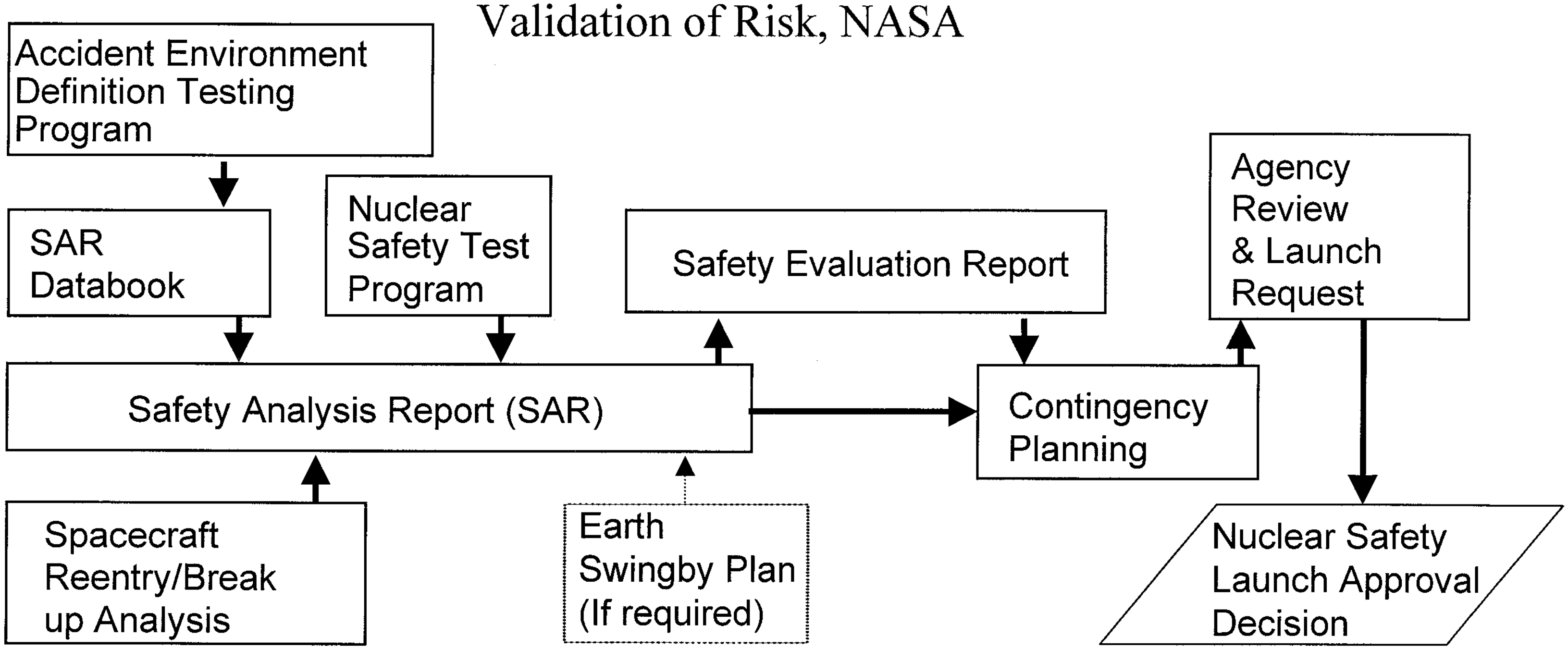
JPL PD/NSC – 25

- Completed Prior to Launch
- Focuses on Baseline Plan
- Considers Contingency Launches
- Radiological Safety Assessment Based on Final Launch Vehicle Data
- Nuclear Safety Launch Approval Decision Made by White House Office of Science & Technology Policy (OSTP) Director, or the President
- Normal Range Safety Launch Approval Required After Ensuring Nuclear Safety

JPL PD/NSC – 25 Process

Requirements:

- Estimate the Radiological Risk - Safety Analysis Report (SAR), DoE
- Conduct Review of SAR – Safety Evaluation Report (SER), Ad Hoc Interagency Nuclear Safety Review Panel (INSRP)
- Request Nuclear Safety Launch Approval through Director of the President's Office of Science and Technology Policy (OSTP) Supported by DoD and EPA Concurrences and DoE Validation of Risk, NASA



JPL Launch Vehicle Databook

- Overview
  - Documents much of the data required to conduct the nuclear safety analyses performed by DoE
  - Prepared for NASA with inputs from:
    - Launch Vehicle Manufacturer
    - JPL
    - JPL Contractors
- Focus
  - Description of the launch vehicle, destruct system(s), command destruct process, and launch complex
  - Definition of accident scenarios and their probability of occurrence
  - Quantification of accident environments which result upon release of stored potential and chemical energy

JPL Accident Scenarios and Probabilities

- Objective
  - Define a set of accident scenarios that represent the overall mission risk
  - Quantify the accident scenario probabilities

JPL Accident Scenarios and Probabilities

- Historical Development
  - Galileo/Ulysses Missions Launched on Shuttle in 1989/1990
    - Descriptive scenarios developed for prelaunch through escape, including aborts
    - NASA JSC provided initiating accident scenario probabilities based on historical failures and engineering judgment
    - NASA Code Q contracted with PRC to develop initiating accident scenario probabilities using probabilistic risk assessment (PRA) techniques. NASA adopted these for use in the SAR.

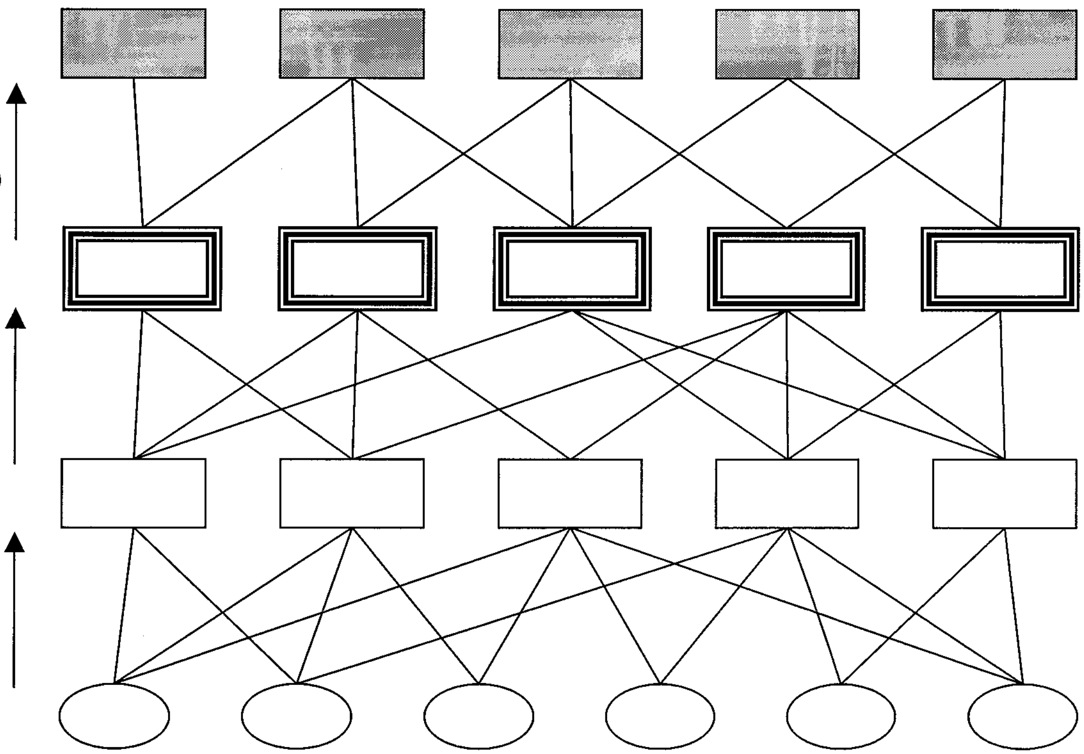
JPL Accident Scenarios and Probabilities

- Historical Development (cont.)
  - Cassini Mission Launched on Titan IV in 1997
    - NASA LeRC, with the support of NASA Code Q, made the decision to implement PRA methodology to define databook accidents and probabilities.
    - PRA methodology was jointly defined by NASA LeRC and Aerospace Corporation
  - Current Missions
    - NASA KSC has requested that LV databooks use PRA methods for defining accidents scenarios/probabilities, with the level of detail consistent with DoE requirements

JPL PRA Methodology

Level-to-level Mapping

MLD Levels



Event Sequence Diagrams (ESDs)

Event Sequence Diagrams (ESDs)

Functional Organization + Bayesian Update

Representative Accident Scenarios (RAS)
Define jointly by NASA and DoE

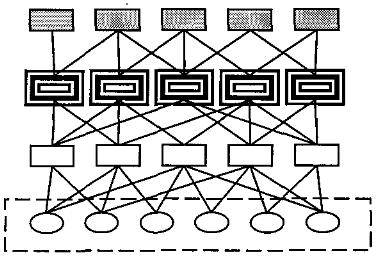
Accident Outcome Conditions (AOCs)
Vehicle-Level Accident End-points

Accident Initial Conditions (AICs)
Vehicle-Level Accident Start-points

Basic Initiating Events (BIEs)
e.g., Component-Level Failures

JPL Basic Initiating Events (BIEs)

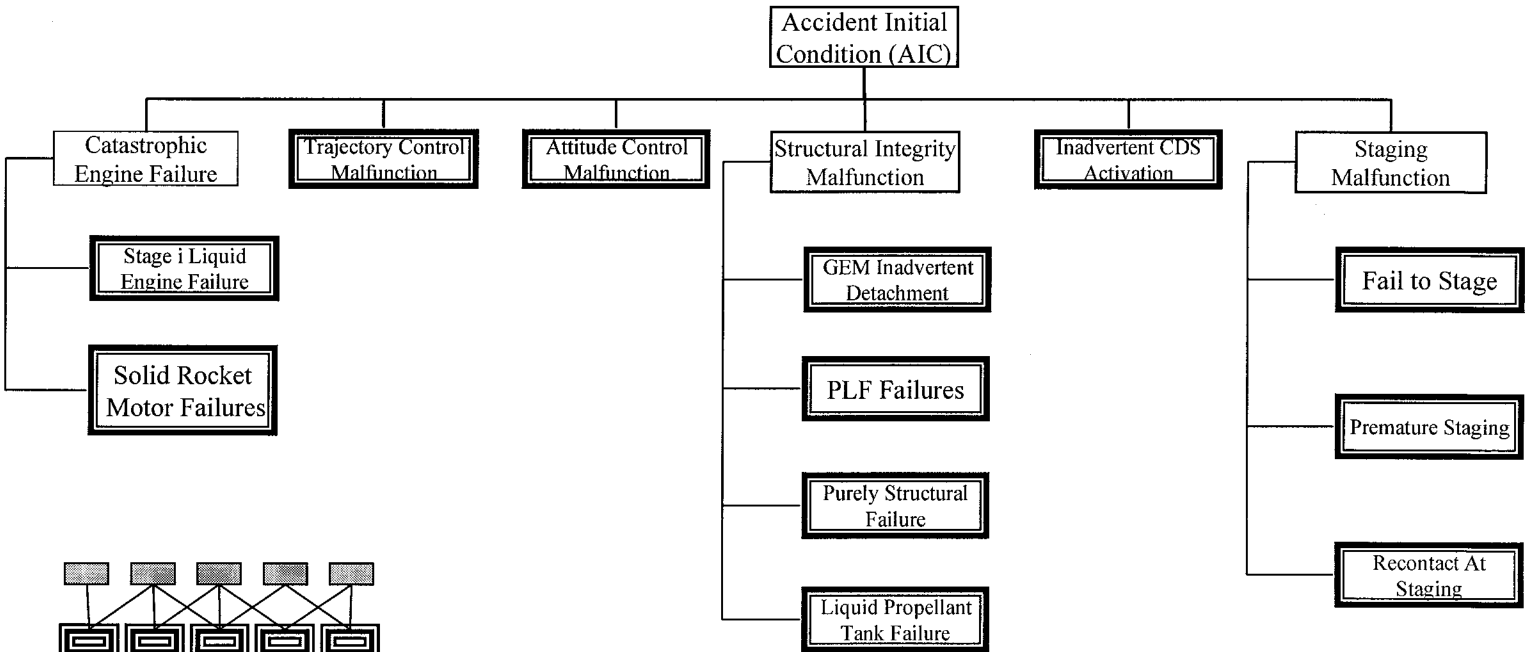
- The basic component level failures which initiate all accident sequences.
- BIE probabilities derived from Launch Vehicle FMEA data.

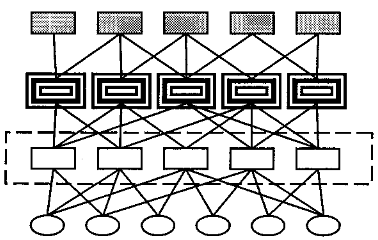


System	Reliability	Failure Probability
Vehicle	**0.xxxx**	**0.yyyy**
First Stage	**0.xxxx**	**0.yyyy**
Propulsion	0.xxxx	0.yyyy
Main Engine	0.xxxx	0.yyyy
Liquid Oxygen	0.xxxx	0.yyyy
Fuel	0.xxxx	0.yyyy
Ullage	0.xxxx	0.yyyy
Graphite Epoxy Motors (GEMs) (Four GEM Basis)	0.xxxx	0.yyyy
GEM (Single GEM Basis)	0.xxxx	0.yyyy
Ignition	0.xxxx	0.yyyy
Case	0.xxxx	0.yyyy
Propellant/Case Bond	0.xxxx	0.yyyy
Internal Insulator	0.xxxx	0.yyyy
Attachment to Nozzle	0.xxxx	0.yyyy
Case/Vehicle Attachment	0.xxxx	0.yyyy
Ordnance	0.xxxx	0.yyyy
GEM Separation (Four GEM Basis)	0.xxxx	0.yyyy
(Single GEM Basis)	0.xxxx	0.yyyy
Stage 1 / 2 Separation	0.xxxx	0.yyyy
Avionics	0.xxxx	0.yyyy
Mechanical	0.xxxx	0.yyyy
Hydraulics	0.xxxx	0.yyyy
Stage 1 / 2 Separation Springs	0.xxxx	0.yyyy

JPL Accident Initial Conditions (AICs)

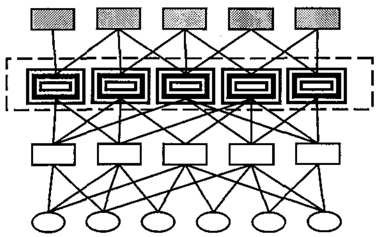
- The first system-level manifestation of a LV or SV failure that may lead to a catastrophic accident or mission failure.
- The AICs are organized in a Master Logic Diagram (MLD) which has been deductively derived.

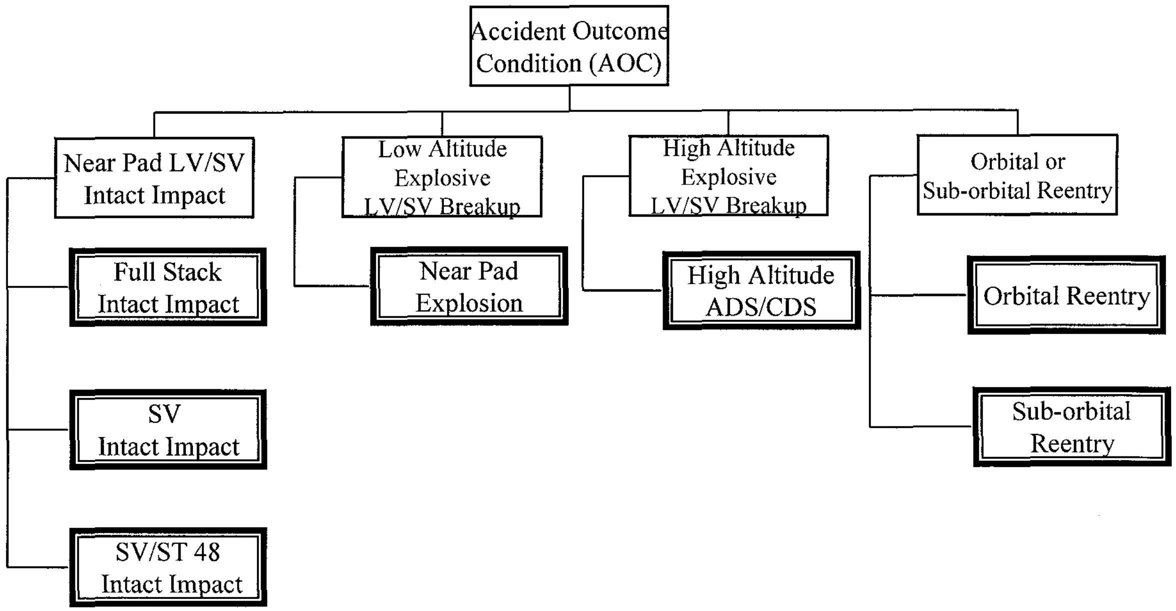




JPL Accident Outcome Conditions (AOCs)

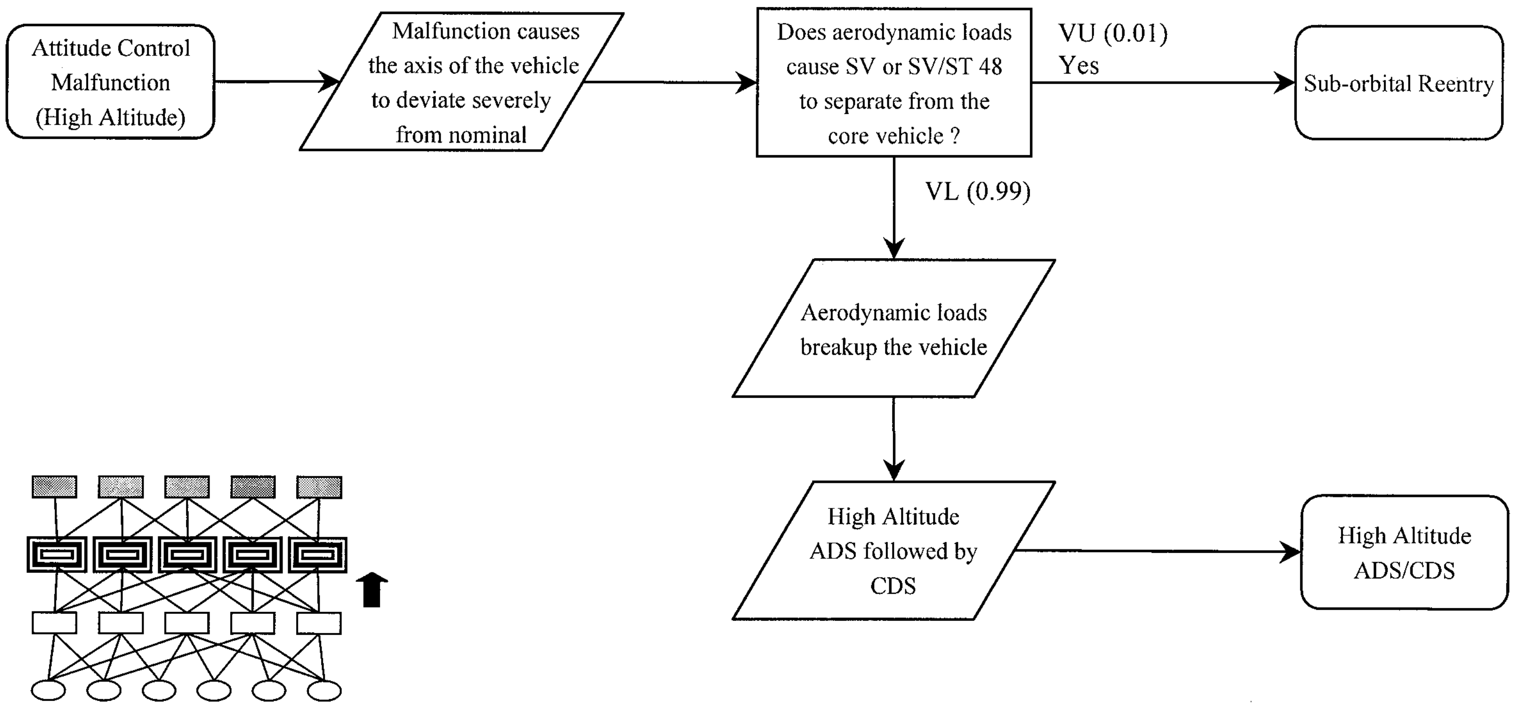
- A Launch Vehicle or Space Vehicle event or condition where the NPS first experiences a potentially damaging environment
- The AOCs are organized in a Master Logic Diagram (MLD) which has been deductively derived.





JPL Event Sequence Diagrams (ESDs)

- Inductively-derived (e.g., cause to effect) logical representations of accident sequences.
- Branch point probabilities are determined by an expert elicitation process or analysis.



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