Larry Reinhart joined the Jet Propulsion Laboratory in 1982 and shortly after, in 1985, became 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

Larry Reinhart, PhD
Jet Propulsion Laboratory
California Institute of Technology

Presented at the
Southern California Society for Risk Analysis
University of California Los Angeles
May 17, 2001
JPL

Content

- Space Nuclear Power System (NPS) Launch Approval Requirements/Processes
  - National Environmental Policy Act (NEPA)

- 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
**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
Radioisotope Heater Unit
- 32 mm long x 26 mm diameter
- FWPF – Fine Weave Pierced Fabric
JPL

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
JPL

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
• 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
Requirements:

- Estimate the Radiological Risk - Safety Analysis Report (SAR), DoE
- 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

Accident Environment Definition Testing Program

SAR Databook

Nuclear Safety Test Program

Safety Evaluation Report

Spacecraft Reentry/Break up Analysis

Earth Swingby Plan (If required)

Contingency Planning

Agency Review & Launch Request

Nuclear Safety Launch Approval Decision

Safety Analysis Report (SAR)


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
    • 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

Event Sequence Diagrams (ESDs)

Event Sequence Diagrams (ESDs)

Functional Organization + Bayesian Update

MLD Levels

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.

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

[Diagram showing Accident Outcome Conditions (AOCs) with branching paths for Near Pad LV/SV Intact Impact, Low Altitude Explosive LV/SV Breakup, High Altitude Explosive LV/SV Breakup, and Orbital or Sub-orbital Reentry, with further sub-branches for Full Stack Intact Impact, Near Pad Explosion, High Altitude ADS/CDS, and Sub-orbital Reentry.]
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.
JPL  Contributors

- Reed Wilcox, Cross Program Launch Approval Engineering Manager, JPL
- Bob Mulvihill, Risk Management & Analysis, Inc.
- Mike Yau, ASCA, Inc.