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Sandia National Laboratories

Databook Inputs to Safety Analysis for Launch Approval

Space Nuclear Systems Launch Safety Group

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U.S. DEPARTMENT OF ENERGY

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The purpose of this document is to define the data inputs required for a full safety analysis to support launch approval.

Mission

While many specifics of the mission are not relevant to a risk assessment focused on public health on Earth, the overall mission goals help a risk analysis team understand the design under consideration. Providing the overall mission goals, even at a high level, establishes a framework for the analysis. One mission detail of particular importance is the launch window, which can identify meteorological conditions of interest.

Databook Need:

- Mission goals
- Launch window dates

Launch Vehicle

While there are numerous details regarding the entire launch vehicle, precise information on every component is not necessary. However, certain information about the launch vehicle is useful for identifying potential accident scenarios. Information on propellant type and amounts are used for determining blast and thermal environments. The Flight Termination System is a safety mechanism designed to terminate the flight of a launch vehicle in the event of a failure, ensuring that it does not pose a risk to populated areas. Information on the flight termination system is used to determine accident sequences and identify which components within the launch vehicle may contribute to various accident scenarios.

Databook Need:

- Launch vehicle type/configuration
- Launch vehicle component
    - Dimensions
    - Relative locations
    - Materials of construction
    - Mass
- Propellant types and masses by stage
    - Solid and liquid propellants
- Flight termination system
    - Components
    - Sequence
    - Timing
    - Locations

Launch Complex

Information about the launch facility and wider complex is used to inform accident scenarios that occur pre-launch and early-launch. Information about the location of the launch site and launch restrictions can inform selection of meteorological conditions for accident scenarios. Information about vehicle processing procedures and emergency systems informs accident scenario definition. Information about nearby structures, fuel or pressurant tanks, the launch pad itself, and soil/topology informs blast environments and impact surfaces/fragments, as well as thermal environments for accident scenarios.

Databook Need:

- Launch complex description
    - Geographical location
- Launch area propellant and pressurant tank
    - Configurations
    - Operating parameters
    - Locations
- Launch platform
    - Configuration
    - Materials
    - Location
- Vehicle processing procedure
- Map of terrain at launch complex (digitized)
- Locations/dimensions of steel structures at launch complex
- Launch processing operations
- Weather/environmental restrictions for launch
- Emergency systems (e.g., water supply, response times)

Launch Sequence

Information about the launch sequence, including event timelines and planned trajectories, informs accident scenarios. Information about the installation of the space nuclear system and fueling of the launch vehicle informs accident scenario timing and relevancy. Information on launch vehicle trajectory determines accident scenario positioning, which then affects potential radiological release effects.

Databook Need:

- Mission timeline of major events, especially:
    - Propellant fueling
    - Stage separation
    - Payload installation
- Launch vehicle trajectory
    - Altitude versus mission time
    - Position versus mission time
    - Velocity versus mission time
    - Acceleration versus mission time
    - Instantaneous impact point (IIP) trace through mission
    - Destruct lines along trajectory

- Flight termination
    - Criteria
    - Process

Accident Probabilities

The accident scenarios identify physical events and their associated probabilities of occurrence that may result from a launch failure. Accidents and their probabilities are developed in terms of Accident Initial Conditions (AICs), defined as the first system-level indication of a launch vehicle failure that could lead to a catastrophic accident or mission failure. The accident progression after the AIC leads to a range of possible Accident Outcome Conditions (AOCs). AOCs are events in the accident sequence when the space nuclear system may first encounter a potentially damaging environment. Accident scenarios are constructed from AOCs and are designed to encompass all possible accidents at an appropriate level of detail. Each accident scenario combines a unique set of AOCs, with approximate time distributions in probability of occurrence, such that the probability of the composite accident case may be regarded as the sum over the probabilities of occurrence of each of the constituent paths.

Databook Need:

- Accident initial conditions (AICs)
- Accident outcome conditions (AOCs)
    - AOC probabilities as a function of time
    - AIC to AOC logic diagrams
- Fault trees
- Accident probabilities/Reliability calculations
- Analysis of potential impacts/destruct near pad describing the state of the launch vehicle (position, velocities) just prior to destruct/ground impact

Accident Environments

Postulated accident environments associated with potential accidents include blast (explosion overpressure), impact on a surface, fragment impact, thermal (burning liquid propellant and/or solid propellant), and reentry (aerodynamic force and heating). A given accident could involve one or more sequential and/or simultaneously occurring accident environments. The nature and severity of such environments would be a function of the type of accident and the time of occurrence.

The response of the space nuclear system components to accident environments is characterized by the probability of release and the generated source term. These in turn are determined by the nature and severity of the accident environments and the design features of the radioisotope hardware and its components. The information about the potential accident environments allows estimates to be made of the probability and amount of release of radioactive material and the subsequent radiological effects on the surrounding environment that could potentially occur during the mission.

Databook Need:

- Solid and liquid propellant explosions
    - Overpressures and impulses experienced at the space nuclear system for expected configurations
- Solid and liquid propellant fire environments
    - Temperatures versus time
- Launch vehicle debris (from destruct or failure)
    - Mass
    - Volume
    - Type
    - Relative locations
- Breakup analysis results for spacecraft
    - Trajectory upon reentry
    - Stability and aerodynamics of reentry
- Suborbital reentry impact locations
- V-gamma (entry velocity versus entry angle) maps for reentry

Spacecraft

Information about the spacecraft can inform accident scenarios. The design of spacecraft components can inform impact scenarios at nearly any stage of the launch (as these are closest to the space nuclear system), as well as reentry scenarios in later stages of the launch. Any propellants on-board the spacecraft could contribute to fire-induced blast or thermal environments.

Databook Need:

- Spacecraft description
    - Configuration
    - Dimensions
    - Materials
    - Masses
- Heat shield/entry vehicle (if applicable)
    - Configuration
    - Dimensions
    - Materials
    - Masses
- On-board propellants
    - Type
    - Amount
- Pressurant tank
    - Type
    - Amount (pressure)

- Science instruments
    - Radioactive material amount

Space Nuclear System

The design of the space nuclear system is the foundation of the analysis because many accident scenario responses are informed by these details.

Databook Need:

- Radioactive material
    - Type
    - Amount
    - Particle size
    - Potential for criticality (if applicable)
    - Reaction or decay products
    - Vaporization/condensation behavior (i.e., vapor pressure)
- Containment and protective features
    - Aeroshells, cladding, heat transfer structures, etc.
    - Material testing data (physical, chemical)
    - Break-up behavior
- Location in spacecraft

General Note:

In some cases, images, diagrams, and CAD models (e.g., SolidWorks) are useful for communicating geometry and dimensions. In cases where numerical data must be provided, especially for communicating trajectories, time histories, or physical relationships, it is most useful to present the data in a machine-readable format (such as a comma-separated values (CSV) file or Excel).