ANS RP3C CoP
Overview and Status: ASME's Plant Systems Design Standard

September 25, 2020

Ralph Hill, Hill Eng Solutions
Chair, ASME Plant Systems Design Standards Committee
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Disclaimer

All statements made by the speaker represent his opinion alone, and do not necessarily represent the position of ASME or Hill Eng Solutions, LLC nor of the ASME Boiler and Pressure Vessel Committee.
Ralph Hill

- Has been actively involved as a contributor and a leader in promulgation of ASME nuclear codes and standards for over 40 years and has been awarded the Bernard F. Langer Nuclear Codes and Standards Award, the Codes and Standards Distinguished Service Award, and the grade of ASME Fellow.

- **ASME**
  - He is past-Chair of the ASME Board on Nuclear Codes and Standards and the Boiler and Pressure Vessel Code, Section III, Nuclear Construction Standards Committee.
  - Although retired, Ralph continues his volunteer activities in support of ASME codes and standards.
  - Currently Ralph serves on the ASME Council on Standards and Certification, the Board on Nuclear Codes and Standards, and as both champion and Chair of the new Standards Committee on Plant Systems Design.
Ralph Hill

- ANS
  - Member of WG on ANS 30.1
  - Member of WG on ANS 30.2
  - Member of RP3C
Topics

• Example of RIPB Life-Cycle Design using Monte Carlo Simulation
• Overview and Status of ASME Plant Systems Design Standard
• A Concept for RIPB Design and Safety Classification
• Very Simple Fluid Injection System
• Model, Assumptions, and Parameters are “out of the blue” with no relevance to any actual design parameters
• For demonstration of technique only → shows how system can be analyzed in a risk-informed approach
• Technique applicable to all types of systems of varying level of complexity
• Technique can be applied at multiple levels ranging from entire system to a sub-system → to level where requirements are defined
RIPB L-C Design Example

Top-Level Requirement: System must be able to inject 200 gallons per minute with a mean reliability greater than 95%

Figure 3. Fluid Injection System Schematic
General assumptions:
- Component Failure
  - Modeled simplistically as Poisson distribution (random) with defined failure rate
  - Initial failure rate depends on component quality
  - Failure rate increases exponentially with time following maintenance/repair, doubling time depends on component quality
- Pump Fouling
  - Pumps foul at a rate that depends on component quality
- Maintenance / Inspection
  - Maintenance occurs at selected interval unless inspection reveals that failure rate is above target level
  - Inspection occurs at sub-intervals of maintenance interval
  - When inspection occurs, there is a probability that it misses fact that failure frequency is too high
• Assumptions on injection system:
  • Any two injection lines can satisfy requirement
  • Injection tanks drain due to demand and are filled from charging system
  • System is off-line if more than two injection lines are unavailable
  • Injection line is unavailable if
    • either a valve or pump is out of service due to maintenance or repair
    • a pump is sufficiently fouled (not inspected - maintenance)
    • the volume of an injection tank becomes too low, that injection line also becomes unavailable until tank is re-filled
RIPB L-C Design Example

- Assumptions on charging system:
  - If any component in charging system is out-of-service, injection tanks cannot be filled
  - Components are out of service due to maintenance or repair
  - Charging pumps are also out of service if sufficiently fouled (not inspected - maintenance

Miller, I., Nutt, M., Hill, R., Probabilistic Simulation Applications to Reliability Assessments, 11th International Conference on Nuclear Engineering, Tokyo, JAPAN, April 20-23, 2003, ICONE11-36597
### RIPB L-C Design Example

#### Interactive Component Information

<table>
<thead>
<tr>
<th>System Component</th>
<th>Component Quality</th>
<th>Maintenance Frequency (day)</th>
<th>Inspection Duration (day)</th>
<th>Capital Cost ($)</th>
<th>Maintenance Cost ($ per Activity)</th>
<th>Inspection Cost ($ per Activity)</th>
<th>Repair Cost ($ per Activity)</th>
<th>Initial Failure Rate (day⁻¹)</th>
<th>Failure Rate Doubling Time (day)</th>
<th>Target Frequency that Forces Inspection</th>
<th>Initial Pump Discharge Rate (gal/min)</th>
<th>Minimum Pump Service Discharge Rate (gal/min)</th>
<th>Pump Fouling Rate</th>
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<tbody>
<tr>
<td>Injection Valves</td>
<td>Good</td>
<td>100</td>
<td>F₁/₂</td>
<td>$50,000</td>
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<td>$2,500</td>
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<td>100</td>
<td>0.002</td>
<td>200</td>
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<tr>
<td></td>
<td>Very Good</td>
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<td>F₁/₅</td>
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<td>$150</td>
<td>$5,000</td>
<td>0.001</td>
<td>300</td>
<td>0.002</td>
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<tr>
<td></td>
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<td>F₁/₁₀</td>
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<td>90</td>
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<td>Charging Isolation Valves</td>
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<td>90</td>
<td>0.002</td>
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<tr>
<td></td>
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<td>500</td>
<td>F₁/₁₀</td>
<td>$800,000</td>
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<td>$150</td>
<td>$12,000</td>
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<td>90</td>
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<td>0.01</td>
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#### Component Reliability Information

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<thead>
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<th>System Component</th>
<th>Initial Failure Rate (day⁻¹)</th>
<th>Failure Rate Doubling Time (day)</th>
<th>Target Frequency that Forces Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Valves</td>
<td>0.004</td>
<td>100</td>
<td>0.002</td>
</tr>
<tr>
<td>Injection Pumps</td>
<td>0.004</td>
<td>100</td>
<td>0.002</td>
</tr>
<tr>
<td>Charging Isolation Valves</td>
<td>0.004</td>
<td>100</td>
<td>0.002</td>
</tr>
<tr>
<td>Charging Valves</td>
<td>0.004</td>
<td>100</td>
<td>0.002</td>
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</table>

#### Pump Discharge Information

<table>
<thead>
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<th>System Component</th>
<th>Initial Pump Discharge Rate (gal/min)</th>
<th>Minimum Pump Service Discharge Rate (gal/min)</th>
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</thead>
<tbody>
<tr>
<td>Injection Valves</td>
<td>110 (gal/min)</td>
<td>90 (gal/min)</td>
</tr>
<tr>
<td>Injection Pumps</td>
<td>20 (gal/min) / 200 (days)</td>
<td>20 (gal/min) / 400 (days)</td>
</tr>
<tr>
<td>Charging Isolation Valves</td>
<td>20 (gal/min) / 600 (days)</td>
<td></td>
</tr>
<tr>
<td>Charging Valves</td>
<td>20 (gal/min) / 400 (days)</td>
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</tr>
</tbody>
</table>

#### System Component Information

<table>
<thead>
<tr>
<th>System Component</th>
<th>Tank Size (gallon)</th>
<th>Minimum Volume Before Filling Begins (gallon)</th>
<th>Minimum Volume For Tank to be On-Line (gallon)</th>
<th>Tank Filling Rate (gallon/min)</th>
<th>Tank Capital Cost ($/gallon)</th>
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<tr>
<td>Injection Tank</td>
<td>500,000 - 3,000,000</td>
<td>1/2 of Tank Size</td>
<td>1/4 of Tank Size</td>
<td>150 - 250</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Notes:

1. Model assumes that the failure frequency increases exponentially with time from an initial failure rate immediately following maintenance or repair at a rate governed by the failure rate doubling time.
2. Model assumes that pumps fail (discharge decreases) linearly with time from an initial discharge rate immediately following maintenance or repair.
3. These are base costs. There is an incremental cost of $0.1 per gallon/day insertion into the injection tanks.
4. This is determined as a function of the tank filling rate.
5. Charging pumps fail at different rates:
   - Water Pump : (Good = 1000 gallon/day/day, Very Good = 500 gallon/day/day, Excellent = 100 gallon/day/day)
   - Stuff Pump : (Good = 200 gallon/day/day, Very Good = 100 gallon/day/day, Excellent = 50 gallon/day/day)
   - Junk Pump : (Good = 100 gallon/day/day, Very Good = 50 gallon/day/day, Excellent = 25 gallon/day/day)

Table 1: Case Study Input
RIPB L-C Design Example 7 of 8

<table>
<thead>
<tr>
<th>Component Quality</th>
<th>Maintenance Frequency (day)</th>
<th>Inspection Frequency (day)</th>
<th>Injection Tank Volume (gallon)</th>
<th>Injection Tank Input Rate (gallon/min)</th>
<th>5%-ile</th>
<th>Median</th>
<th>95%-ile</th>
<th>Mean</th>
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<tbody>
<tr>
<td>Excellent</td>
<td>500</td>
<td>2,000,000</td>
<td>200</td>
<td>92.2%</td>
<td>95.6%</td>
<td>97.9%</td>
<td>95.3%</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>2,000,000</td>
<td>200</td>
<td>92.5%</td>
<td>94.6%</td>
<td>97.0%</td>
<td>94.7%</td>
<td>1.89</td>
</tr>
<tr>
<td>Excellent</td>
<td>250</td>
<td>2,000,000</td>
<td>200</td>
<td>96.0%</td>
<td>98.2%</td>
<td>97.9%</td>
<td>98.2%</td>
<td>2.07</td>
</tr>
</tbody>
</table>

This choice of component quality and injection tank design parameters results in system reliability that meets the performance criterion regardless of the maintenance/inspection intervals. However, there is still an approximately 50% chance of system reliability being greater than 95%. Analysis of the results indicates that overall reliability is controlled by the reliability of the injection tank. The next cases consider a larger injection tank.

| Excellent         | 500                         | 2,500,000                   | 200                            | 94.8%                                 | 97.2%  | 99.2%  | 97.2%  | 2.1  |
|                   | 500                         | 2,500,000                   | 200                            | 93.3%                                 | 96.5%  | 99.1%  | 96.6%  | 2.1  |
| Excellent         | 250                         | 2,500,000                   | 200                            | 94.4%                                 | 96.9%  | 98.1%  | 96.7%  | 2.1  |

The increase in the tank size results in system reliability that meets the target with a higher risk tolerance (represented by the 5%-ile reliability. Further analysis indicates that system reliability is controlled by the performance of the injection tanks and not by the injection valve/pump system. The reliability of the injection tanks is a direct result of the reliability of the charging system, which is not redundant. Thus, the quality of the injection valves/pumps components can be reduced due to redundancy in the injection system.

| Excellent - Charging System Good - Injection System | 500 | 250 (Infrequent) | 2,500,000 | 200 | 93.7% | 95.6% | 97.7% | 95.6% | 1.7 | 180 | 195 | 212 | 196 | 1.896 |
| Excellent - Injection System 250 - Charging System | 250 (Infrequent) - Injection System 125 (Infrequent) - Charging System | 2,500,000 | 200 | 93.0% | 96.3% | 97.9% | 95.8% | 1.7 | 181 | 195 | 208 | 194 | 1.894 |
| Excellent - Injection System 250 - Charging System | 250 (Infrequent) - Injection System 25 (Frequent) - Charging System | 2,500,000 | 200 | 93.2% | 95.9% | 98.3% | 96.0% | 1.7 | 192 | 206 | 220 | 205 | 1.905 |

Table 2: Case Study Results
What Do The Results Say:

- Excellent components, frequent maintenance and inspection, and a large injection tank can meet the goal with ample margin
  - System would be over-designed with a significant cost associated
- Several options exist that meet the target goal - other factors/requirements need to be considered
  - What is the desired level of risk tolerance - how “bad” is acceptable
  - How do costs play into the decision - larger capital and lower O&M or vice-versa
- Decisions made determine which options are advanced to next phase
- Sub-system requirements can be defined
- Sub-system models can be further refined and optimized
Summary

• Example of RIPB Life-Cycle Design using Monte Carlo Simulation

~5 Minutes Q&A
PSD-1 Standard

- Overview and Status of ASME Plant Systems Design Standard
the Problem

New plants and facilities with potential for significant environmental, safety and health hazards to the worker and or public ...

... may not be built in the United States unless costs to license, design and construct can be significantly reduced, while ensuring safety and health of the worker, the public and the environment.
the Solution

Plant Systems Design Standard (PSD-1)

A technology neutral standard that provides a framework, including requirements and guidance, for design organizations to:

• Conduct plant process hazard analysis in early stages of plant design that (a) advance as the design matures and (b) provide structure to the initial development of a quantitative risk assessment.

• Incorporate systems engineering design processes, practices and tools with traditional architect engineering design processes, practices and tools.

• Incorporate risk informed probabilistic design methodologies with traditional deterministic design methods using reliability and availability targets.

... and integrate these into a design organizations existing design processes and procedures.
the Solution, PSD-1

PLANT SYSTEMS DESIGN INFLUENCE DIAGRAM

HAZARDS ANALYSIS (HAPRA)

SYSTEMS ENGINEERING (SEDI)

Pre-Conceptual Design

Conceptual Design

Preliminary Design

Final Design

Plant Startup

PROBABILISTIC DESIGN (PDM)

PRA (HAPRA)
the Objectives

1. **Safer and more efficient** system designs and design alternatives with **quantified safety** levels

2. **More effective requirements management**
   1. including assumptions, TBDs and TBVs
   
3. Cover the **entire life cycle** of a plant (design, construction, operation, decontamination and decommissioning)

4. Be **system based**, vs. component based, and **inclusive of multiple disciplines** (mechanical, electrical, instrumentation & control, HVAC, etc.)
PSD-1 Related Initiatives

The following are ongoing and include similar objectives.

- LMP w NEI-18-04 and RG 1.233
- ANS including ANS 30.1 & 30.2
- EPRI Body of Knowledge (BoK)
- BPTCS TG Risk-Based Design
- Section XI, Div. 2, Requirements for Reliability and Integrity Management Programs for Nuclear Power Plants (RIM)

See next slide for more detail on ANS
ANS New Reactor RIPB Standards Structure

This slide is ~ 18 mos old and not current
PSD-1 Progress to date ...

• Defined activities covered by PSD-1 using roadmaps, process flow diagrams, and WBS Data Sheets

• Developed block flow diagrams and N-square diagrams to integrate activities within 3 technical areas and to integrate the technical areas together.

• Imported this information into Innoslate, a Model-Based Systems Engineering cloud-based software tool, to plan and organize contents of PSD-1.
PSD-1 Progress to date ...
PSD-1 Progress to date ...

In parallel with integration and scheduling activities:

- Drafted Part 1, General Principles, of the standard:
  - tailoring use of the standard
  - safety goals
  - taxonomy and boundaries
  - technical baseline descriptions
- Started writing Part 2, Design Development Process
  - both an initial writing effort and a pilot effort
  - results will provide guidance to other working groups
PSD Structure & Development

- SE Process Overview
- Taxonomy & Baselines
- Product/Document Hierarchy
- Use of Innoslate
- Example of Part 2 Content
- Part 1 Section on RIPB Design
Plant System Design Taxonomy

- **Infrastructure**
  - **System**
    - Storm Water
    - Fire Water
  - **Structure**
    - Well House
    - Maintenance Facilities
  - **Final Site Grading**
    - Retaining Walls
    - Roads

- **Plant**
  - **System**
    - Conveyance
    - Utility
  - **Structure**
    - Office Buildings
    - Misc. Buildings
  - **Final Site Grading**
    - Slopes

- **Legend**:
  - Functional Baseline
  - Allocated Baseline
  - Product Baseline

- **Legend**:
  - System
  - Subsystem
  - Component
  - Sub-Component
  - Bulk Material

- **Legend**:
  - Structural Subsystem
  - Frames
  - Beams
  - Columns
  - Bracing

- **Legend**:
  - Component
  - Stairs
  - Platforms
  - Minor Supports

- **Legend**:
  - Bulk Material
  - Racks
  - Hand rails
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<thead>
<tr>
<th>Technical Baseline Design Stage</th>
<th>Functional</th>
<th>Allocated</th>
<th>Product</th>
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<tr>
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<td>Preliminary for long lead and key components</td>
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<td>Preliminary</td>
<td>Updates as required</td>
<td>Approved</td>
<td>Preliminary</td>
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<tr>
<td>Final</td>
<td>Updates as required</td>
<td>Updates as required</td>
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PSD-1 Standard Development

Project Processes to be Addressed in the Standard

Glossary
2-2.2 PRE Functional Baseline Activities (H.3)

Activity H.3, Evaluate Site/Infrastructure/Plant (SIP) Risks, generates SIP process, production, and external hazard and risk information to inform the Conceptual Design Development. This information includes lists of hazards and their causes, event sequences and frequencies, event consequences, and recommended functions for barriers to be included in the design to avoid or mitigate identified hazards. This includes validation of SIP risk evaluation results against the stakeholder identified ESH and production goals.

Technical requirements and information typically provided with the contract are listed in the description of Contract Technical Requirements (CTR) included in 1-1.6.3, Technical Baselines. A more detailed list of typical design documents associated with performing this activity is included in Appendix 1-1, Baseline Documents Table.

At this early stage of design, it is expected that the maturity level of SIP hazards, sequences and consequences and risk evaluation is low in terms of level of detail and design development. Qualitative risk evaluation methods described in Appendix 3-1, Process Risk Evaluation Toolbox, can be used to help inform the design process.

more
## 1.13 R-I & P-B Design

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<th>Activity Number</th>
<th>Requirement Number</th>
<th>Description</th>
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<tr>
<td>H.3</td>
<td>H.3-1</td>
<td>The RO shall GENERATE SIP process, production, and external hazard and risk information to inform the Conceptual Design Development. [Product]</td>
</tr>
<tr>
<td>H.3</td>
<td>H.3-2</td>
<td>The RO shall GENERATE SIP hazard and risk information for each plant operating mode.</td>
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PSD-1, 1.13 R-I & P-B Design

1-1.13 Risk-Informed Design and Performance-Based Design

This section describes what, why and how “risk-informed”, “performance-based”, and “risk-informed and performance-based” design approaches are applicable to, and used in, this Standard. In this context, “design approach” means that the design process includes considerations associated with each of these approaches. Although these considerations can occur anywhere, they are particularly relevant in fulfilling the objectives in Section 1-1.6.3, “Technical Baselines”.

1-1.13.1 Risk Informed (RI) Approach

A risk-informed approach to decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that focus attention on design and operational issues commensurate with their importance to the health, safety, and the environment of the public.

A "risk-informed" approach enhances the deterministic approach by: (1) allowing explicit consideration of a broader set of potential challenges to safety, (2) providing a logical means for prioritizing these challenges based on risk significance, operating experience, and/or engineering judgment, (3) facilitating consideration of a broader set of resources to defend against these challenges, (4) explicitly identifying and quantifying sources of uncertainty in the analysis (although such analyses do not necessarily reflect all important sources of uncertainty), and (5) leading to better decision-making by providing a means to test the sensitivity of the results to key assumptions. Here, “prioritization” is key; while “risk-informed” means, in part, “not relying purely on the PRA,” it also means being able to say that some scenarios or systems are more important than others and understanding how sure we are about the statements we are making. US NRC SRM SECY-98-144 [11-3]

For example, does the Functional Baseline (Section 1-1.6.3.2) reflect functional and performance requirements that allocate priorities and criteria in a way that resources are assigned commensurate with importance to safety?

1-1.13.2 Performance Based (PB) Approach

A performance-based approach is one that establishes performance and results as the primary basis for safety decision-making, and incorporates the following attributes:

(a) measurable (or calculable) parameters (i.e., direct measurement of the physical parameter of interest or of related parameters that can be used to calculate the parameter of interest) exist to monitor system, including facility and operational performance,
Summary

- Overview and Status of ASME Plant Systems Design Standard

~ 5 Minutes Q&A
RIPB Design Concept

• A Concept for RIPB Design and Safety Classification

See next slide
<table>
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<th>Stage</th>
<th>Phase</th>
<th>Requirement</th>
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<tr>
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<td>CONTRACT TECHNICAL REQUIREMENTS</td>
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<td>Pre-Conceptual Design</td>
<td>Plant Functional &amp; Performance Rqmts</td>
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RIPB Safety Classification Concept
CATEGORISATION OF SAFETY FUNCTIONS AND CLASSIFICATION OF STRUCTURES, SYSTEMS AND COMPONENTS

- Following 3 slides contain figures and a table extracted from the ONR Guide.
- These extracts illustrate that at least one regulator understands and recognizes the relationship between RIPB principles and how to implement those principles using good systems engineering practices.
- We will not discuss these or the ONR Guide in detail during today’s presentation.
- ANS 30.2 working group should include the ONR Guide as an input to development of the 30.2 standard.
Figure 1 – Role of safety function categorisation (green box) and SSC classification (blue box) within the lifecycle model (‘V-diagram’).
3a – Off-site frequency / consequence regions for initial safety function categorisation (see section 5.6.2)
<table>
<thead>
<tr>
<th>SSC Class</th>
<th>Failure frequency per year (ff)</th>
<th>Probability of failure on demand (pfd)</th>
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<td>$10^{-3} \geq pfd \geq 10^{-5}$</td>
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<td>$10^{-1} \geq pfd &gt; 10^{-2}$</td>
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Table 2 – Relationship between SSC class and the failure frequency and probability of failure on demand, (see reference 3)
Summary

• Example of RIPB Life-Cycle Design using Monte Carlo Simulation
• Overview and Status of ASME Plant Systems Design Standard
• A Concept for RIPB Design and Safety Classification
  • UK ONR Guide implements RIPB SE approaches and methodologies

DISCUSSION