

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

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Systems Design Standards Committee

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# 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

# RIPB L-C Design Example 1 of 8

- 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 2 of 8

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

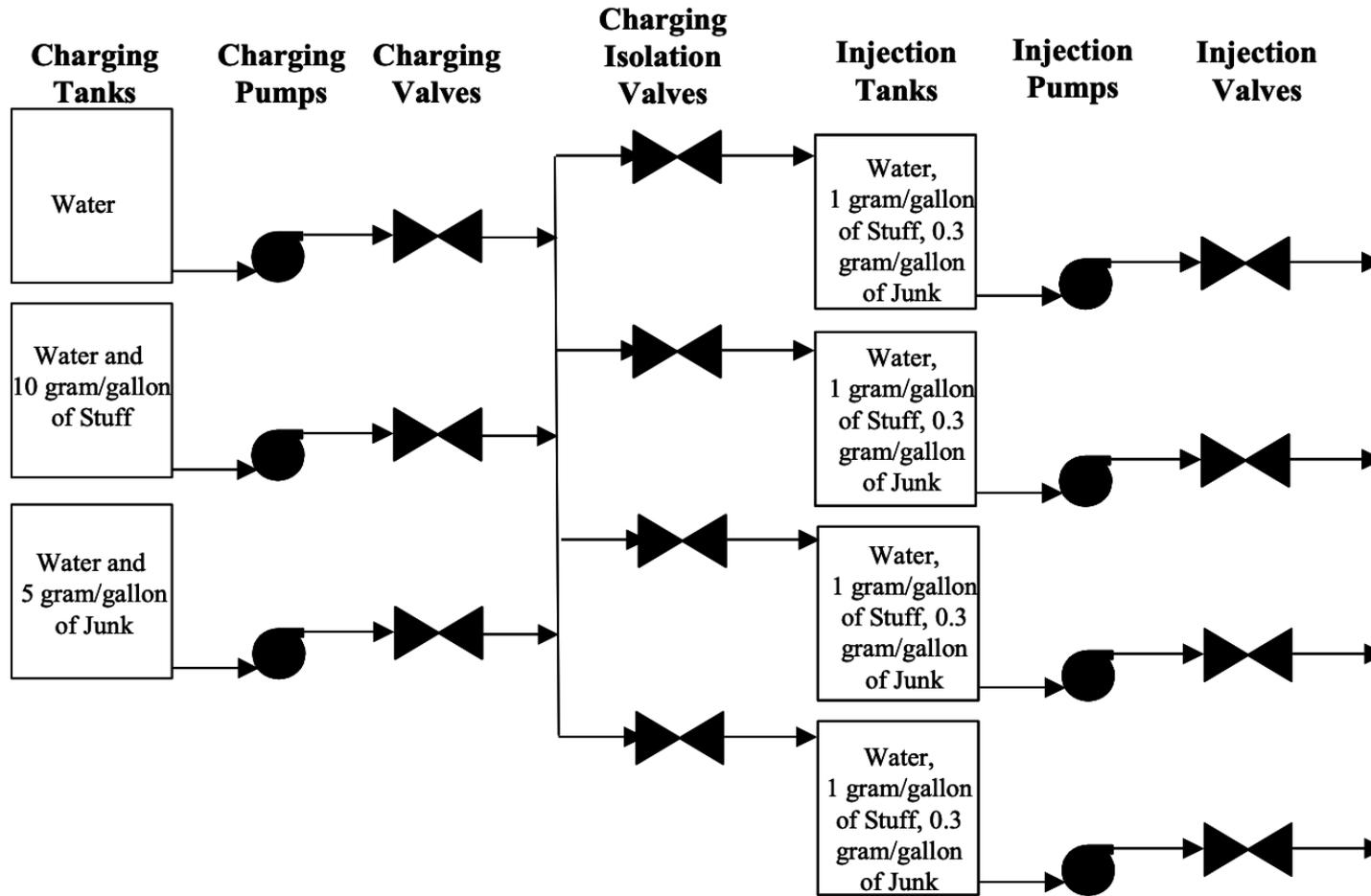


Figure 3. Fluid Injection System Schematic

# RIPB L-C Design Example 3 of 8

- General assumptions:
  - Component Failure
    - Modeled simplistically  $\square$  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

# RIPB L-C Design Example 4 of 8

- 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 5 of 8

- 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, 11<sup>th</sup> International Conference on Nuclear Engineering, Tokyo, JAPAN, April 20-23, 2003, ICONE11-36597

# RIPB L-C Design Example 6 of 8

System Component	Interactive Component Information			Component Cost Information				Component Reliability Information <sup>1</sup>			Pump Discharge Information <sup>2</sup>		
	Component Quality	Maintenance Frequency (day)	Inspection Duration (day)	Capital Cost (\$)	Maintenance Cost (\$ per Activity)	Inspection Cost (\$ per Activity)	Repair Cost (\$ per Activity)	Initial Failure Rate (day <sup>-1</sup> )	Failure Rate Doubling Time (day)	Target Frequency that Forces Inspection	Initial Pump Discharge Rate	Minimum Pump Service Discharge Rate	Pump Fouling Rate
Injection Valves	Good	100	F <sub>m</sub> /2	\$50,000				0.004	100				
	Very Good	250	F <sub>m</sub> /5	\$100,000	\$1,000	\$150	\$2,500	0.002	200	0.008			
	Excellent	500	F <sub>m</sub> /10	\$200,000				0.001	300				
Injection Pumps	Good	100	F <sub>m</sub> /2	\$75,000				0.004	100				
	Very Good	250	F <sub>m</sub> /5	\$150,000	\$2,000	\$150	\$5,000	0.002	200	0.008	110 (gal/min)	90 (gal/min)	20 (gal/min) / 200 (days) 20 (gal/min) / 400 (days) 20 (gal/min) / 600 (days)
	Excellent	500	F <sub>m</sub> /10	\$300,000				0.001	300				
Charging Isolation Valves	Good	100	F <sub>m</sub> /2	\$25,000				0.004	100				
	Very Good	250	F <sub>m</sub> /5	\$30,000	\$1,000	\$150	\$2,000	0.002	200	0.008			
	Excellent	500	F <sub>m</sub> /10	\$50,000				0.001	300				
Charging Valves	Good	100	F <sub>m</sub> /2	\$50,000				0.0035	40				
	Very Good	250	F <sub>m</sub> /5	\$100,000	\$3,000	\$150	\$5,000	0.0025	50	0.01			
	Excellent	500	F <sub>m</sub> /10	\$250,000				0.0015	60				
Charging Pumps	Good	100	F <sub>m</sub> /2	\$200,000 <sup>3</sup>				0.0035	40				
	Very Good	250	F <sub>m</sub> /5	\$400,000 <sup>3</sup>	\$5,000	\$150	\$8,000	0.0025	50	0.01	Note 4	50% of Initial Discharge	Note 5
	Excellent	500	F <sub>m</sub> /10	\$600,000 <sup>3</sup>				0.0015	60				

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

- Notes:
- <sup>1</sup>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
  - <sup>2</sup>Model assumes that pumps fail (discharge decreases) linearly with time from an initial discharge rate immediately following maintenance or repair.
  - <sup>3</sup>These are base costs. There is an incremental cost of \$0.1 per gallon/day insertion into the injection tanks.
  - <sup>4</sup>This is determined as a function of the tank filling rate.
  - <sup>5</sup>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

Component Input Choices					System Reliability Results				System Cost Results					
Component Quality	Maintenance Frequency (day)	Inspection Frequency (day)	Injection Tank Volume (gallon)	Injection Tank Input Rate (gallon/min)	5%-ile	Median	95%-ile	Mean	Capital Cost (million \$)	Annual Costs (\$1,000 / year)				Capital + Mean Annual (million \$)
										5%-ile	Median	95%-ile	Mean	
Excellent	500	50 (Frequent)	2,000,000	200	92.2%	95.6%	97.9%	95.3%	1.89	123	133	142	133	2.023
Excellent	500	250 (Infrequent)	2,000,000	200	92.5%	94.6%	97.0%	94.7%	1.89	108	117	127	117	2.007
Excellent	250	25 (Frequent)	2,000,000	200	92.9%	95.2%	97.8%	95.2%	1.89	144	155	164	155	2.045
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	50 (Frequent)	2,500,000	200	94.8%	97.2%	99.2%	97.2%	2.1	124	132	139	132	2.232
Excellent	500	250 (Infrequent)	2,500,000	200	93.3%	96.5%	99.1%	96.6%	2.1	105	118	125	116	2.216
Excellent	250	25 (Frequent)	2,500,000	200	94.4%	96.9%	98.1%	96.7%	2.1	147	157	170	157	2.257
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 - Charging System Good - Injection System	500 - Injection System	250 (Infrequent) - Injection System	2,500,000	200	93.0%	96.3%	97.9%	95.8%	1.7	181	195	208	194	1.894
Excellent - Charging System Good - Injection System	500 - Injection System	250 (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

# RIPB L-C Design Example 8 of 8

- 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)

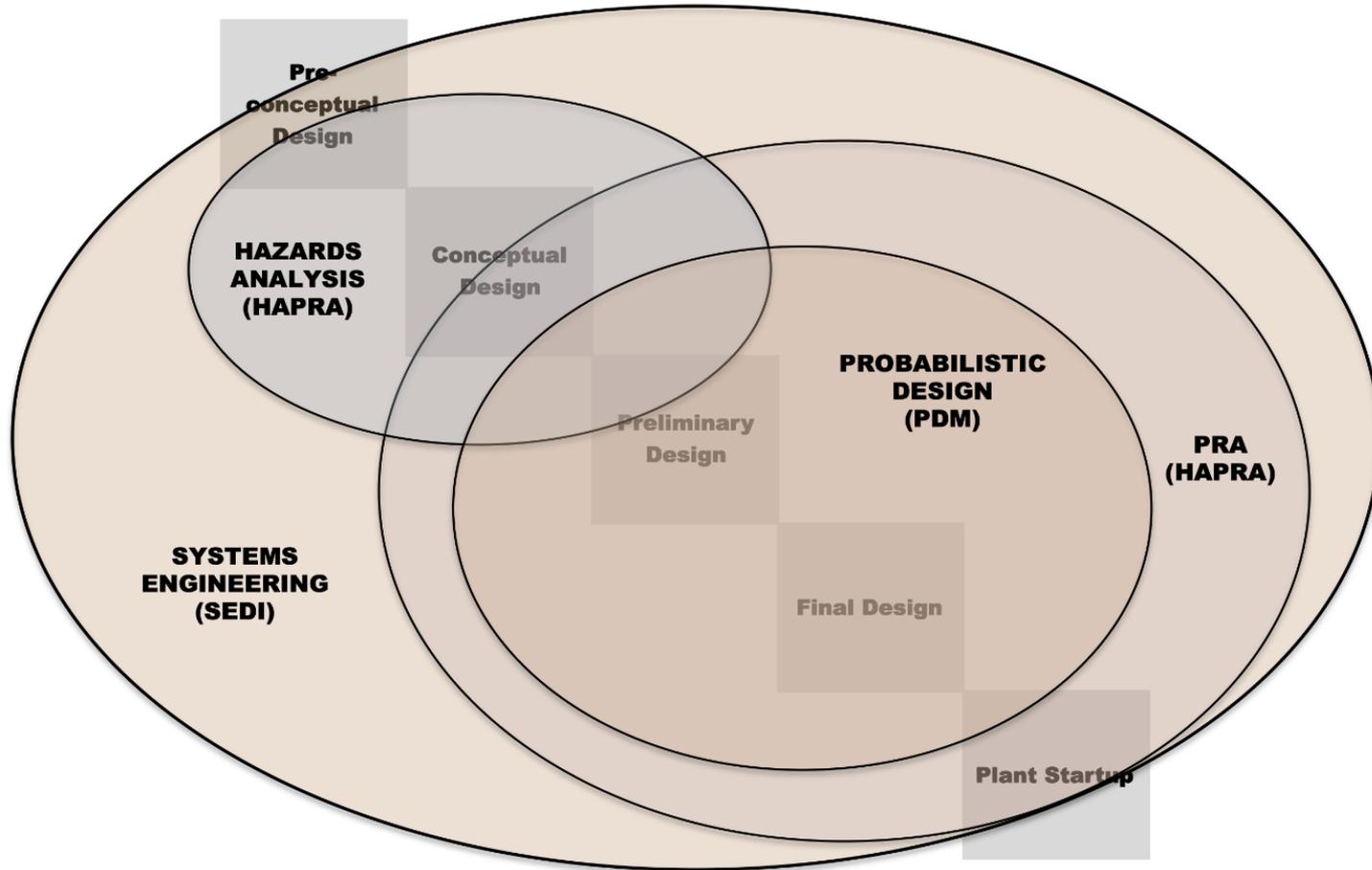
A technology neutral standard that provides a framework, including requirements and guidance, for **design organizations** to:

- 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



# 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.)

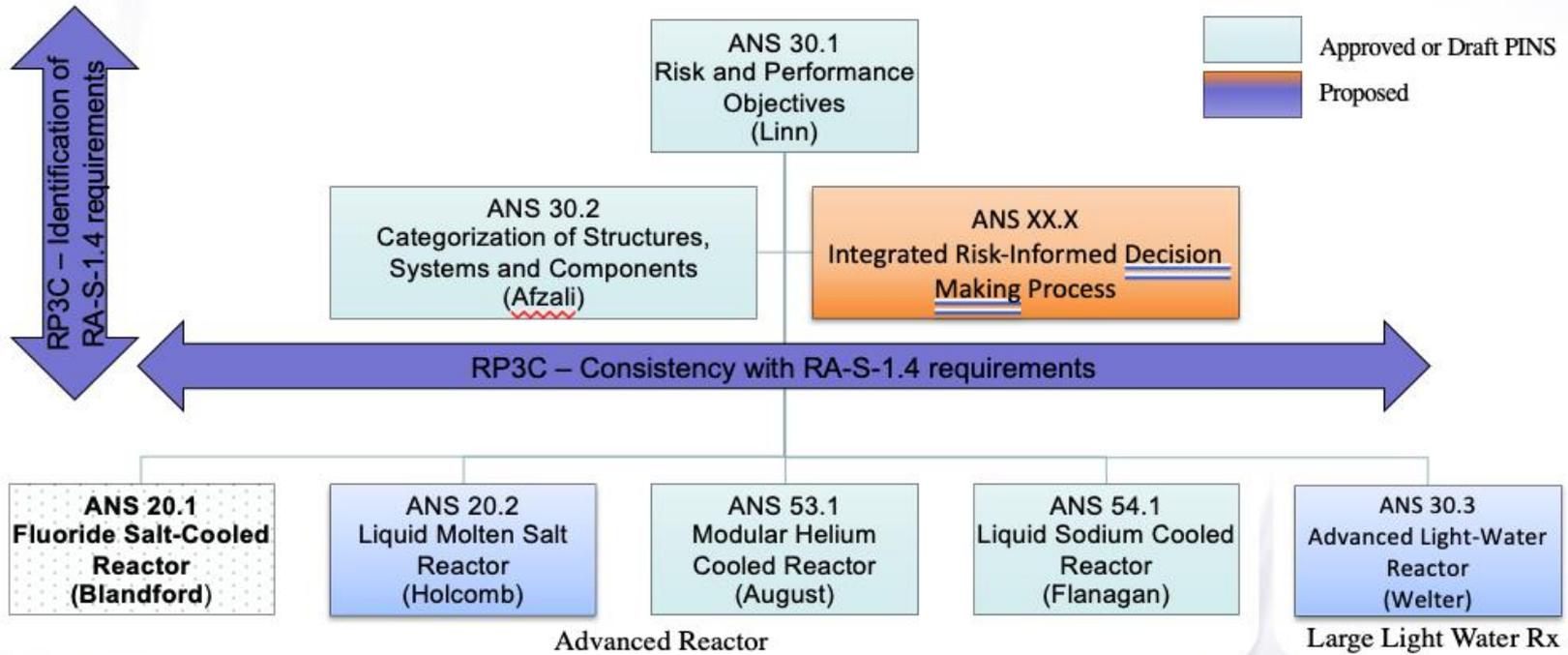
# PSD-1 Related Initiatives

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

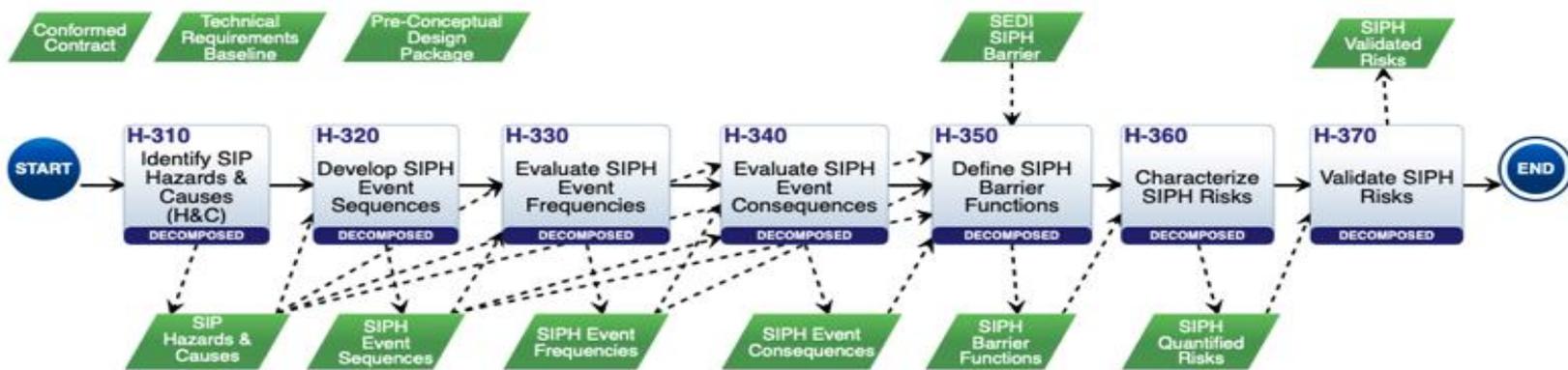
ANS and other SDO standards as needed:  
- Cross cutting topics  
- Reactor technology specific issues



# 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 ...

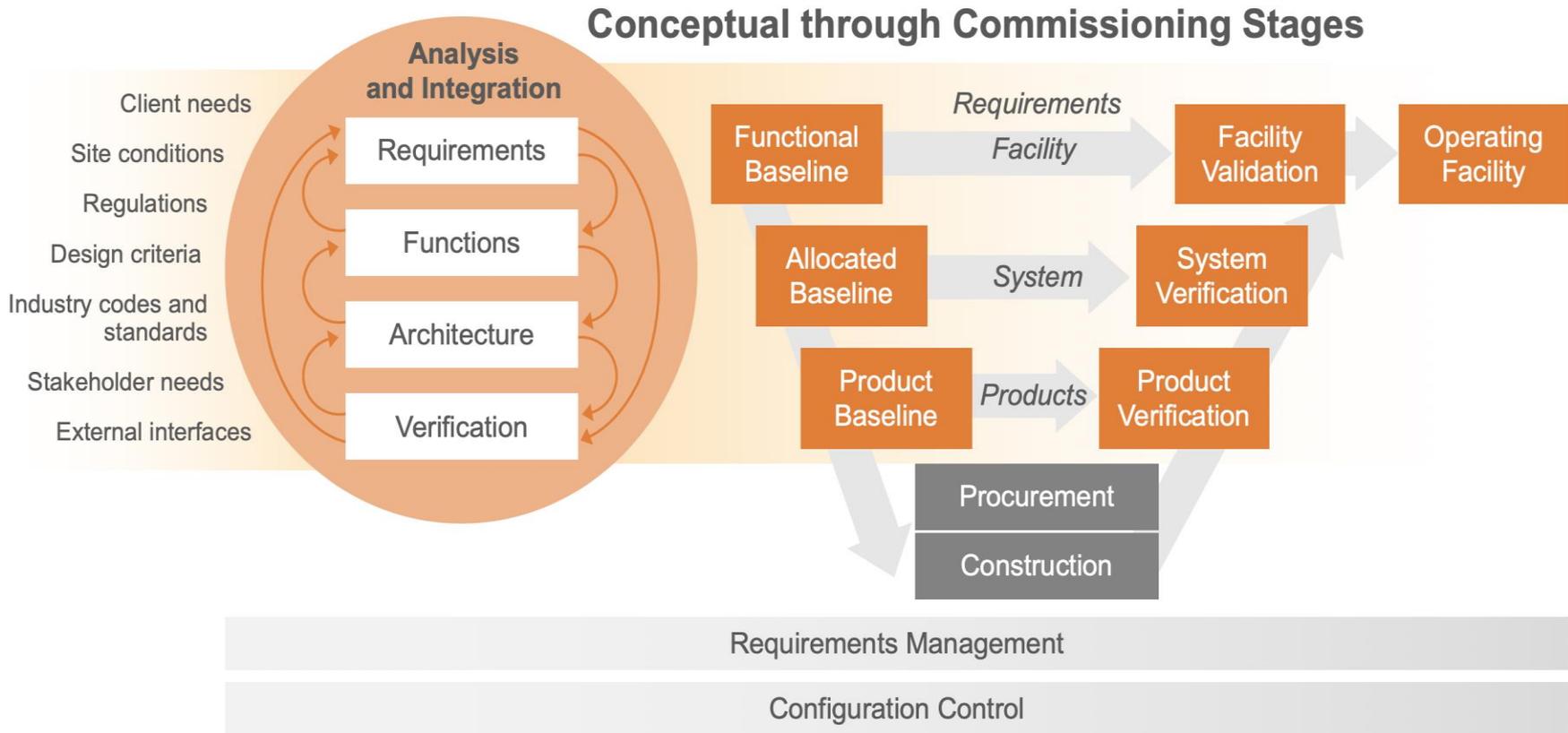
In parallel with integration and scheduling activities:

- 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

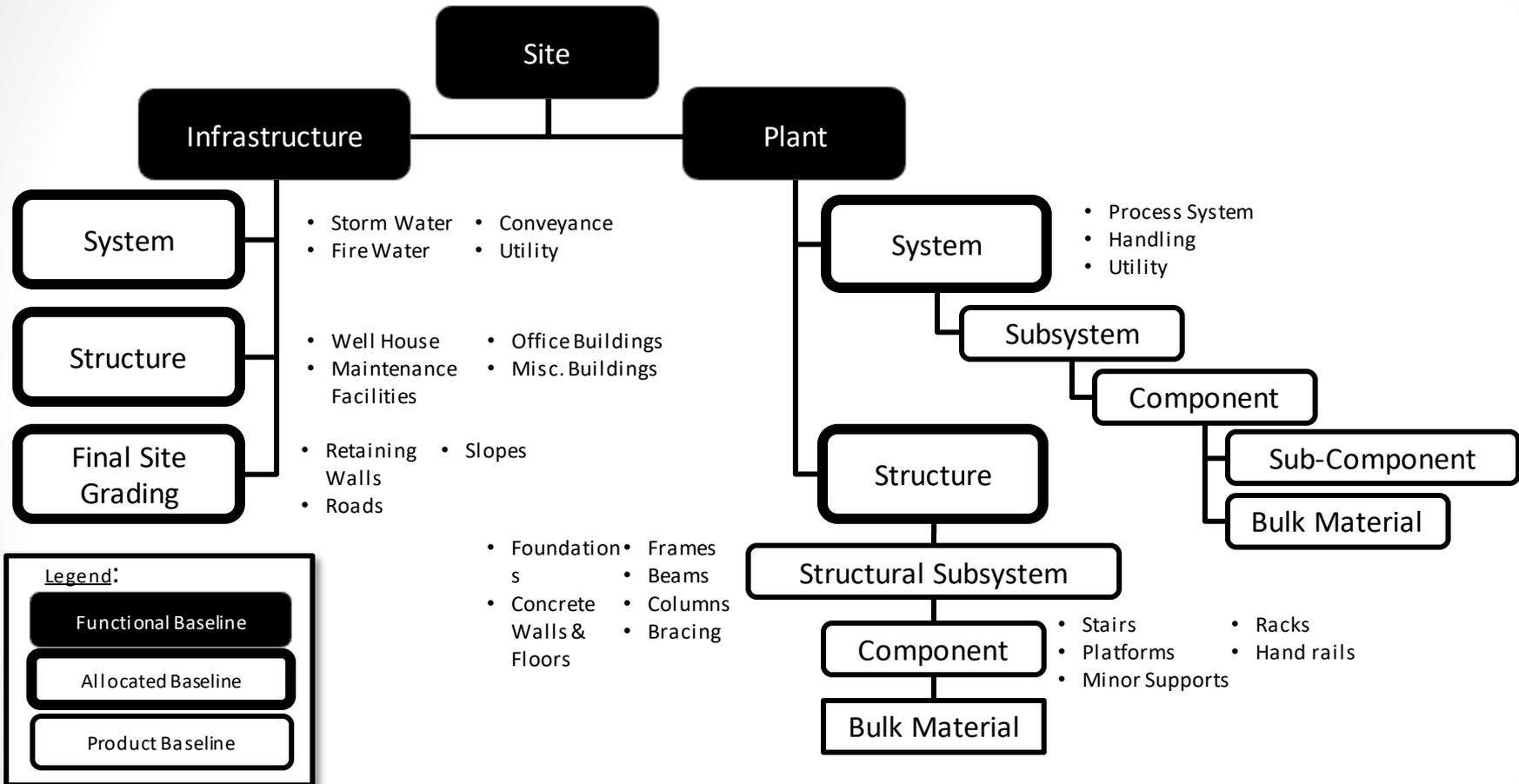
# PSD Structure & Development

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

# Putting it All Together



# Plant System Design Taxonomy

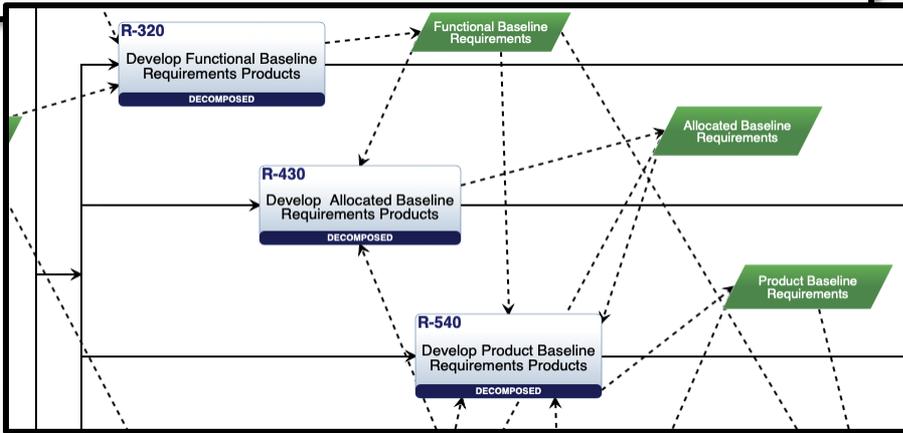
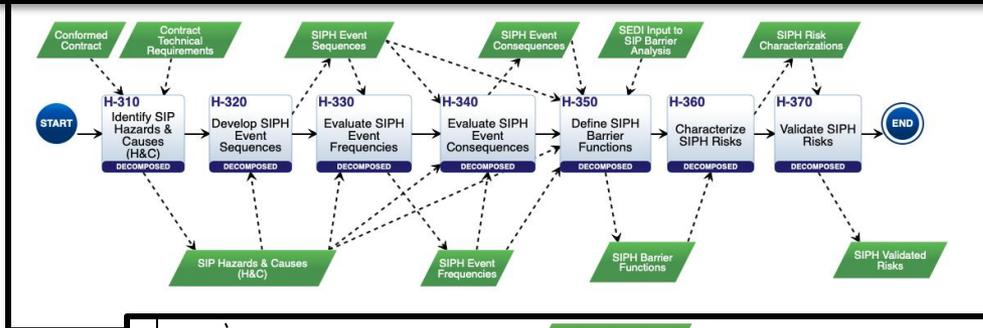


**Table 1-2, Project Design Development Stages vs. Baseline**

<b>Technical Baseline Design Stage</b>	<b>Functional</b>	<b>Allocated</b>	<b>Product</b>
<b>Conceptual</b>	<b>Approved</b>	Preliminary	Preliminary for long lead and key components
<b>Preliminary</b>	Updates as required	<b>Approved</b>	Preliminary
<b>Final</b>	Updates as required	Updates as required	<b>Approved</b>

# PSD-1 Standard Development

## Project Processes to be Addressed in the Standard



**Standard**

Table 1-1, Design Development Stages

**Pre-Conceptual:** perform mission needs analysis, conduct exploratory research, identify stakeholder needs, and select technology. Provide siting information, production and ESH goals, and other information necessary to initiate Conceptual Design.

**Conceptual:** develop site, infrastructure and plant functional requirements.

**Preliminary:** develop system level functional requirements and design documentation.

**Final:** complete the design effort at the production/component level and produce approved design documentation necessary to permit procurement, construction, start-up and commissioning to proceed.

Similarly, the red box within Figure 1-2, depicts the scope of this Standard relative to: INCOSE life-cycle stages, typical architect/engineer design stages, and DOE project development stages. The last column in the diagram depicts the scope of this standard relative to the technical baselines as defined and used in this Standard and as shown in Figure 1. These baselines are further described and discussed in the following Section.

**1.6.3 Technical Baselines**

Figure 1-1, Plant Systems Design Taxonomy, and Figure 1-2, Plant Systems Design Boundary Diagram, include references to technical baselines. A technical baseline describes the technical characteristics of the plant at a particular point in time. Different industries have slightly different definitions of technical baselines. This section describes technical baselines in as they are used throughout this Standard.

Technical baselines are essential to Configuration Management a process to manage and control system elements and configurations over the life cycle. This is accomplished by ensuring effective management of the evolving configuration of plant systems including both hardware and software. Key to this objective is the establishment, control and maintenance of software and hardware technical baselines.

A technical baseline specifies the requirements, designs, constraints, assumptions, and interfaces for the configured items (CI) included within that baseline, at the time the baseline is approved. Technical baselines are established by a review and acceptance of requirements, design, and product specification documents. As the plant evolves through the various project design stages, the software and hardware baselines are maintained under configuration control. The previous baseline is the basis for design development activities conducted to develop the successor baseline.

Technical baselines are composed primarily of requirements and design. These are the required elements by which acceptance is measured. Other supporting information such as calculations, trade studies, simulations and descriptive items are not included in the technical baseline but form the design basis for the documents that are included.

ISO 9001 Process Element	INCOSE Stages	AS E Design Stage	DOE	Key Success Metric
Technical Processes	Pre-Conceptual, Conceptual, Preliminary, Final	Conceptual Design, Preliminary Design, Final Design	Conceptual Design, Preliminary Design, Final Design	Quality, Cost, Schedule, Safety, Reliability
Business/Mission Analysis	Pre-Conceptual	Conceptual Design	Conceptual Design	Feasibility
Requirements Analysis & Requirements Definition	Pre-Conceptual, Conceptual	Conceptual Design, Preliminary Design	Preliminary Design	Allocation
System Requirements Definition	Pre-Conceptual, Conceptual	Conceptual Design, Preliminary Design	Preliminary Design	Product
Design Architecture	Conceptual, Preliminary	Conceptual Design, Preliminary Design	Preliminary Design	Product
Integration	Preliminary, Final	Final Design	Final Design	Product
Structural and Component Identification	Final	Final Design	Final Design	Product
Production and Component Validation	Final	Final Design	Final Design	Product

**Glossary**

Materials that form part of a site, system, structure or component, are used as needed, and that are produced or purchased by quantity such as by weight, volume, length or lot. Bulk materials purchased to the same specification are interchangeable. They are typically materials that are indistinguishable and not uniquely identified. Examples: Bolts, cement, gravel, standard electrical receptacle, bulk valve, bulk pipe

1. A system is an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not. (INCOSE) 2. "Combination of interacting elements organized to achieve one or more stated purposes" (ISO/IEC/IEEE Std 24765, 2017, p. 453).

1. A agreed and controlled set of requirement and design information defining the capabilities, functionality and associated design architecture for the entity of interest. For the purpose of this standard, the entity of interest is a site containing one or more plants and supporting site infrastructure. 2. "description of the system's performance (functional, interoperability, and interface characteristics) and the verification required to demonstrate the achievement of those specified characteristics" (ISO/IEC/IEEE Std 24765, 2017, p. 193).

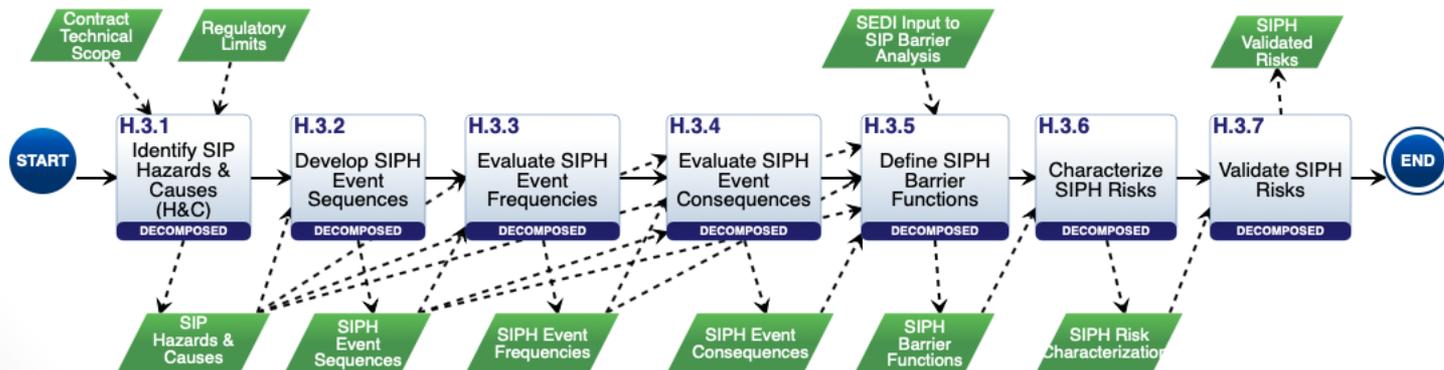
# 2-2.2 PRE Functional Baseline Activities (H.3)

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

Table 2-2.1-1, Requirements for Evaluate Site/Infrastructure/Plant (SIP) Risks (H.3)

Activity Number	Requirement Number	Description
H.3	H.3-1	The RO shall GENERATE SIP process, production, and external hazard and risk information to inform the Conceptual Design Development. [Product]
<u>H.3</u>	<u>H.3-2</u>	<u>The RO shall GENERATE SIP hazard and risk information for each plant operating mode.</u>

# 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

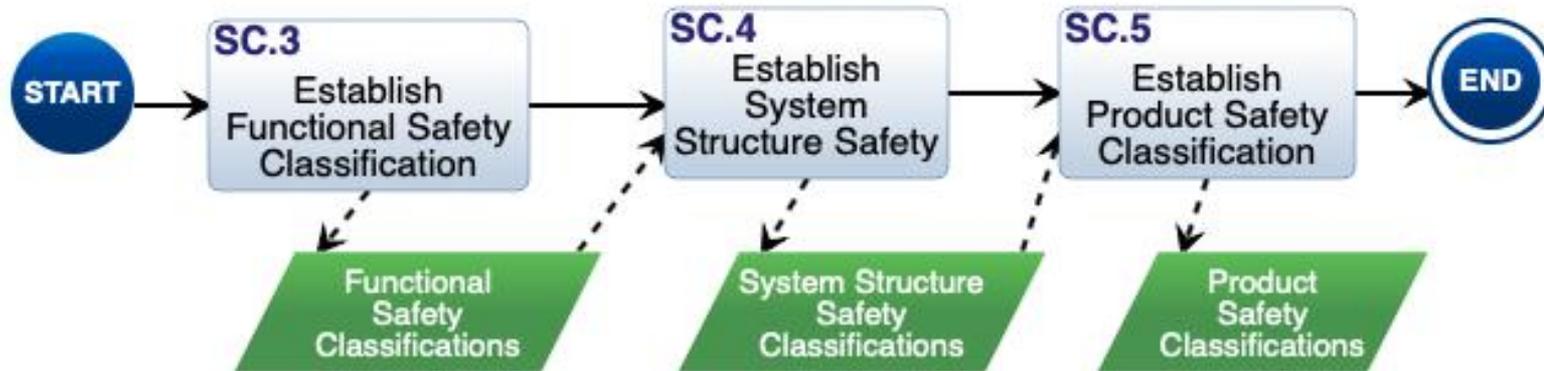
# RIPB Design Concept

- A Concept for RIPB Design and Safety Classification

See next slide

R&D						
		CONTRACT TECHNICAL REQUIREMENTS				
Pre-Conceptual Design						
	Plant Functional & Performance Rqmnts					
		Plant Hazard Identification				
			Plant Risk Evaluation			
				Plant F-C Curve		
					Plant Safety Functions	
		FUNCTIONAL BASELINE				
Conceptual Design						
	SS Functional & Performance Rqmnts					
SS = System/Structure		SS Hazard Identification				
			SS Risk Evaluation	→	SS Safety Strategy & Safety Functions	→
			↑		SS Target Reliability	↓
			↑		←	SS Safety Classification
		ALLOCATED BASELINE				
Detailed Design						
	Product Functional & Performance Rqmnts					
		Product Hazard Identification				
			Product Hazard Evaluation			
				Product Target Reliability		
					Product Safety Classification	
		PRODUCT BASELINE				

# RIPB Safety Classification Concept



# UK ONR Guide NS-TAST-GD-094 – Rev

## 2

### **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 a 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.**

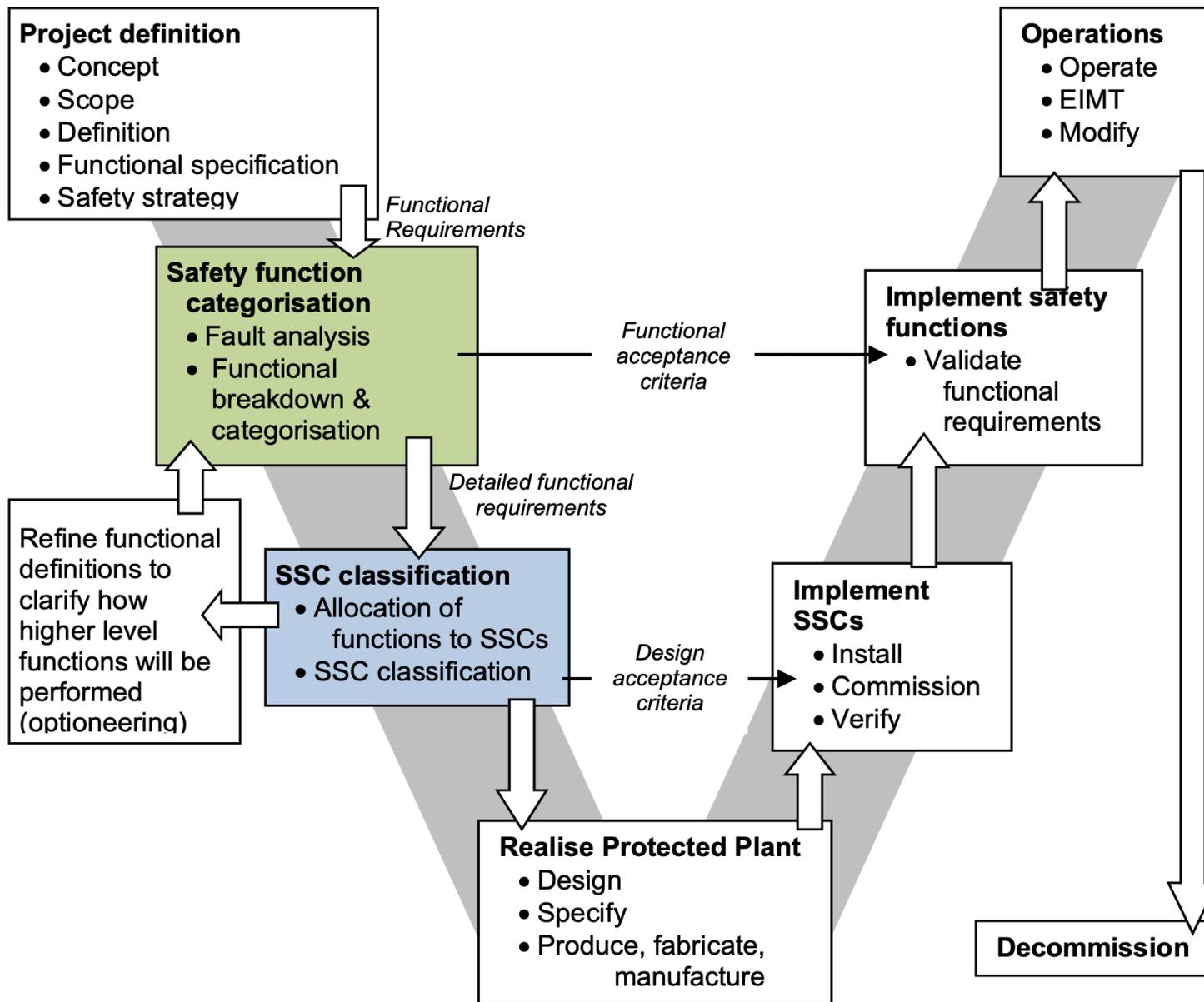
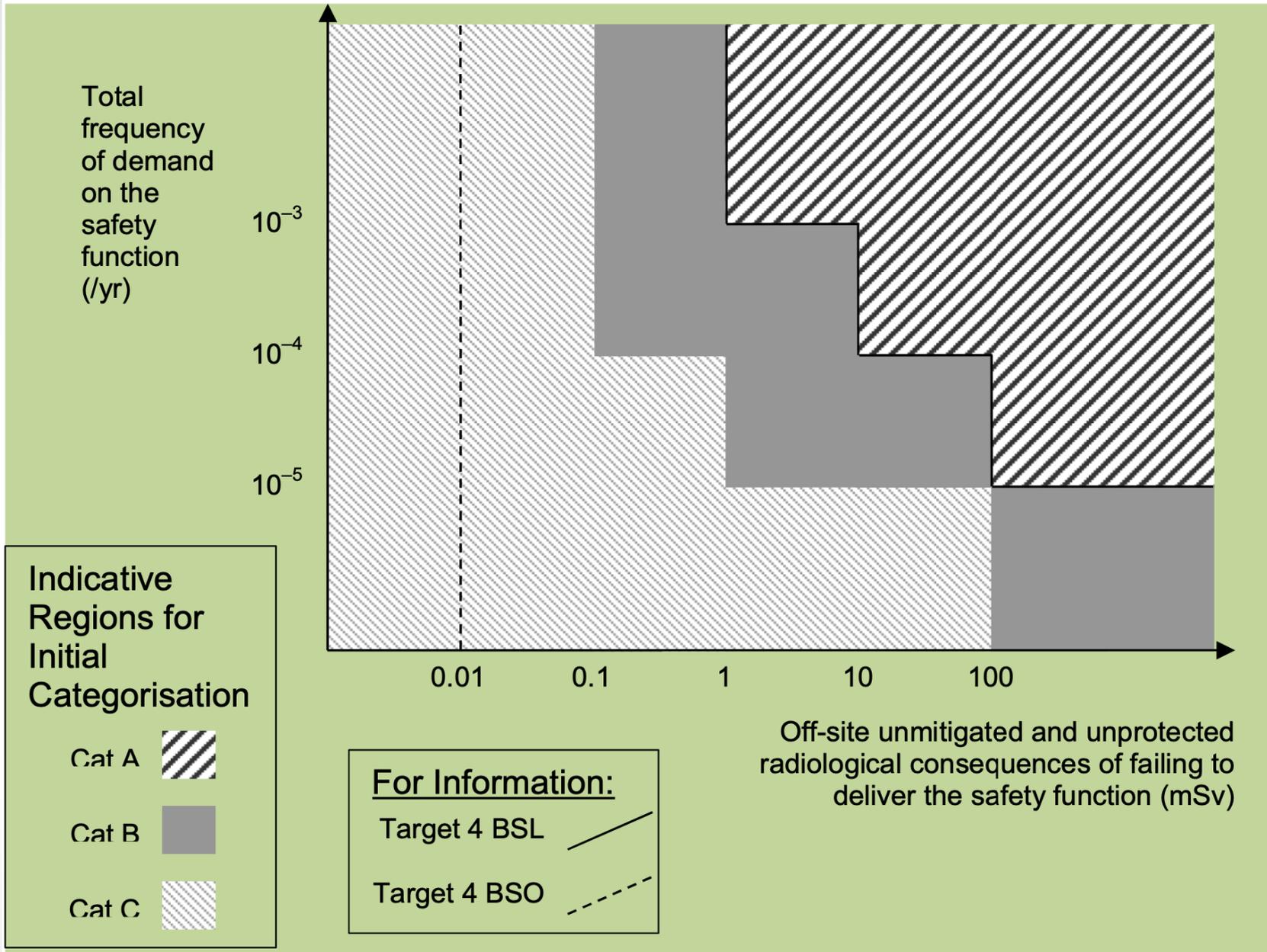


Figure 1 – Role of safety function categorisation (green box) and SSC classification (blue box) within the lifecycle model ('V-diagram')



3a – Off-site frequency / consequence regions for initial safety function categorisation (see section 5.6.2)

<b>SSC Class</b>	<b>Failure frequency per year (ff)</b>	<b>Probability of failure on demand (pfd)</b>
Class 1	$10^{-3} \geq ff \geq 10^{-5}$	$10^{-3} \geq pfd \geq 10^{-5}$
Class 2	$10^{-2} \geq ff > 10^{-3}$	$10^{-2} \geq pfd > 10^{-3}$
Class 3	$10^{-1} \geq ff > 10^{-2}$	$10^{-1} \geq pfd > 10^{-2}$

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