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

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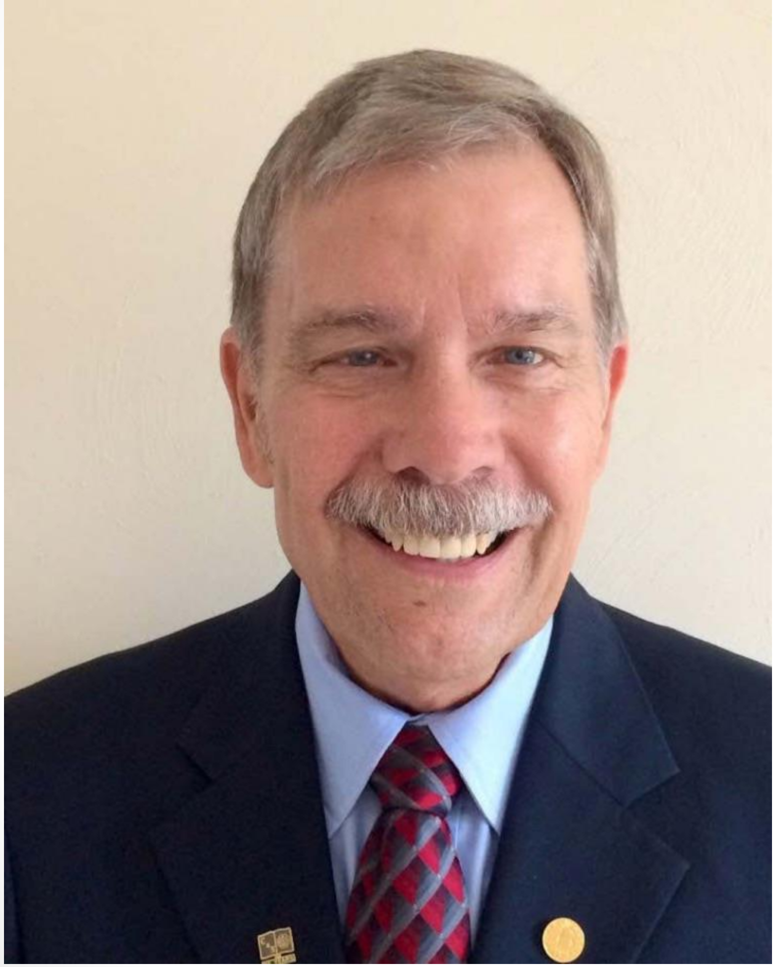
Ralph Hill

- 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

- 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%

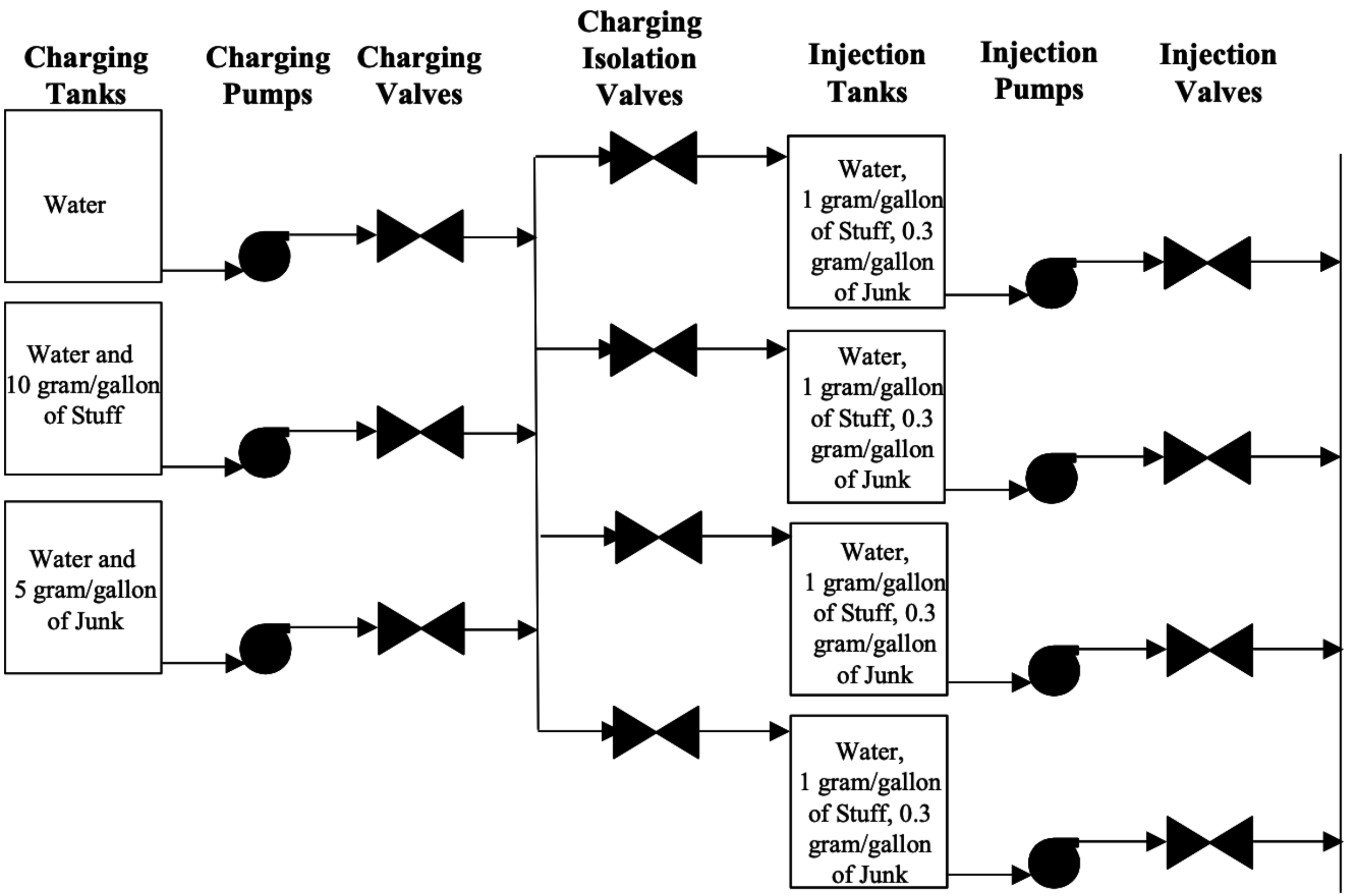


Figure 3. Fluid Injection System Schematic

RIPB L-C Design Example

- General assumptions:
  - Component Failure
    - Modeled simplistically 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, 11th International Conference on Nuclear Engineering, Tokyo, JAPAN, April 20-23, 2003, ICONE11-36597

RIPB L-C Design Example

System Component	Interactive Component Information			Component Cost Information				Component Reliability Information[1]			Pump Discharge Information[2]		
	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^{-1})	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	$F_m/2$	$50,000				0.004	100				
	Very Good	250	$F_m/5$	$100,000	$1,000	$150	$2,500	0.002	200	0.008			
	Excellent	500	$F_m/10$	$200,000				0.001	300				
Injection Pumps	Good	100	$F_m/2$	$75.000				0.004	100				20 (gal/min) / 200 (days)
	Very Good	250	$F_m/5$	$150,000	$2,000	$150	$5,000	0.002	200	0.008	110 (gal/min)	90 (gal/min)	20 (gal/min) / 400 (days)
	Excellent	500	$F_m/10$	$300.000				0.001	300				20 (gal/min) / 600 (days)
Charging Isolation Valves	Good	100	$F_m/2$	$25,000				0.004	100				
	Very Good	250	$F_m/5$	$30,000	$1,000	$150	$2,000	0.002	200	0.008			
	Excellent	500	$F_m/10$	$50.000				0.001	300				
Charging Valves	Good	100	$F_m/2$	$50,000				0.0035	40				
	Verv Good	250	$F_m/5$	$100.000	$3,000	$150	$5,000	0.0025	50	0.01			
	Excellent	500	$F_m/10$	$250,000				0.0015	60				
Charging Pumps	Good	100	$F_m/2$	$200,000[3]				0.0035	40				
	Verv Good	250	$F_m/5$	$400.000[3]	$5,000	$150	$8,000	0.0025	50	0.01	Note 4	50% of Initial Discharge	Note 5
	Excellent	500	$F_m/10$	$600,000[3]				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:

[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

Component Input Choices					System Reliability Results				System Cost Results					
										Annual Costs ($1,000 / year)				
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 $)	5%-ile	Median	95%-ile	Mean	Capital + Mean Annual (million $)
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 - 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 - Charging System Good - Injection System	500 - 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

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

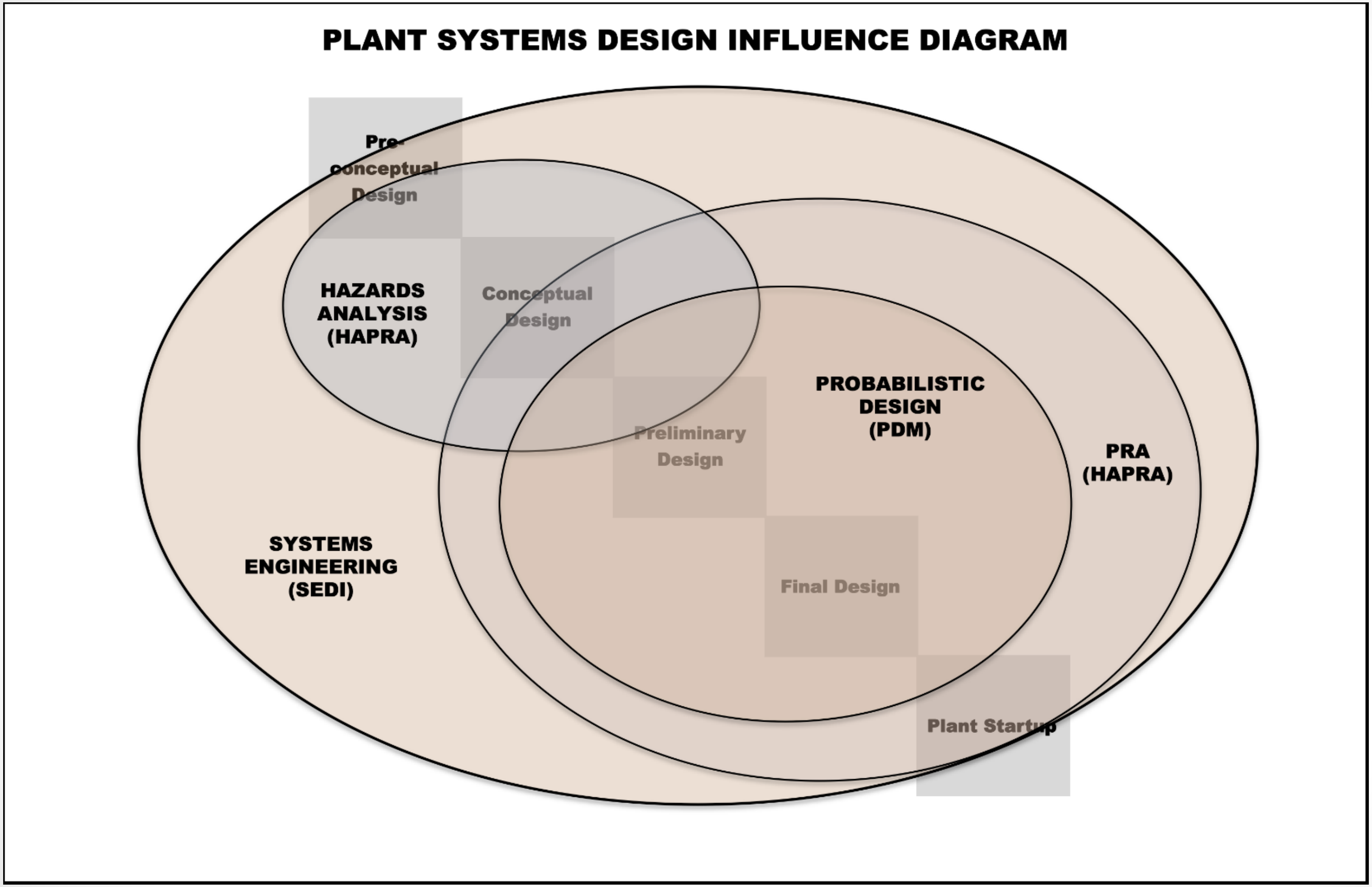
Plant Systems Design Standard (PSD-1)

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



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.)

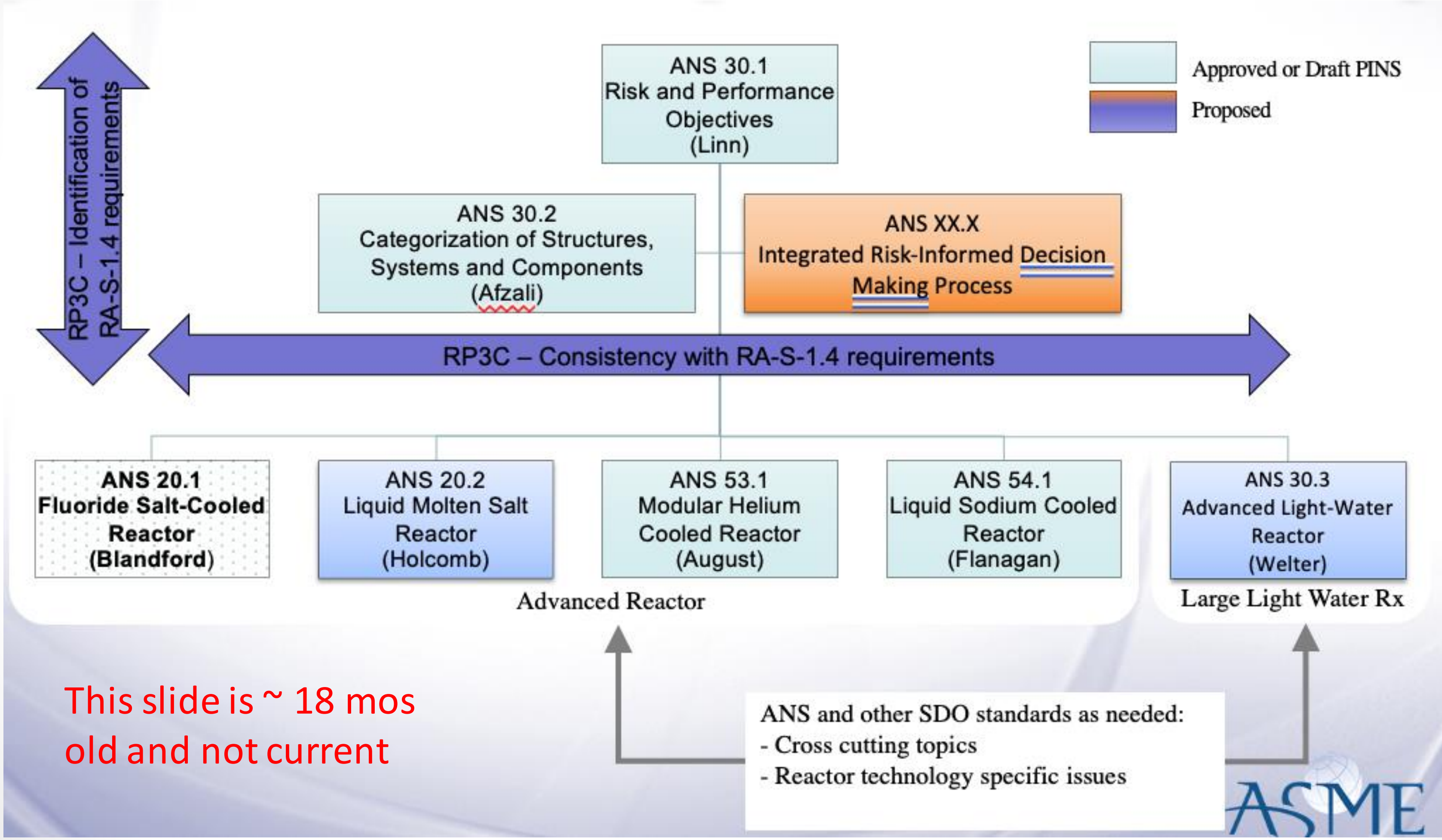
PSD-1 Related Initiatives

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



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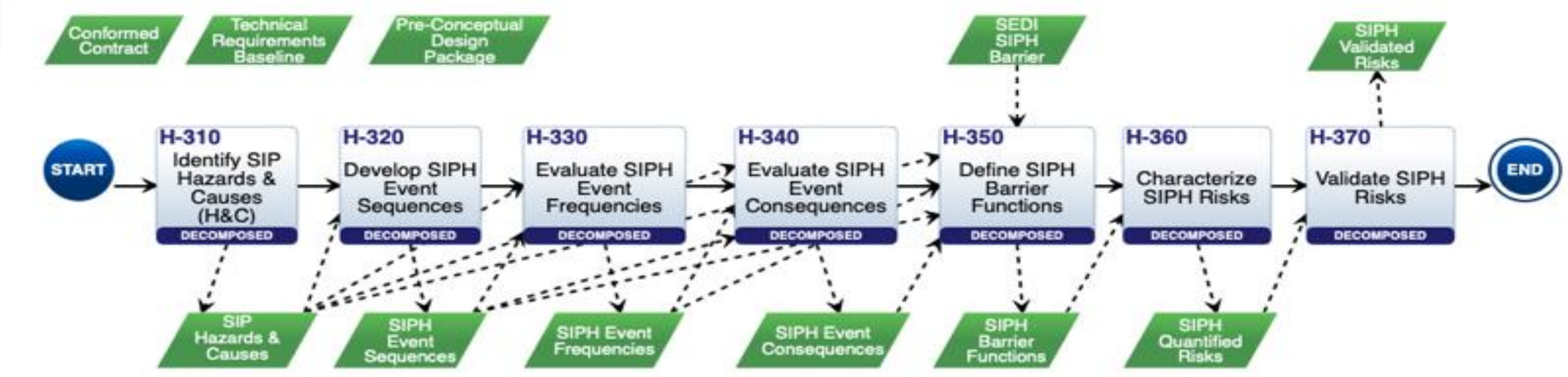
PSD-1 Progress to date …

- 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 …

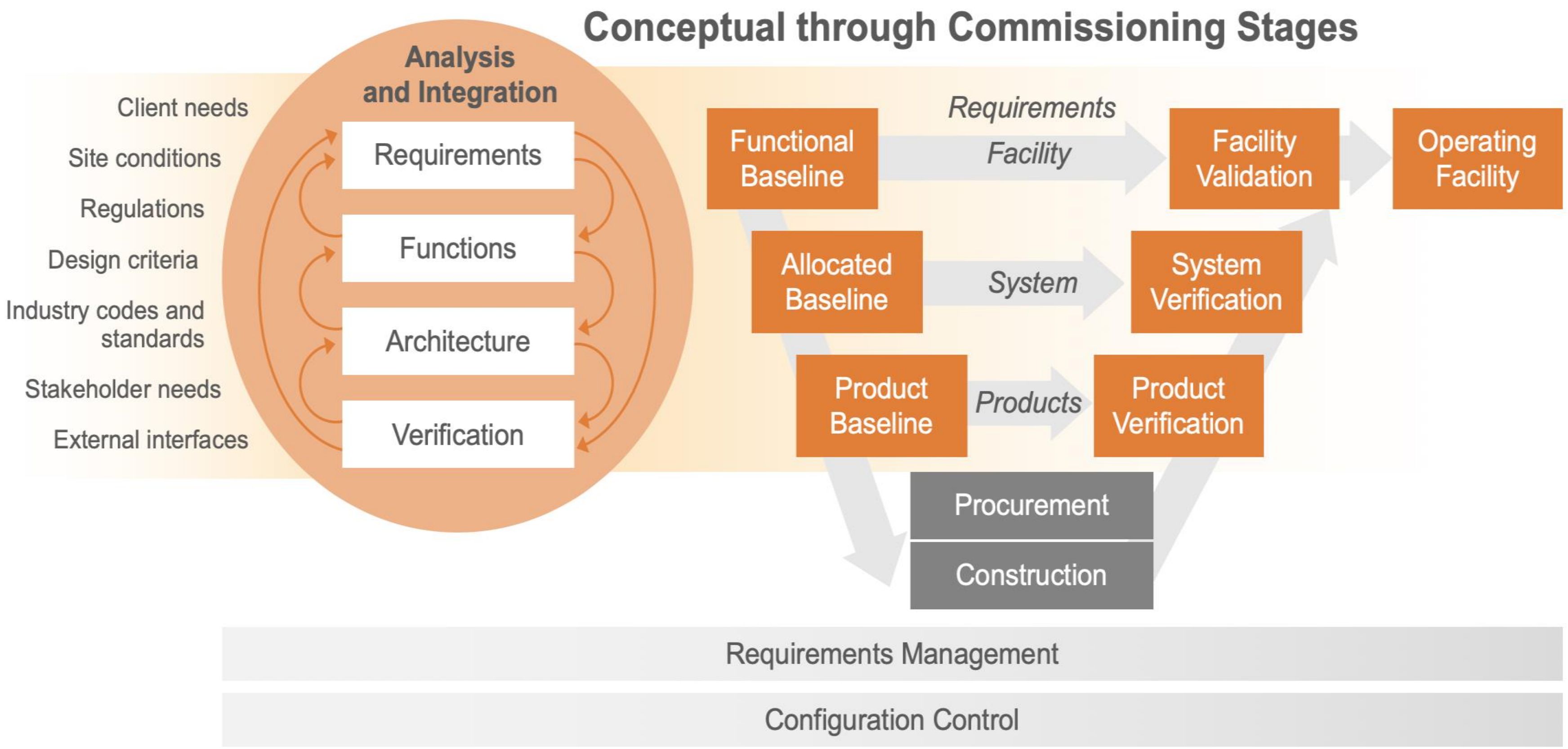
In parallel with integration and scheduling activities:

- 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

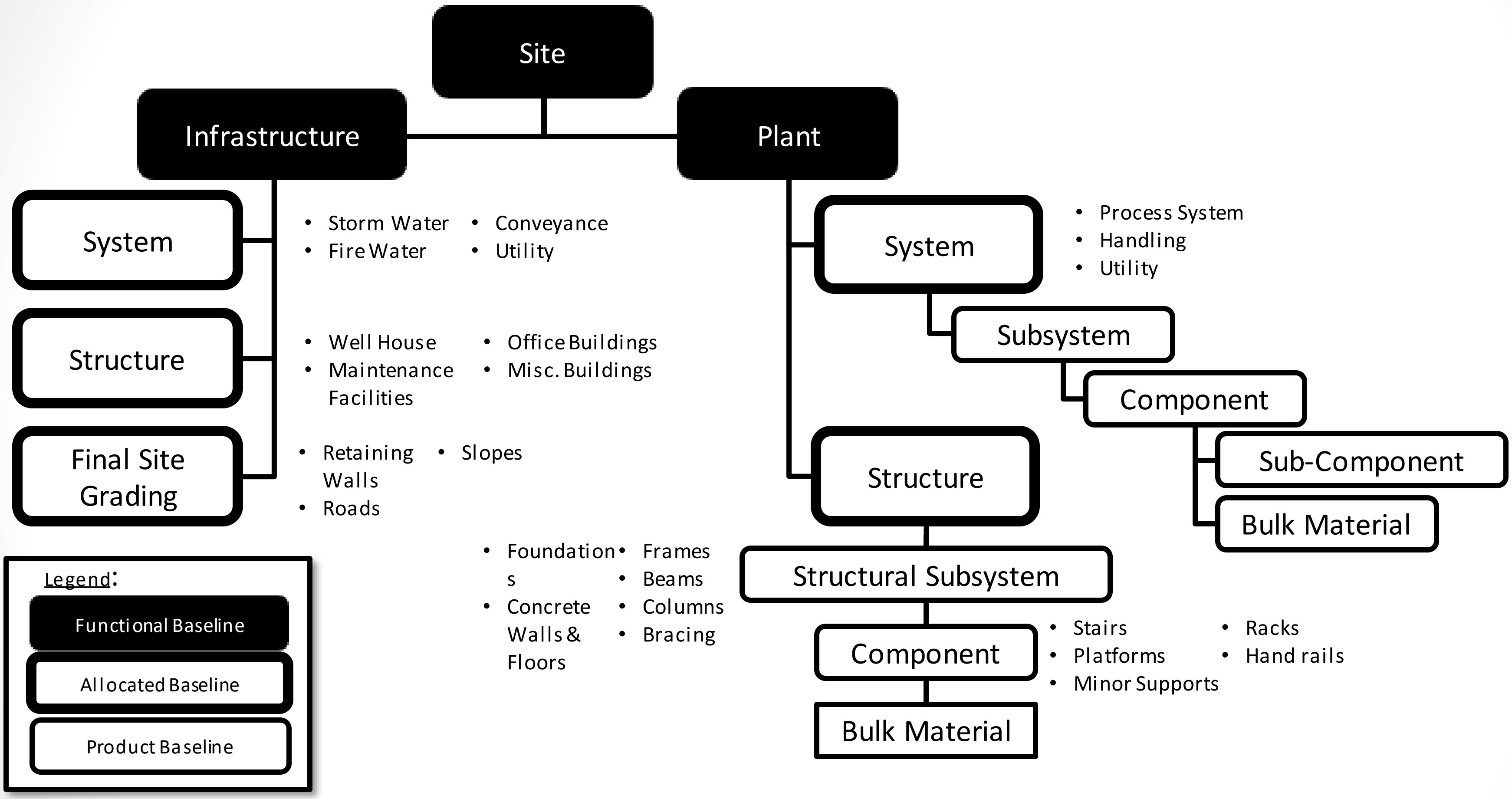
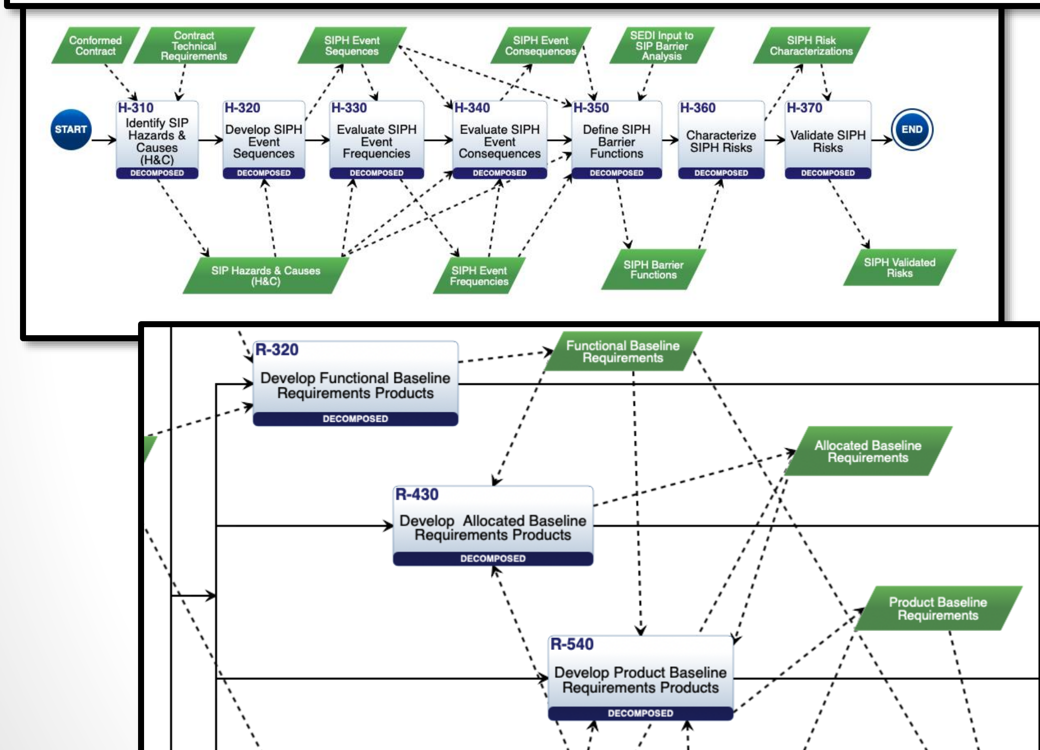


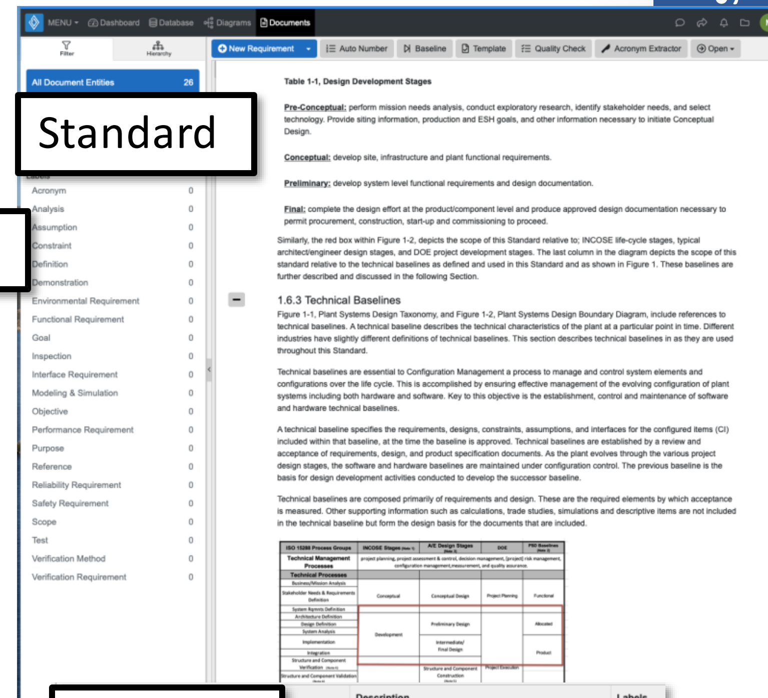
Table 1-2, Project Design Development Stages vs. Baseline			
Technical Baseline / Design Stage	**Functional**	**Allocated**	**Product**
Conceptual	**Approved**	Preliminary	Preliminary for long lead and key components
Preliminary	Updates as required	**Approved**	Preliminary
Final	Updates as required	Updates as required	**Approved**

PSD-1 Standard Development

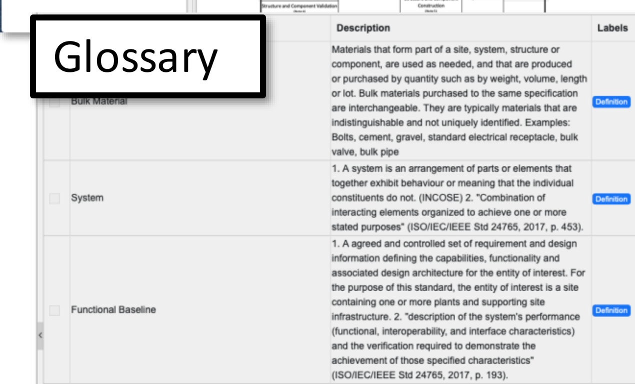
Project Processes to be Addressed in the Standard



Standard



Glossary



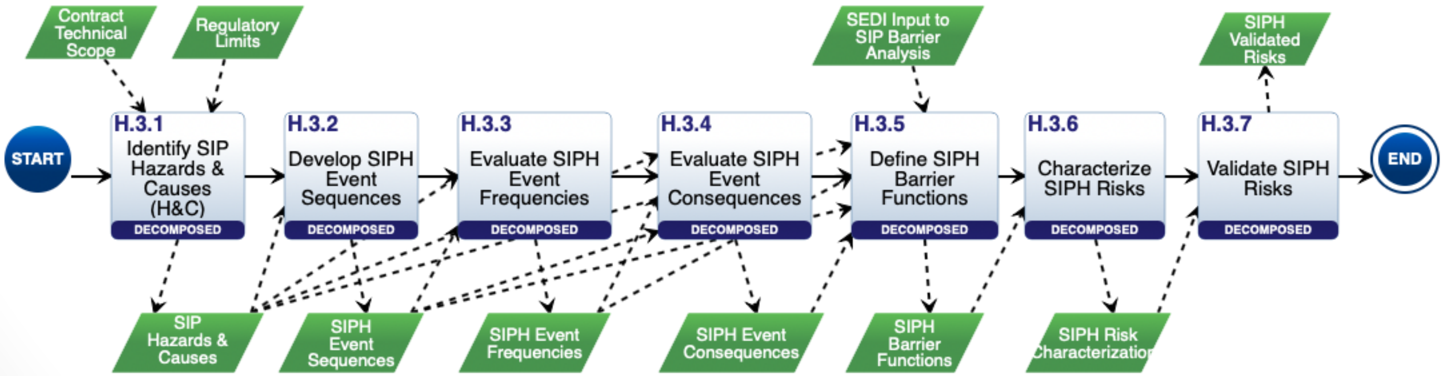
2-2.2 PRE Functional Baseline Activities (H.3)

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

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]
H.3	H.3-2	The RO shall GENERATE SIP hazard and risk information for each plant operating mode.

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 [I1-3]

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

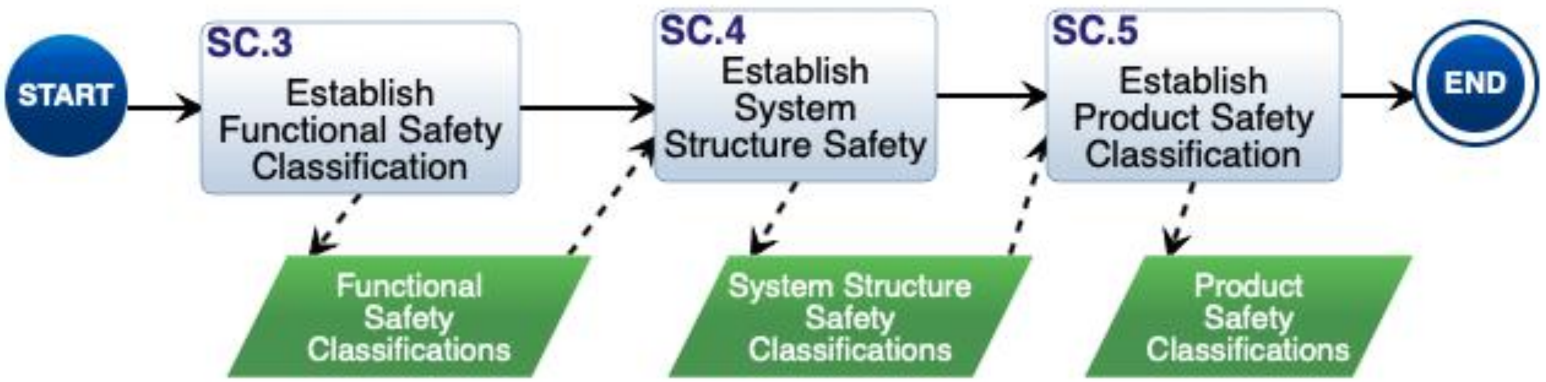
RIPB Design Concept

- A Concept for RIPB Design and Safety Classification

See next slide

STAGE							
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 Safety Function Allocatons
			↑		SS Target Reliability		↓
			↑		←		SS Safety Classsification
		ALLOCATED BASELINE					
Detailed Design							
	Product Functional & Performance Rqmnts						
		Product Hazard Identification					
			Product Hazard Evaluation				
					Prodiuct Target Reliability		
							Product Safety Classsification
		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.**

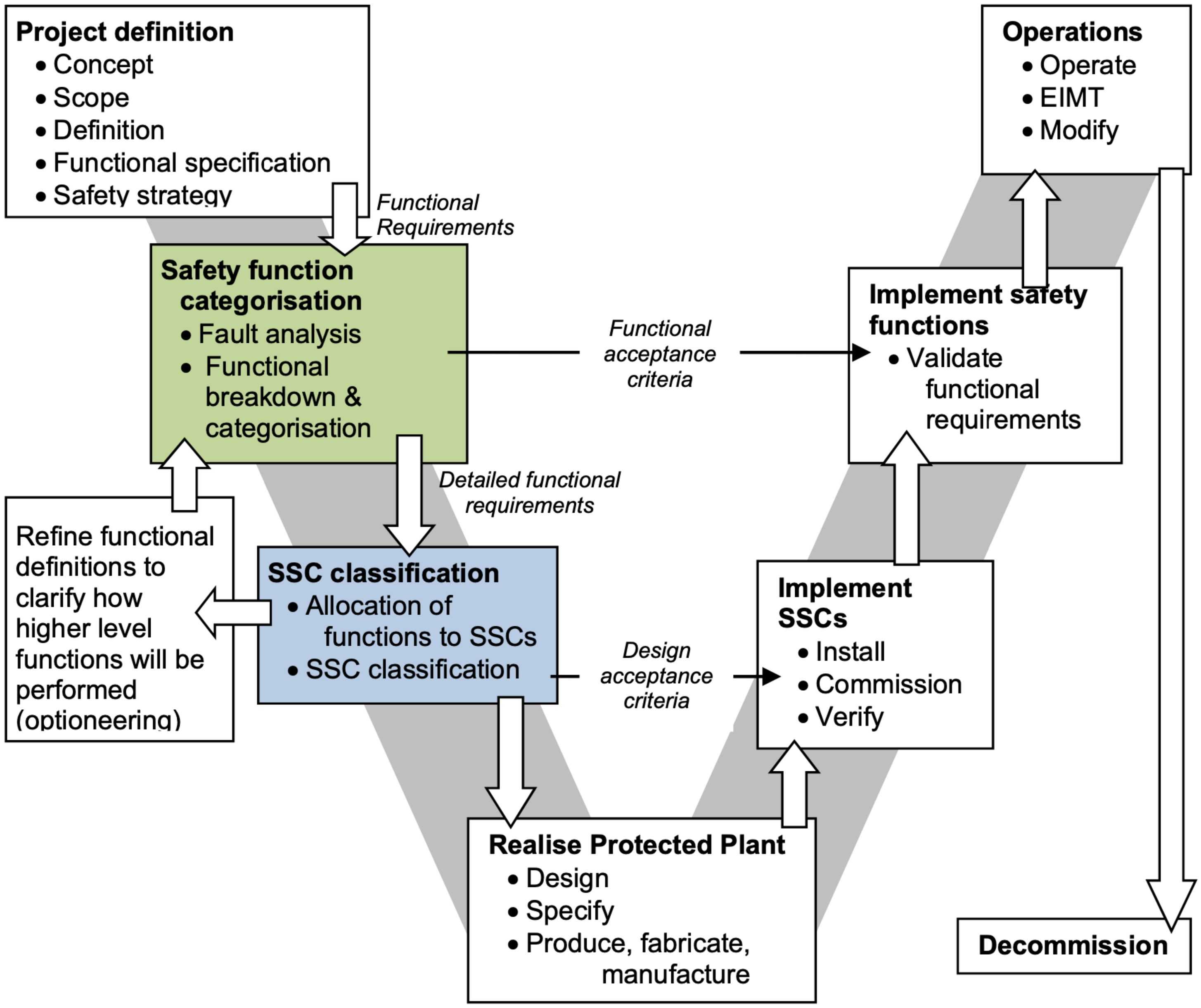
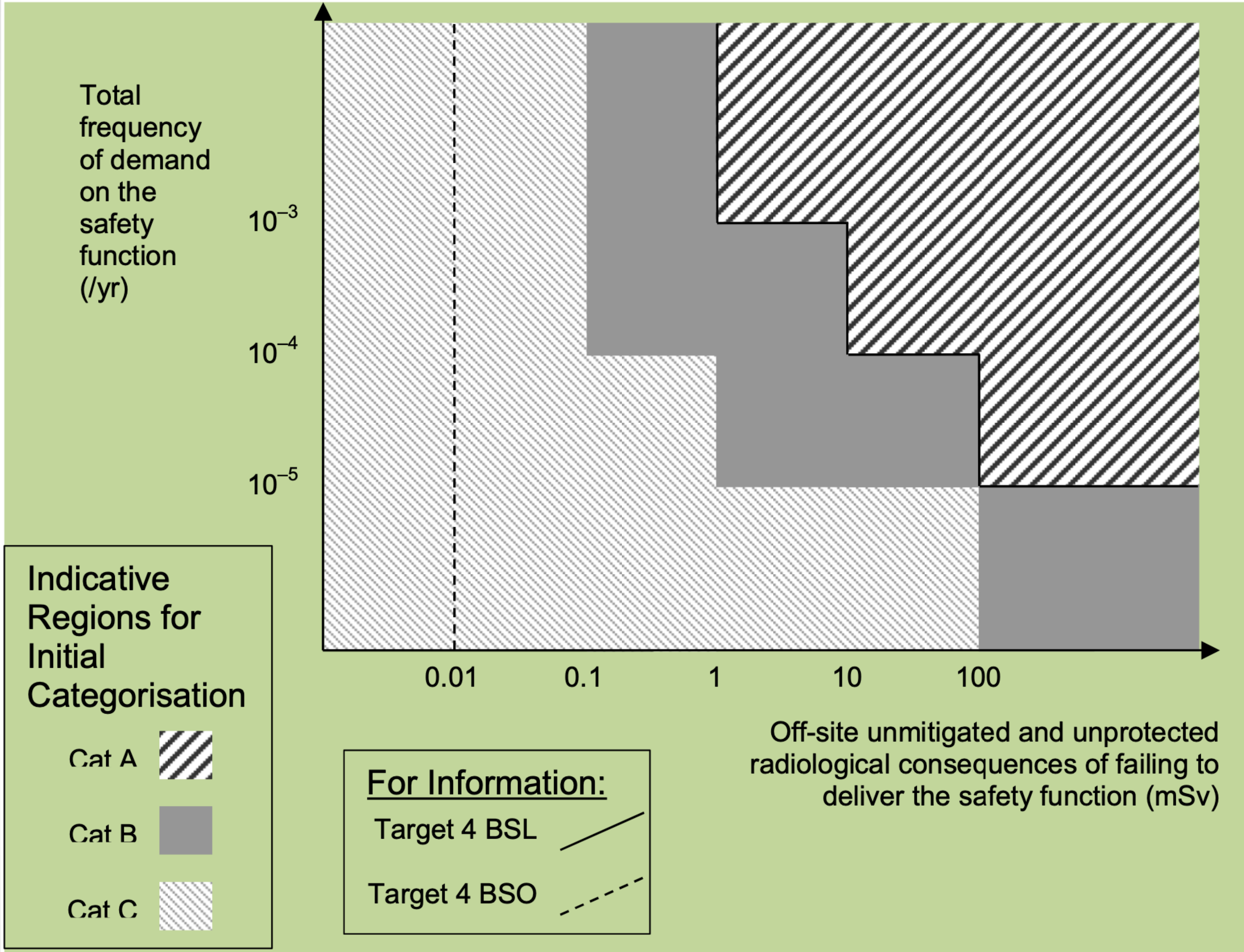


Figure 1 – Role of safety function categorisation (green box) and SSC classification (blue box) within the lifecycle model ('V-diagram')



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

SSC Class	Failure frequency per year (ff)	Probability of failure on demand (pfd)
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