GEN IV International Forum℠

INTRODUCING NEW PLANT SYSTEMS DESIGN (PSD) CODE

Prof. Nawal Prinja, Jacobs, UK

25 March 2021

Meet the Presenter

Professor Nawal Prinja, Technology Director of Jacobs (Clean Energy), has 40 years of academic and industrial experience in the nuclear sector. He holds a position of Honorary Professor at four British universities: School of Engineering, Aberdeen University; College of Engineering, Brunel University London; School of Engineering, Bolton University; and School of Computer Science and Electronic Engineering, the International Centre of Nuclear Engineering, Bangor University. Currently, he is working with WNA on Harmonization of Nuclear Codes. He has been on IAEA missions to China, South Africa, UAE, Spain and Poland. Dr. Prinja was appointed as an advisor to the UK Government to help formulate their long-term R&D strategy for nuclear industry and continues to advise as a member of the Fusion Advisory Board of UKRI and Nuclear Propulsion Science and Technology Advisory Group of Ministry of Defense. He participates in several international committees notably the ASME code committee for developing new Plant Systems Design code and represents the UK at the Senior Industry Advisory Panel of the Generation IV International Forum.

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Current Position

- Technology Director, Jacobs
- Honorary Professor in the School of Engineering at Aberdeen University.
- Honorary Professor in the College of Engineering, Brunel University London.
- Honorary Professor, School of Engineering, Bolton University.
- Honorary Professor, School of Computer Science and Electronic Engineering, the International Centre of Nuclear Engineering, Bangor University.

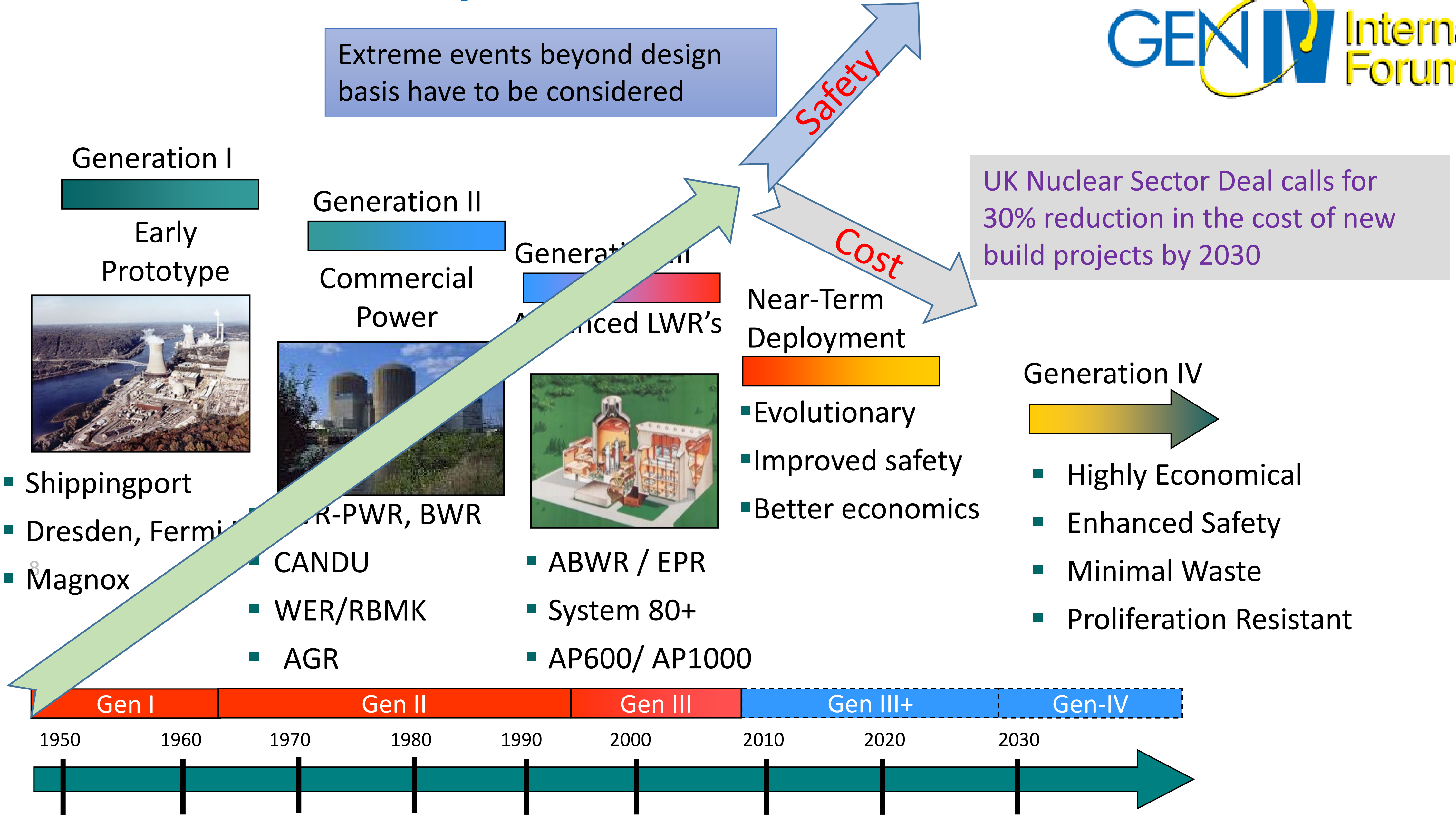
Experience

- 40 years of engineering and technology experience in aerospace, automotive, oil & gas and nuclear power.
- Over 50 Technical publications including 3 books.

Appointments

- Advisor to the Ministry of Defence (MOD) on the Nuclear Propulsion Research & Technology programme for the nuclear submarines.
- Member of the Nuclear R&D Advisory Board to the UK Government.
- Chairman of WNA/CORDEL international Task Force for harmonisation of mechanical Codes & Standards and Vice-chair of CORDEL Steering Committee.
- Technical Expert invited by the IAEA (United Nations) to chair expert meetings on safety classification and Technology Readiness Levels and to participate in Nuclear Knowledge Management and Seismic expert missions to UAE, S Africa, China, Spain and Poland.
- Independent assessor appointed by the Innovate UK of UKRI.
- Member of the EC funded FENET and EASIT2 projects aimed at developing computer based simulation competencies.
- Ex-Member of Technical Assessment Panel of Fusion for Energy (F4E)
- Member of the Board of Directors for the Professional Simulation Engineer (PSE) certification scheme.
- Chair of Industry Advisory Committee for the National Structural Integrity Research Centre at Cambridge.
- Member of the Fusion Advisory Board, EPSRC of UKRI.
- UK representative at the Senior Industry Advisory Panel of Gen IV International Forum (GIF)
- Member of Plant Systems Design code committee of ASME.

Need to Increase Safety and Decrease Cost



Extreme Events Beyond Design Basis : Nuclear Industry Approach

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Operating Basis

- Adverse events that are reasonably likely to occur during the life
- Typical return period of 1 in 100 years or less
- Operating environmental conditions : moderately severe condition at platform

Design Basis

- Design to withstand hazards and accidents
- Naturally occurring hazards more frequent than 10^{-4} per annum
- Manmade hazards more frequent than 10^{-7} per annum

Beyond Design Basis

- Significant fault sequences with initiating events less frequent than the design basis
- Require more onerous functional requirements with regard to withstanding hazards

Lessons learnt from recent disasters : Design Extension Conditions (DEC) involving more severe hazards, multiple hazards, multiple sites are being considered.

The Solution : New PSD Code

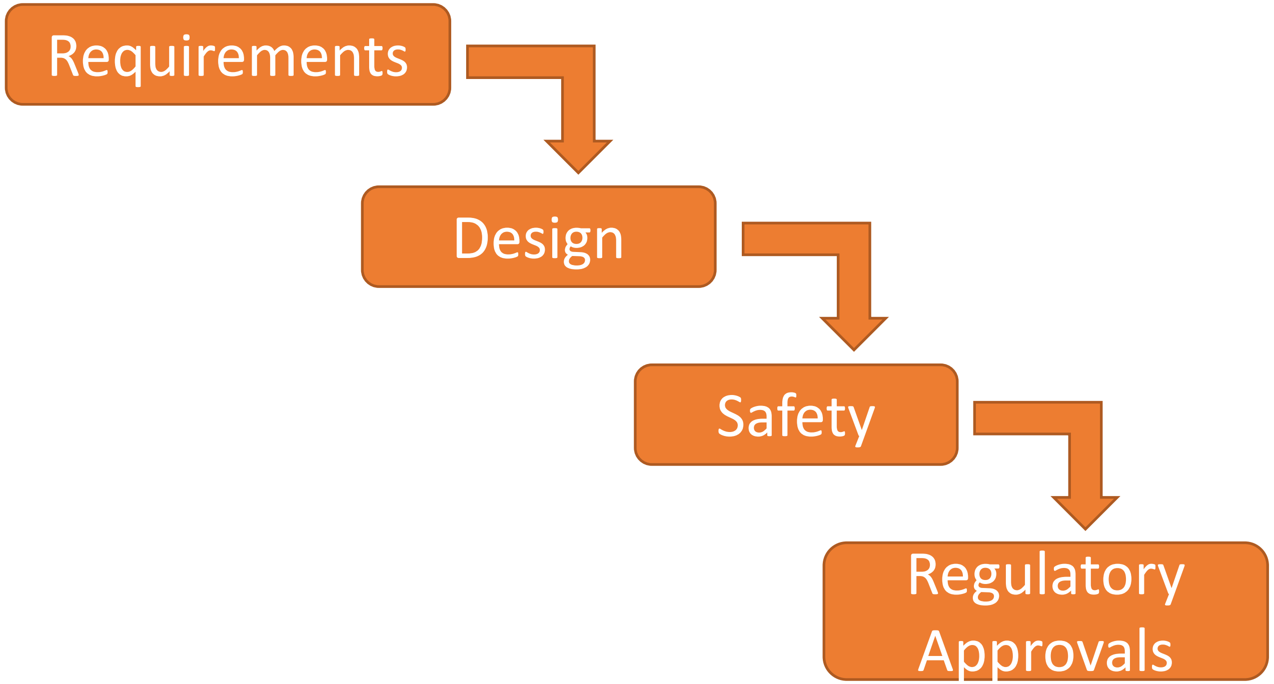
- The focus of this standard is to reduce the cost of new build and increase safety. It provides a technology independent framework, including requirements and guidance, for organizations implementing this Standard to:
- conduct plant process hazard evaluations and analyses in the early stages of plant design that
  - advance as the design matures
  - provide structure to the initial development of a quantitative risk assessment,
- integrate systems engineering design processes, practices and methods with traditional design processes, practices and tools, and
- integrate risk informed probabilistic design processes with traditional deterministic design methods and processes using reliability and availability targets.

Systems Engineering

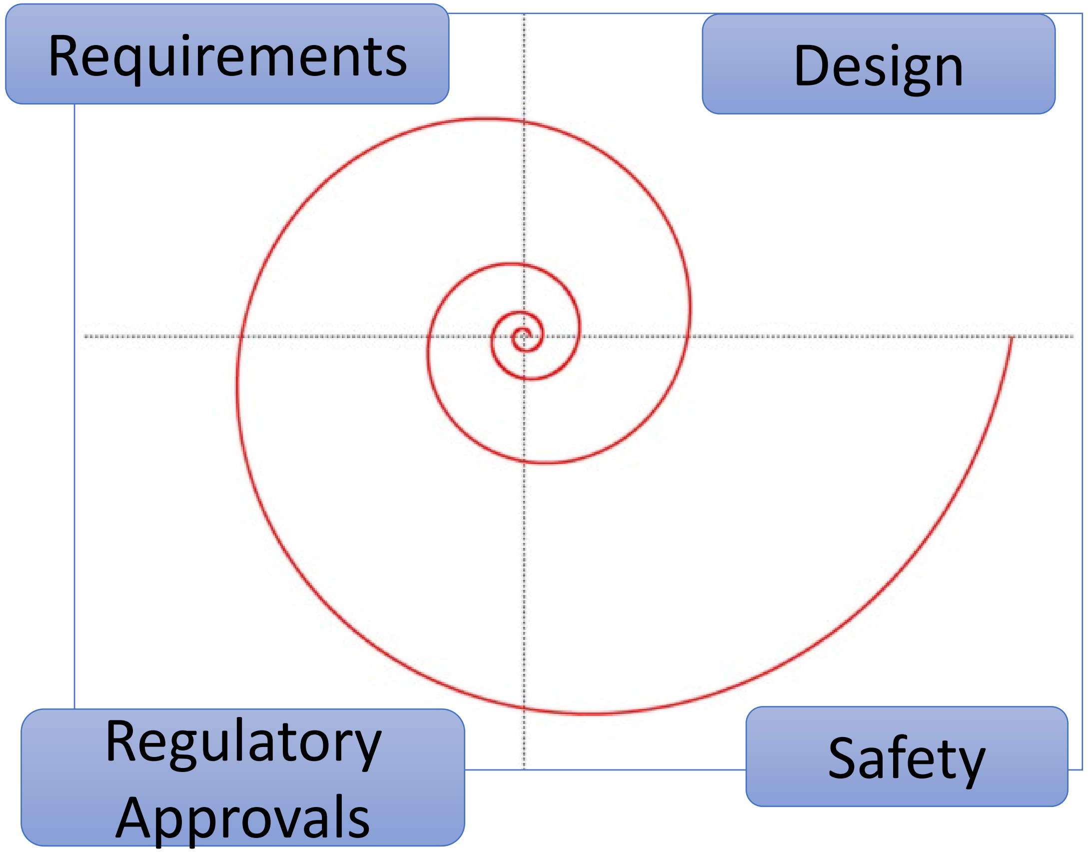
… a transdisciplinary and integrative approach, to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods. (www.incose.org)

From a Waterfall to a Spiral

Current: Sequential Activity



Future: Integrating Safety & Design



The Objectives

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1. **Safer** and **more efficient** system designs and design alternatives with **quantified safety levels**
2. **More effective requirements management**
3. More **cost-effective** and **timely** strategies for issue resolution and design maturation
   - e.g., alternatives analysis, design modifications, earlier formulation of safety function design criteria, additional research, laboratory testing, and scale testing

The Objectives

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4. **Combine risk informed probabilistic design** methodologies **with traditional deterministic design** methods using reliability and availability targets developed by JCNRM* in accordance with a companion standard for Establishing Plant System & Component Reliability Targets.
5. Cover design of facility plant systems over the **entire life cycle** of a plant (design, construction, operation, decontamination and decommissioning)
6. Be **system based**, vs. component based, and cover multiple disciplines (mechanical, electrical, instrumentation & control, HVAC, etc.)

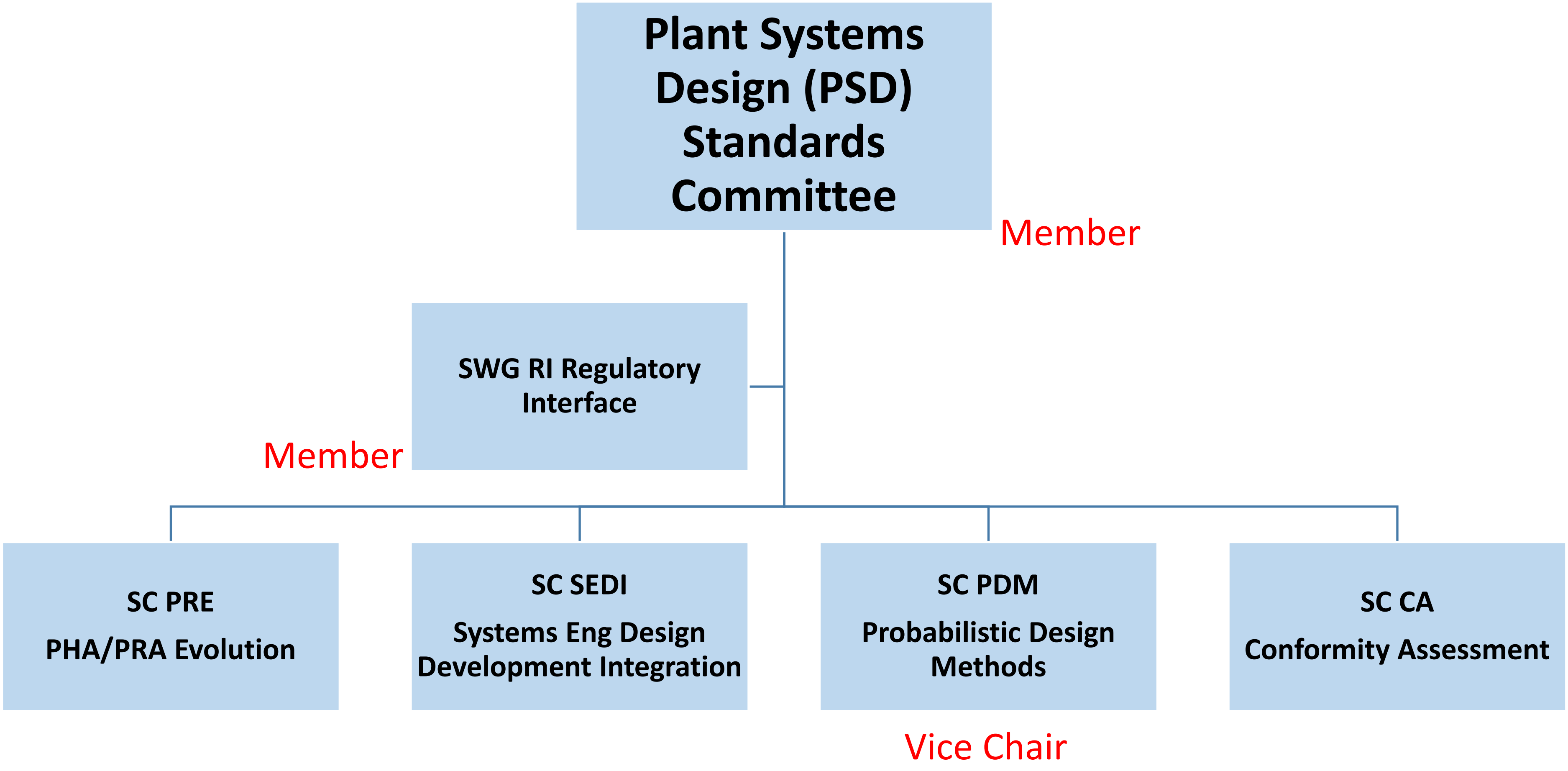
*** ANS/ASME Joint Committee on Nuclear Risk Management (JCNRM)**

Related Initiatives

The following are ongoing and include similar objectives.

- ANS & ANS 30.1
- EPRI Body of Knowledge (BoK)
- ASME Section XI, Div. 2, Requirements for Reliability and Integrity Management Programs for Nuclear Power Plants (RIM)

Proposed PSD Committee Structure



Charter: PSD Subcommittee on PHA & PRA Evolution (SC PRE)

To develop, review and maintain technology neutral processes and procedures for design organizations to conduct **process hazard analysis** for nuclear, fossil, petrochemical, chemical, and hazardous waste plants and facilities **that can; (a) be integrated in the early stages of design, (b) advance as the design matures, and (c) provide structure to the initial development of a probabilistic risk assessment for advanced technologies and designs**. The focus is to provide requirements and guidance for hazard analysis and probabilistic risk assessment processes, methodologies and tools that will provide safer and more efficient system and component designs with quantified reliability levels.

Charter: PSD Subcommittee on Systems Engineering Design Development Integration (SC SEDI)

To develop, review and maintain technology neutral processes and procedures for design organizations to incorporate and integrate existing systems engineering processes, practices and tools with traditional architect engineer design development processes, practices and tools for design of nuclear, fossil, petrochemical, chemical, and hazardous waste plants and facilities. This includes integration with enabling technical management processes and design development tools and databases. The focus is to provide requirements and guidance for system development and design integration processes, methodologies and tools that will provide safer and more efficient system and component integrated designs with quantified reliability levels.

Charter: PSD Subcommittee on Probabilistic Design Methods (SC PDM)

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To develop, review and maintain technology neutral processes and procedures for design organizations to **incorporate risk informed probabilistic design methodologies with traditional deterministic design methods using reliability and availability targets** for design of nuclear, fossil, petrochemical, chemical, and hazardous waste plants and facilities. The focus is to provide requirements and guidance for probabilistic design methodologies and tools that will provide safer and more efficient system and component designs with quantified reliability levels.

Risk Informed Performance Based (RIPB) Approach

RI

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.

PB

A performance-based approach is one that establishes performance and results as the primary basis for safety decision-making. and incorporates measurable (or calculable) parameters, objective criteria to assess performance are established based on risk insights, deterministic analyses and/or performance history.

RIPB

A risk-informed and performance-based design approach to decision-making combines the "risk-informed" and "performance-based" elements.

An approach in which risk insights, engineering analysis and judgment including the principle of defense-in-depth and the incorporation of safety margins, and performance history are used, to

(1) focus attention on the most important activities,

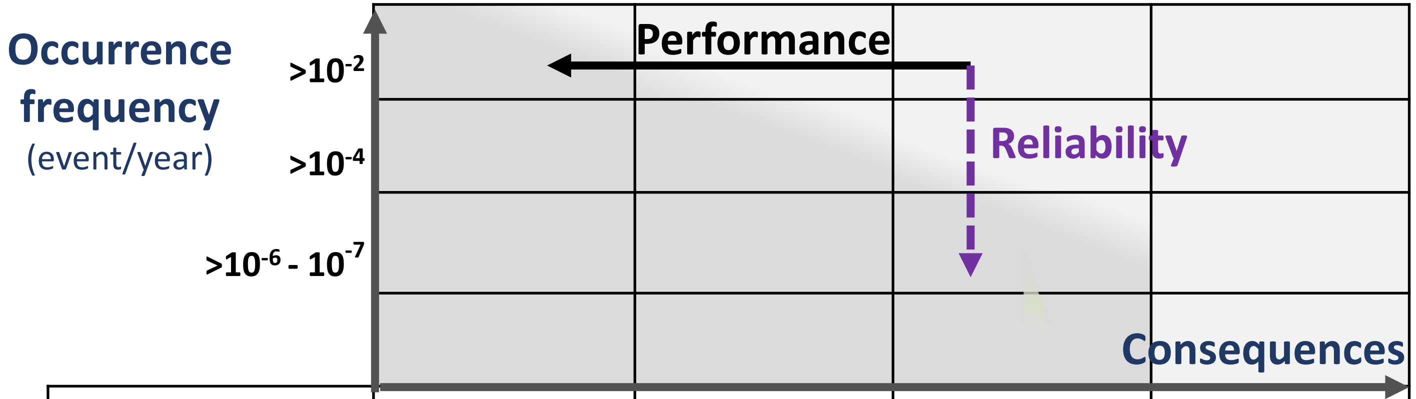
(2) establish objective criteria for evaluating performance,

(3) develop measurable or calculable parameters for monitoring system and licensee performance,

(4) provide flexibility to determine how to meet the established performance criteria in a way that will encourage and reward improved outcomes, and

(5) focus on the results as the primary basis for safety decision-making

Risk Domain



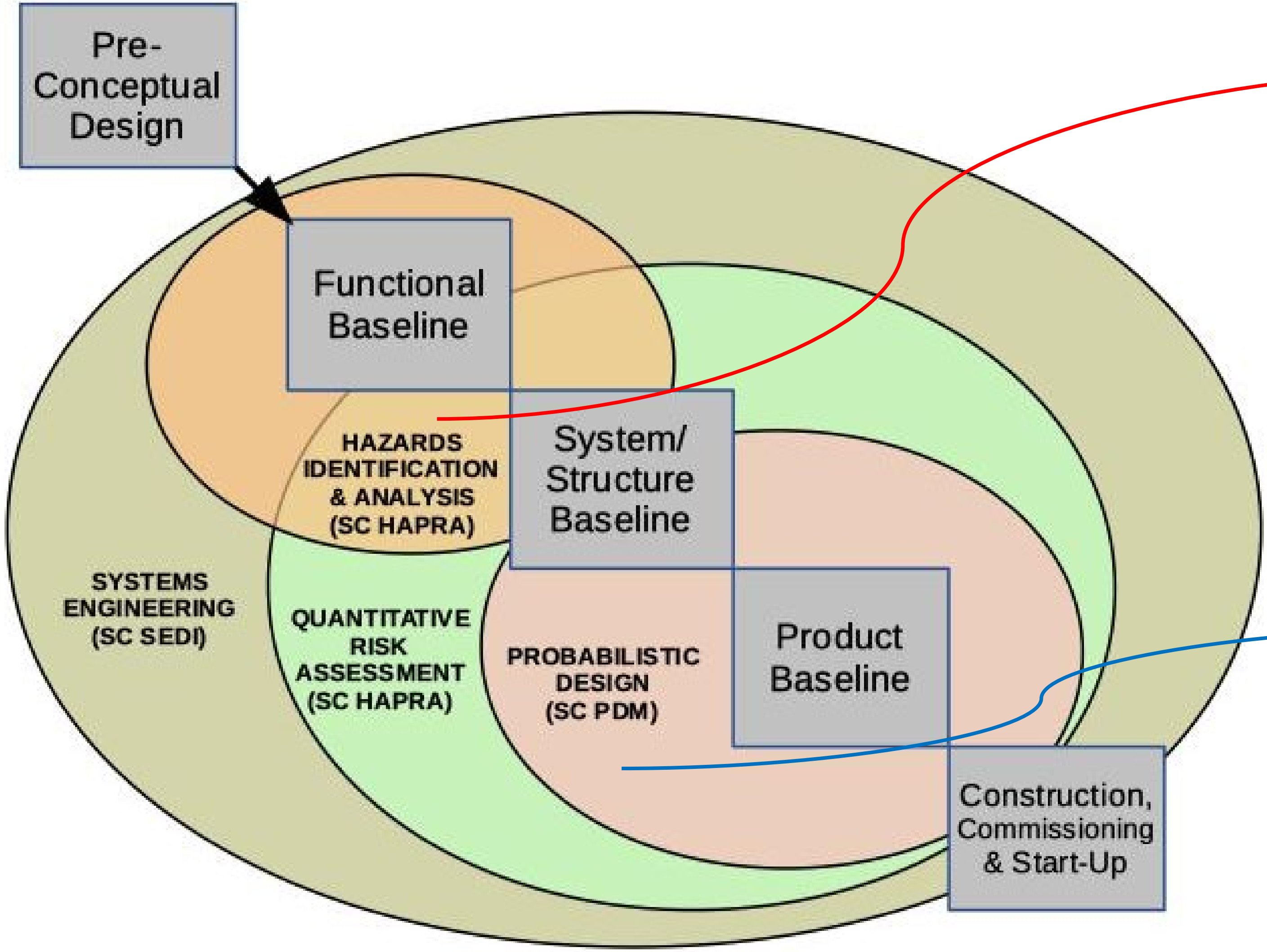
PLANT STATES	**Design basis AOO**	**Design basis DBA**	**Design basis DBA / DEC**	**Beyond design basis**
DiD LEVEL	**DiD Level 2** No off-site radiological impact	**DiD Level 3.a** No or only minor off-site radiological impact	**DiD Level 3.b** No or only minor off-site radiological impact **DiD Level 4** Limited protective measures in area and time	**No cliff-edge effect & pratically eliminated**
SEVERITY LEVEL IAEA SSG 30	**Low & Medium**	**Medium**	**High**	

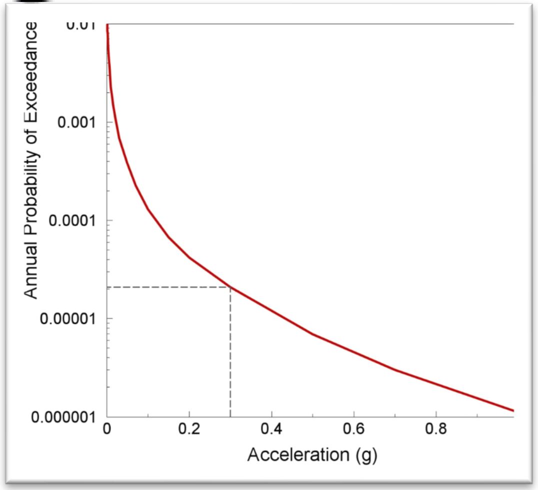
Options to bring an undesirable event that puts a plant into an uncontrolled state back into a controlled or safe state (shaded zone).

A safety related SSC (more generally, a ‘layer of provisions’) can be introduced, against an (initiating) event with unacceptable consequence, to :

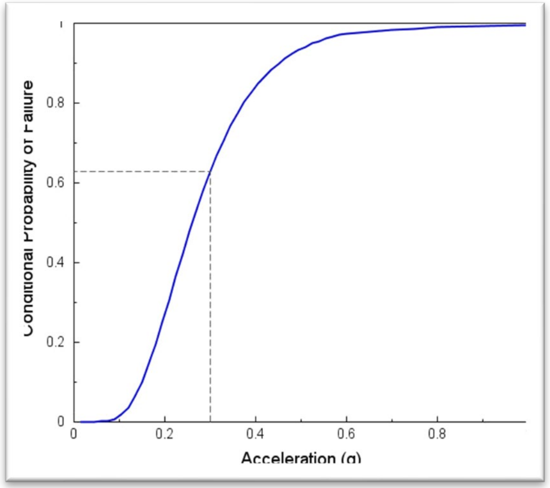
either reduce the severity of consequence
or reduce the frequency of occurrence
or both.

PLANT SYSTEMS DESIGN INFLUENCE DIAGRAM r2





Hazard



Fragility

Example: Calculating Risk by Combining Seismic Hazard Curve with Fragility Curve

Hazard curve H(a) and fragility curve Pf(a) can be combined by numerical convolution by either of the two equations:-

$$P_F = -\int_0^{+\infty} P_F(a)\left\{\frac{dH(a)}{da}\right\} da \qquad P_F = \int_0^{+\infty} H(a)\left\{\frac{dP_F(a)}{da}\right\} da$$

Typical hazard curves are close to linear in log-log scale and can be approximated by a power law:

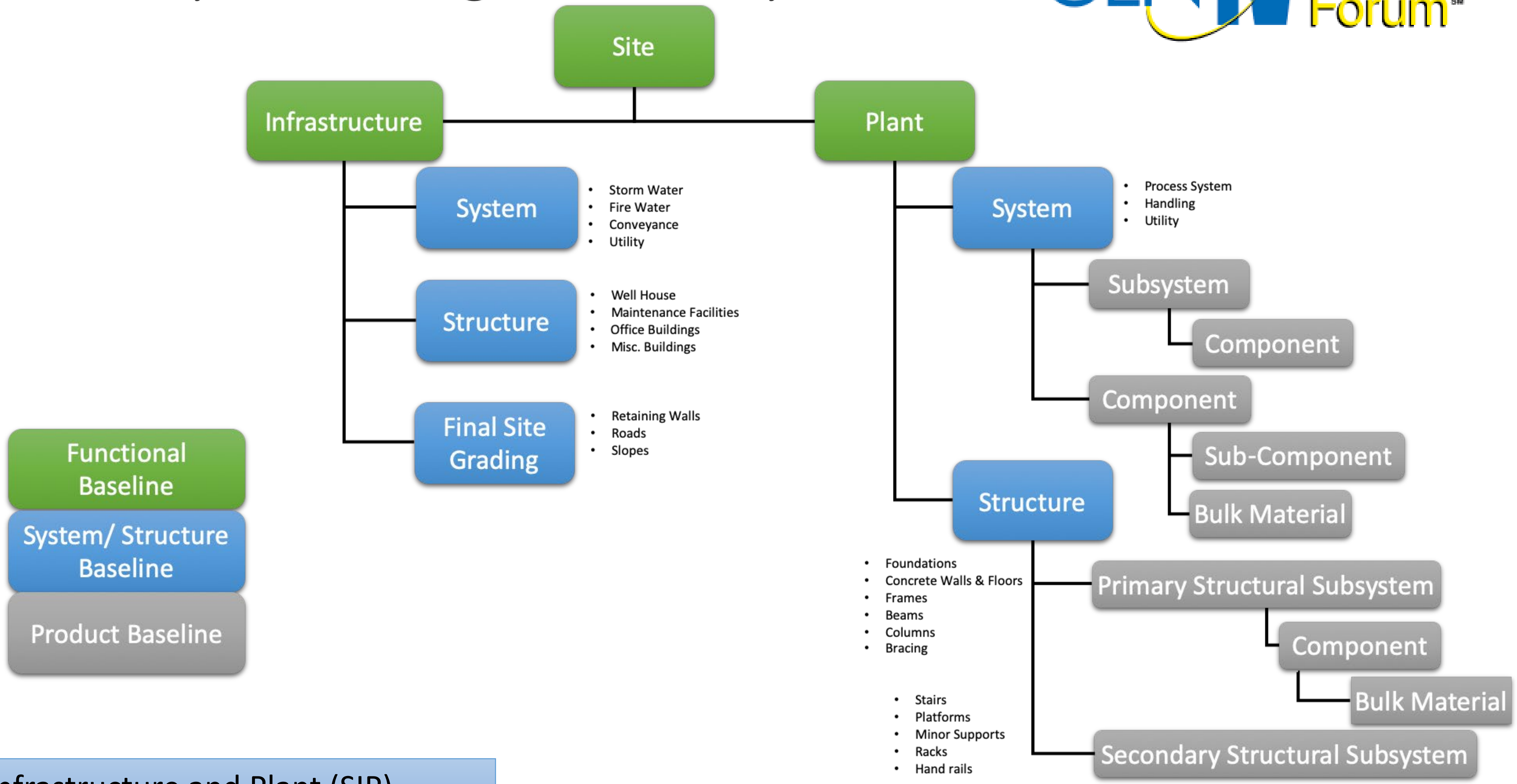
$H(a) = K_I a^{-K_H}$ K_I is constant and K_H *is slope parameter*

$$P_F = H\, F_{50\%}^{-K_H}\, e^{\propto} \qquad F_{50\%} = \frac{C_{50\%}}{C_H} \qquad \propto = {}^{1}/_{2}\,(K_H \beta^2)$$

H is reference exceedance frequency, C_H is UHRS ground motion level at H, $C_{50\%}$ is median fragility capacity and β is the logarithmic standard deviation of the fragility.

Ref: Robert P Kennedy, Trans of SMiRT 19, Toronto, 2007

Plant System Design Taxonomy

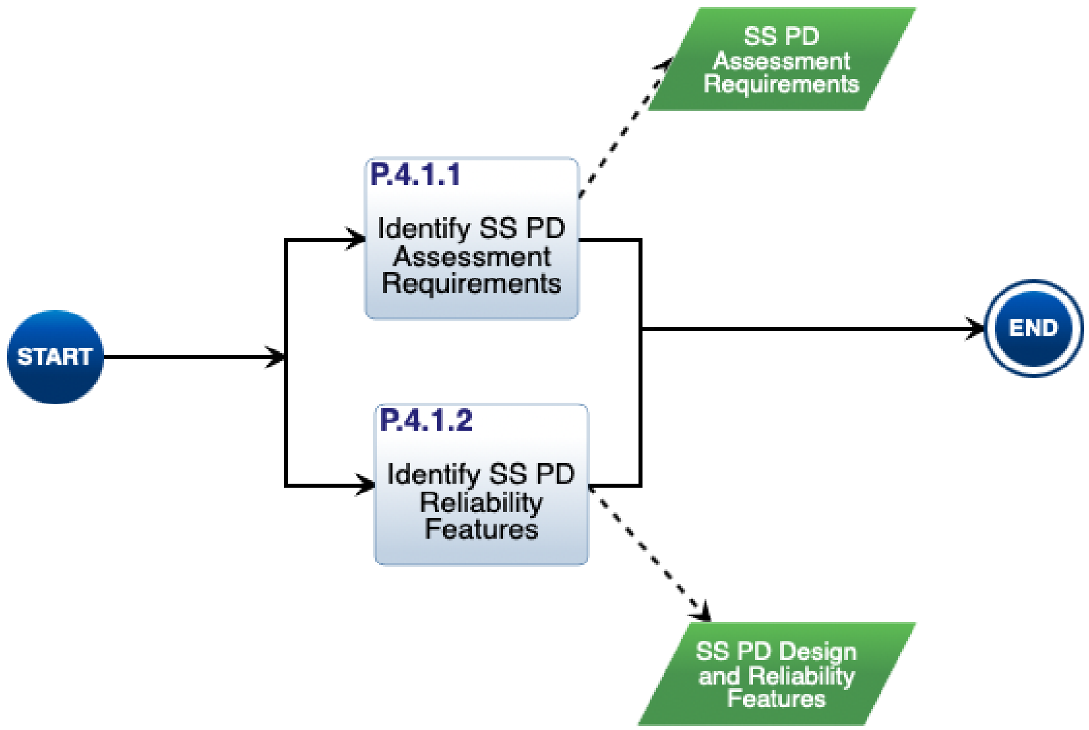


Site, Infrastructure and Plant (SIP)

Project Stage vs Baseline

Baselines / Project Stages (Example)	Functional	System/Structure	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 Style : Activity Diagrams

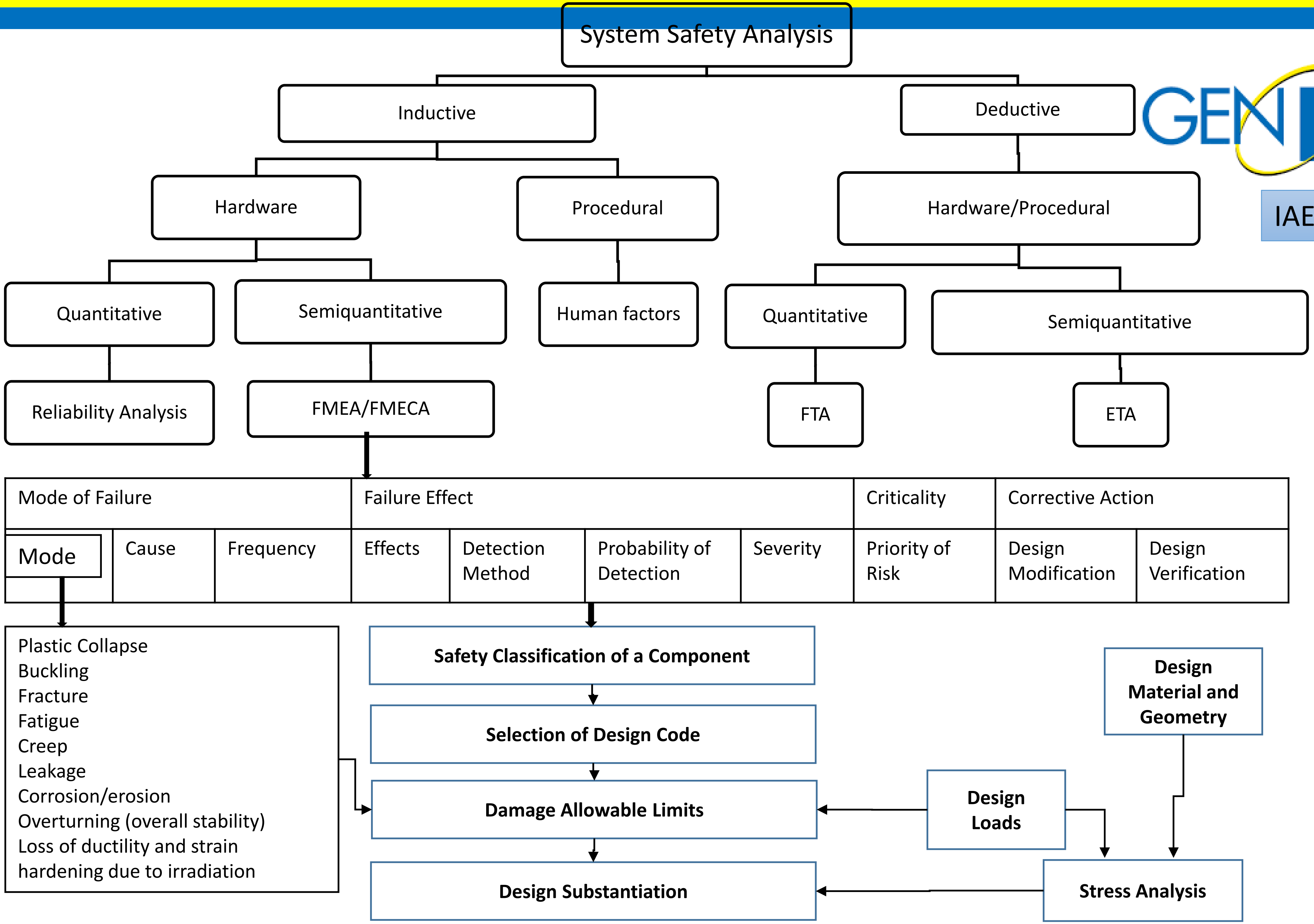


P.4.1 is a compilation of P.4.1.1 and P.4.1.2

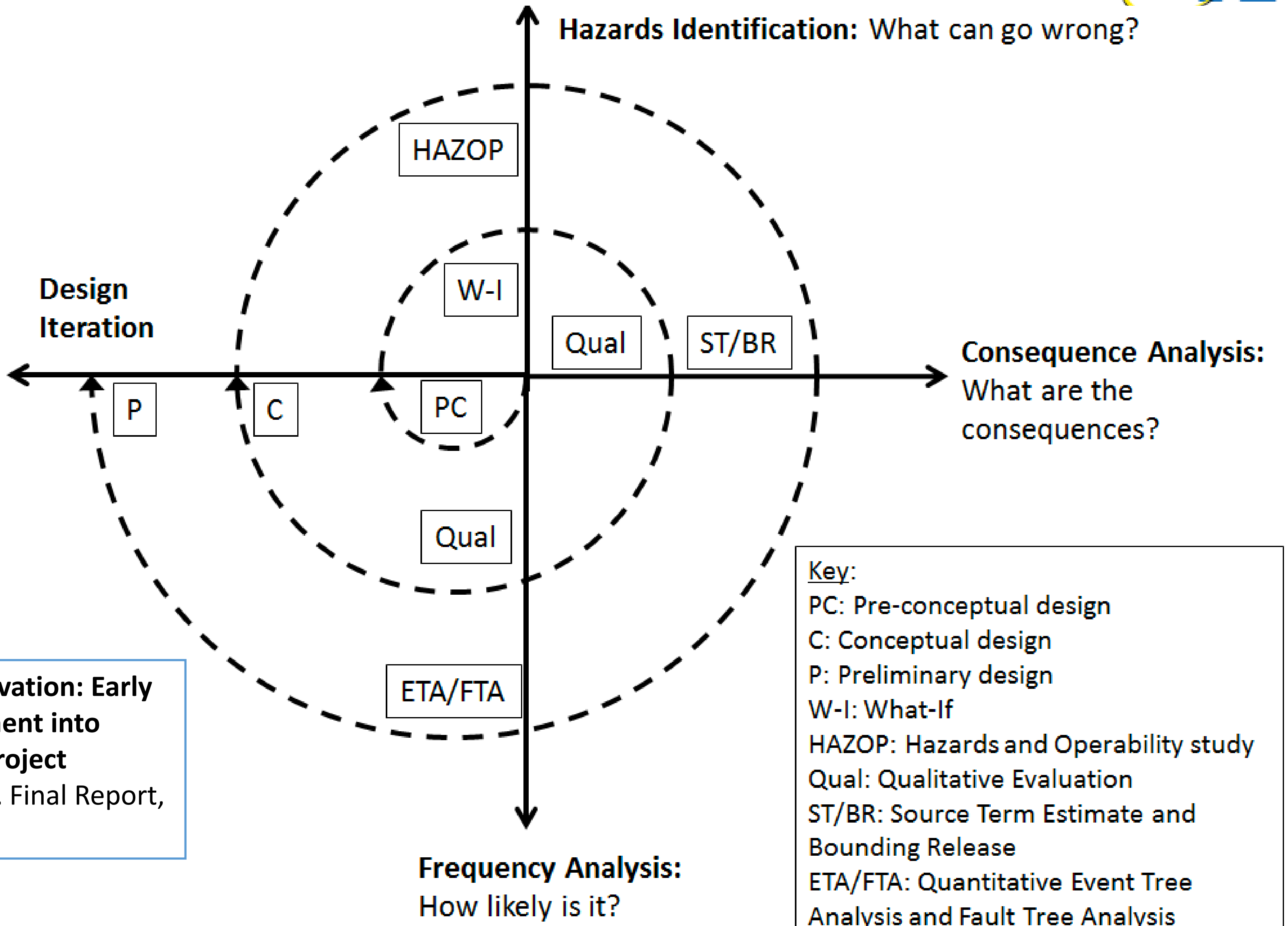
Activity P.4.1 reviews the latest design and reliability information and identifies the key SS systems that contribute the most to the overall plant reliability and availability. The purpose of the activity is to identify which features would benefit the most from a PD approach based on the key requirements from stakeholders.

Table of INPUT – ACTIONS - OUTPUTS

INPUTS	ACTIONS	OUTPUTS
H300 PRE Input to FBL	P.4.1 Review SS Design and Reliability Assessments	P410 SS PD Design and Reliability Features
P300 PDM Input to FBL	P.4.1.1 Identify SS PD Assessment Requirements	P411 SS PD Assessment Requirements
S400 Approved FBL Design Products	P.4.1.2 Identify SS PD Reliability Features	P412 SS PD Design and Reliability Features



IAEA TECDOC 1851



Program on Technology Innovation: Early Integration of Safety Assessment into Advanced Reactor Design—Project Capstone Report 3002015752 Final Report, October 2019, EPRI

Key:
PC: Pre-conceptual design
C: Conceptual design
P: Preliminary design
W-I: What-If
HAZOP: Hazards and Operability study
Qual: Qualitative Evaluation
ST/BR: Source Term Estimate and Bounding Release
ETA/FTA: Quantitative Event Tree Analysis and Fault Tree Analysis

Timeline for the New PSD Code from ASME

- Approved for publication end of March 2023.
- The timeline for PSD suits well with the Gen IV initiatives.

Conclusions

- Safer but more cost-effective designs needed
- New design approach required in nuclear industry
- Include hazard analysis in early stages of design that
  - advance as the design matures
  - provide structure to the initial development of a probabilistic risk assessment
- Incorporate "Systems Engineering" design processes, practices and tools
- Incorporate risk informed probabilistic design methodologies with traditional deterministic design methods using reliability and availability targets
- Integrate them into the existing design processes and procedures to produce a new 'Plant System Design' code

Thank You

Contact: nawal.prinja@Jacobs.com

Acknowledgement:

Ralph S. Hill III
Chair, Plant Systems Design Standards Committee, ASME

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