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EVALUATING DIVERSITY IN NPP SAFETY SYSTEM DESIGNS

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REGULATORY REQUIREMENTS FOR DIVERSITY

- 10CFR50 Appendix A, GDC 22, "Protection System Independence," requires
  - ". . . . Design techniques, such as functional diversity or diversity in component design and principles of operation, shall be used to the extent practical to prevent loss of the protection function."

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REGULATORY POSITIONS

- SRM for SECY 93-087
  - Verify adequate diversity has been provided to meet the criteria established by NRC requirements
- BTP 7-19
  - Identify potential CCFs
  - Analyze Chapter 15 events using realistic assumptions in conjunction with each CCF
  - If the calculation exceeds a safety threshold, add diversity to mitigate the effects of the CCF
- NUREG/CR-6303 describes a method for assessing D3

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OBJECTIVE OF RESEARCH

- Issue
  - D3 analysis is used to determine whether diversity should be added or incorporated into a proposed safety system design
  - If diversity is required, how much diversity is enough?
- Objective
  - Develop a process for determining the adequacy of proposed diversity added or incorporated into safety system designs on the basis of experience from other industries, countries and agencies, and NUREG/CR-6303 diversity attributes and criteria

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ASSUMPTIONS

- Diversity strategies developed by other industries, agencies, and countries are based on experience and logical rationale
- This experience and rationale can be combined with NUREG/CR-6303 diversity attribute criteria to develop a process for evaluating diversity in proposed I&C designs
- The process can be used to evaluate diversity in I&C system designs independent of the technology used in the diverse designs
- The acceptance threshold can be derived on the basis of experience and best practices, with industry and public feedback

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SOURCES OF INFORMATION

- NASA
- Aviation
- Industrial Applications
- International Positions on Diversity
- Nuclear Power Plants using Diversity in Safety Systems
- Typical ATWS systems

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REVISED NUREG/CR-6303 DIVERSITY ATTRIBUTES AND CRITERIA

Design
- Different technologies
- Different approaches within a technology
- Different architectures

Function
- Different underlying mechanisms
- Different purpose, function, control logic, or actuation means
- Different response time scale

Life Cycle
- Different design organizations/companies
- Different management teams within the same company
- Different designers, engineers, and/or programmers
- Different testers, installers, or certification personnel

Equipment Manufacturer
- Different manufacturers of fundamentally different designs
- Same manufacturer of fundamentally different designs
- Different manufacturers of same design
- Same manufacturer of different versions of same design

Logic Processing Equipment
- Different logic processing architectures
- Different logic processing versions in same architecture
- Different component integration architectures
- Different communication architectures

Logic
- Different algorithms, logic, and logic architectures
- Different timing or order of execution
- Different operating systems
- Different logic languages

Signal
- Different reactor or process parameters sensed by different physical effects
- Different reactor or process parameters sensed by the same physical effect
- The same process parameter sensed by a different set of similar sensors

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USES OF DIVERSITY ATTRIBUTE CRITERIA

- Explicit use
  - Criteria used by a system developer to incorporate diversity into a system design
- Inherent use
  - Criteria invoked thru the explicit use of other criteria
- Example
  - A system developer chooses **Different Technologies** for the diversity approach, and implements the diverse system using analog components - **Different Technologies** has been selected explicitly
  - As a result, applicable **Equipment Manufacturer**, **Logic Processing**, **Software**, and **Life Cycle** diversity attribute criteria are inherently included in the diverse system implementation

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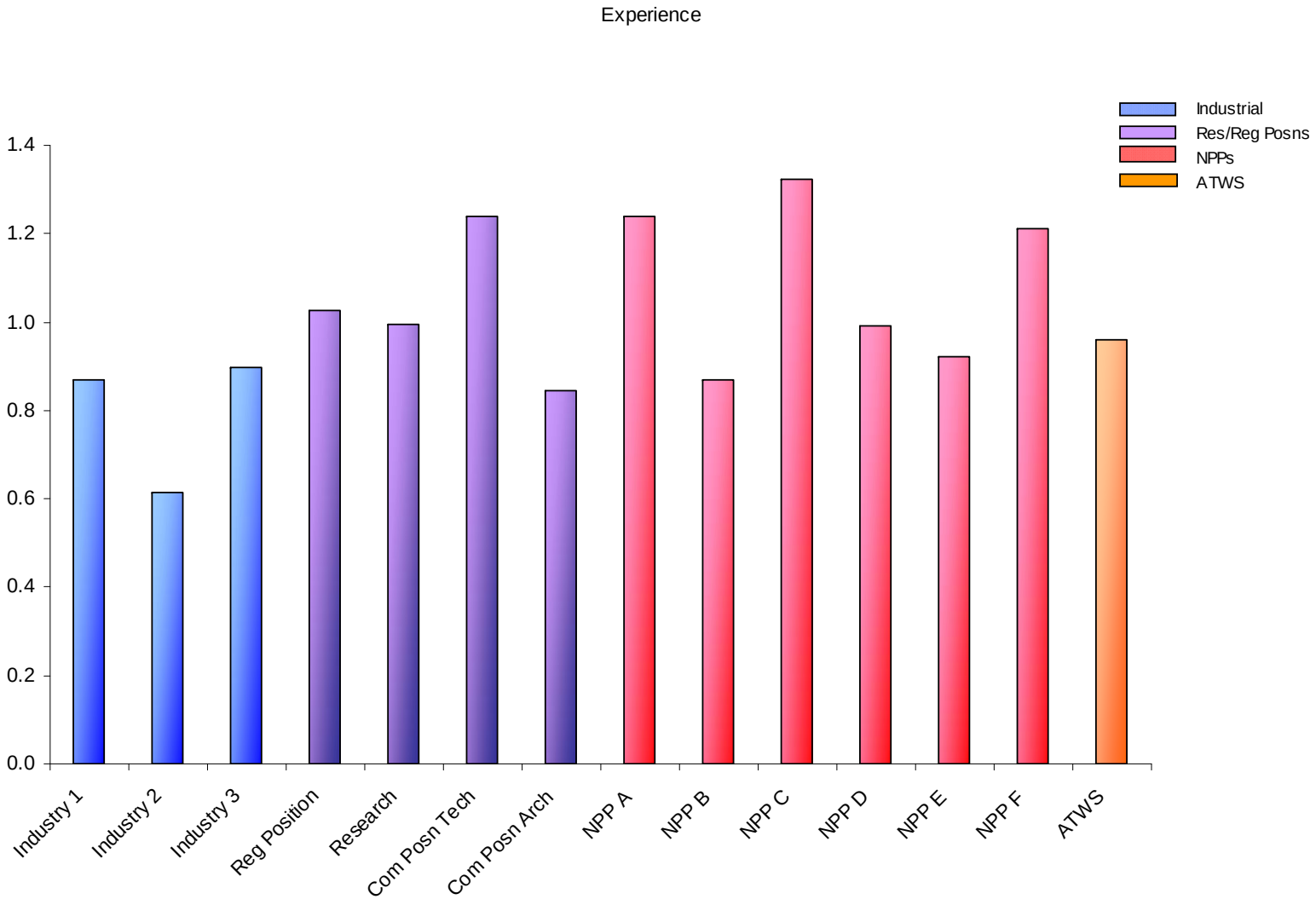
EVALUATING DIVERSITY IN SAFETY SYSTEM DESIGNS

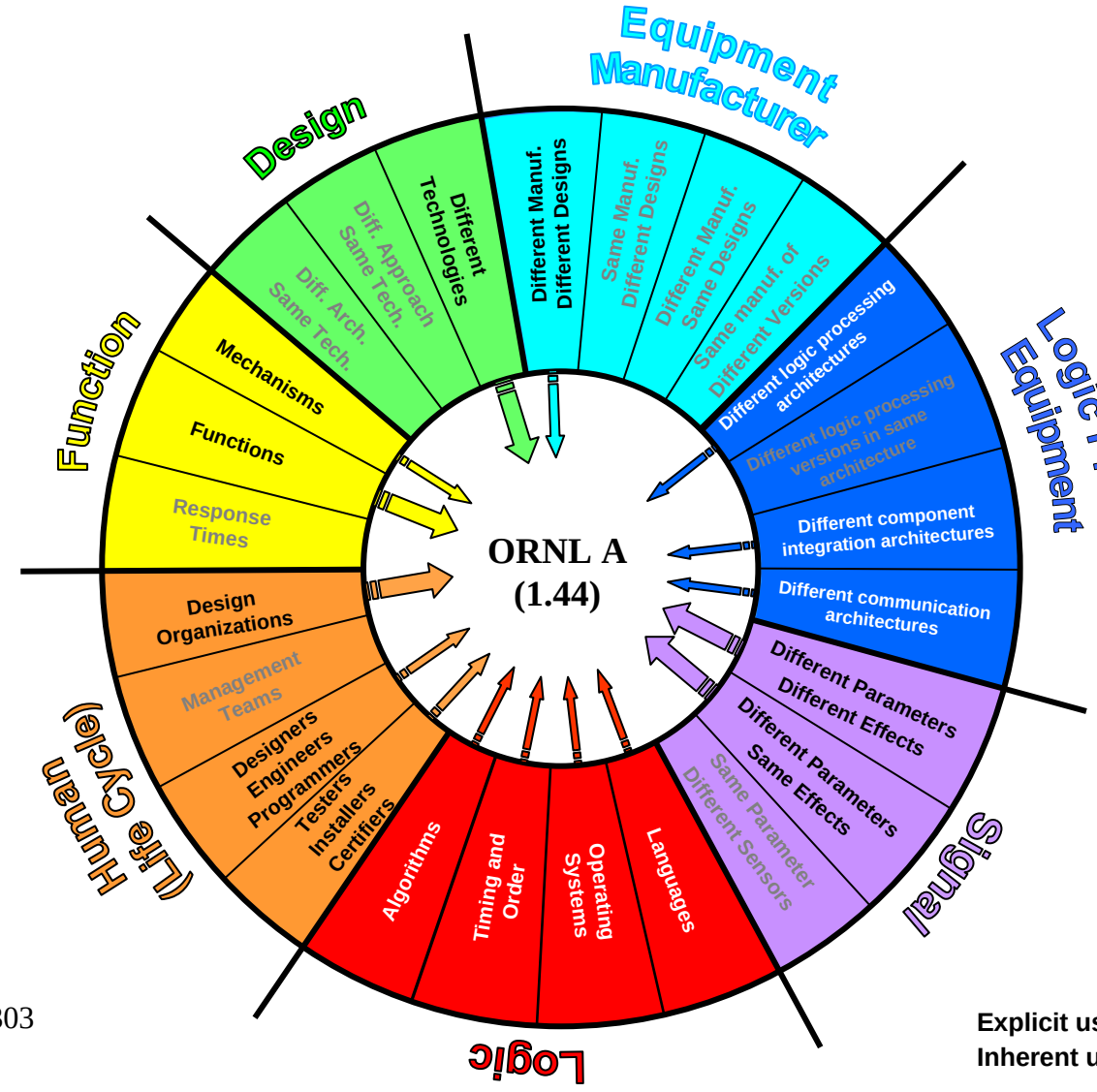
- Development of scoring method
  - Size, weight, and application complexity screened out NASA and aircraft system applications
  - Criteria usage by other countries, industries, and agencies were correlated with revised NUREG/CR-6303 diversity attributes and criteria to calculate weighted scores for each diverse I&C system design
  - The scores were used to develop an initial example threshold value
  - The scores and threshold value were then normalized by the threshold value
- Final acceptance threshold to be determined

DIVERSE SYSTEM DESIGN SCORING



ORNL DEVELOPED THREE DESIGN-BASED DIVERSE SAFETY SYSTEM APPROACHES

DIFFERENT TECHNOLOGIES



NUREG/CR-6303
Norm = 1.0

Explicit use of Criterion
Inherent use of Criterion

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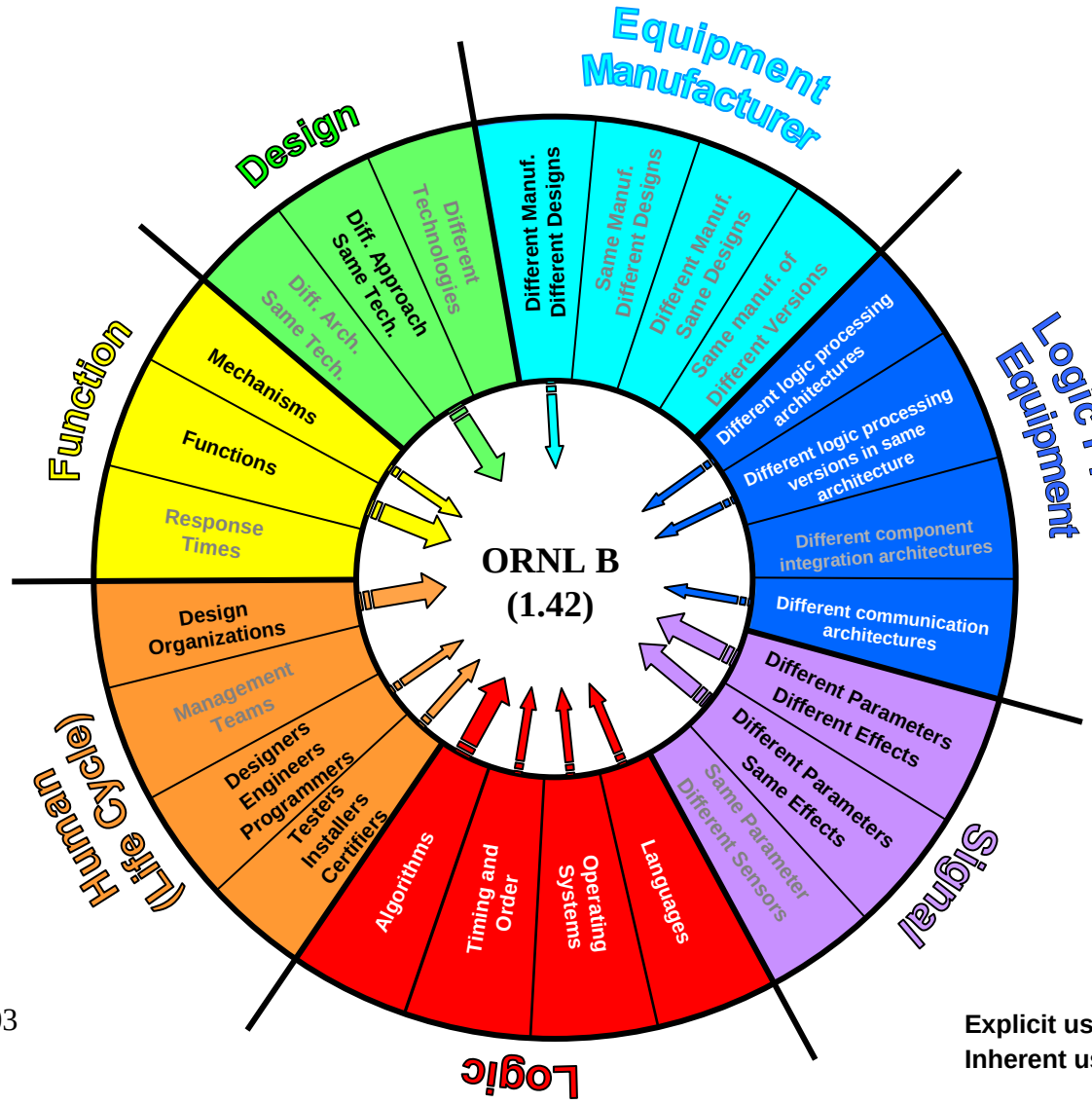
DIFFERENT APPROACHES IN SAME TECHNOLOGY



NUREG/CR-6303
Norm = 1.0

Explicit use of Criterion
Inherent use of Criterion

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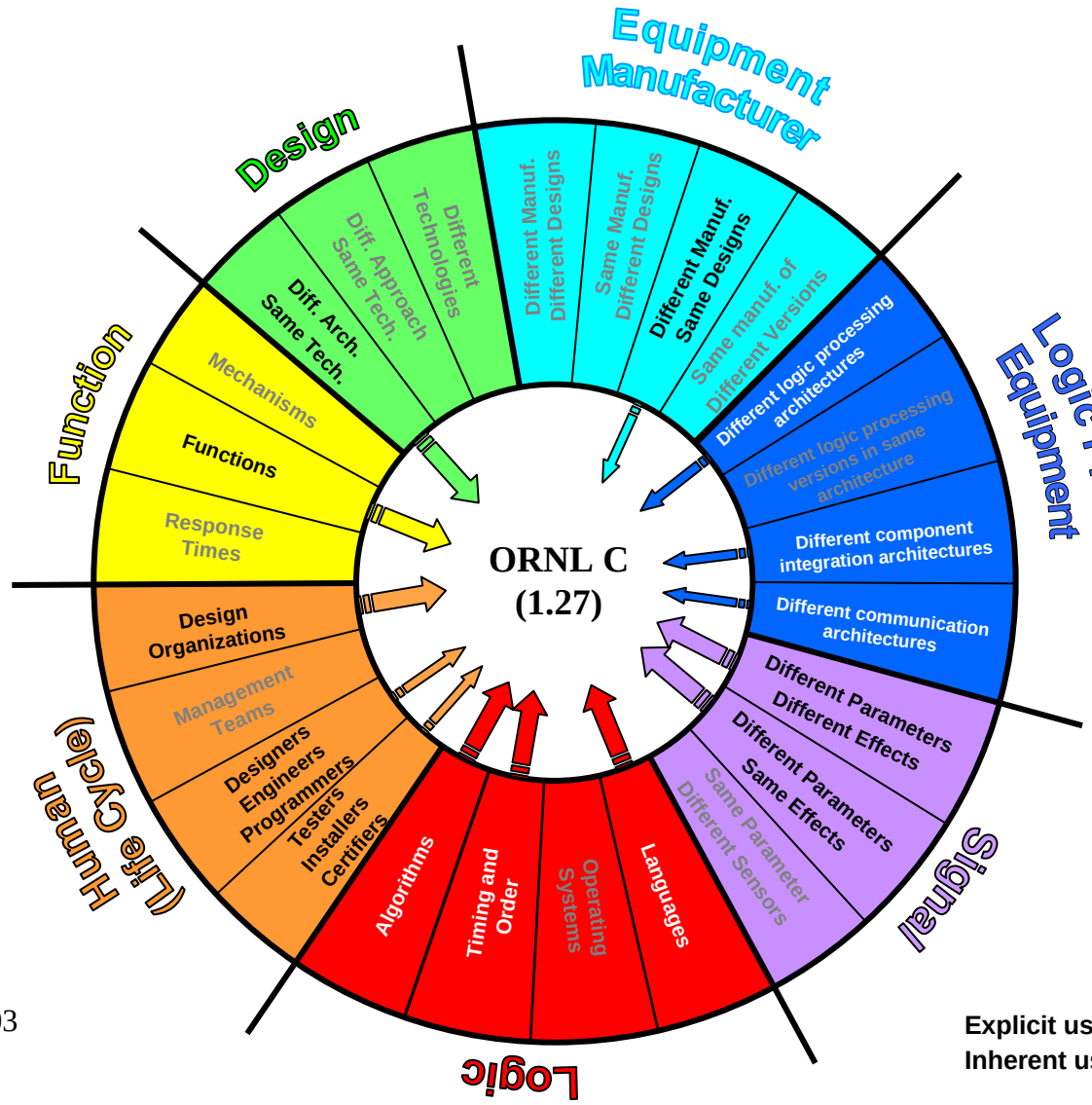
DIFFERENT ARCHITECTURES IN SAME TECHNOLOGY



NUREG/CR-6303
Norm = 1.0

Explicit use of Criterion
Inherent use of Criterion

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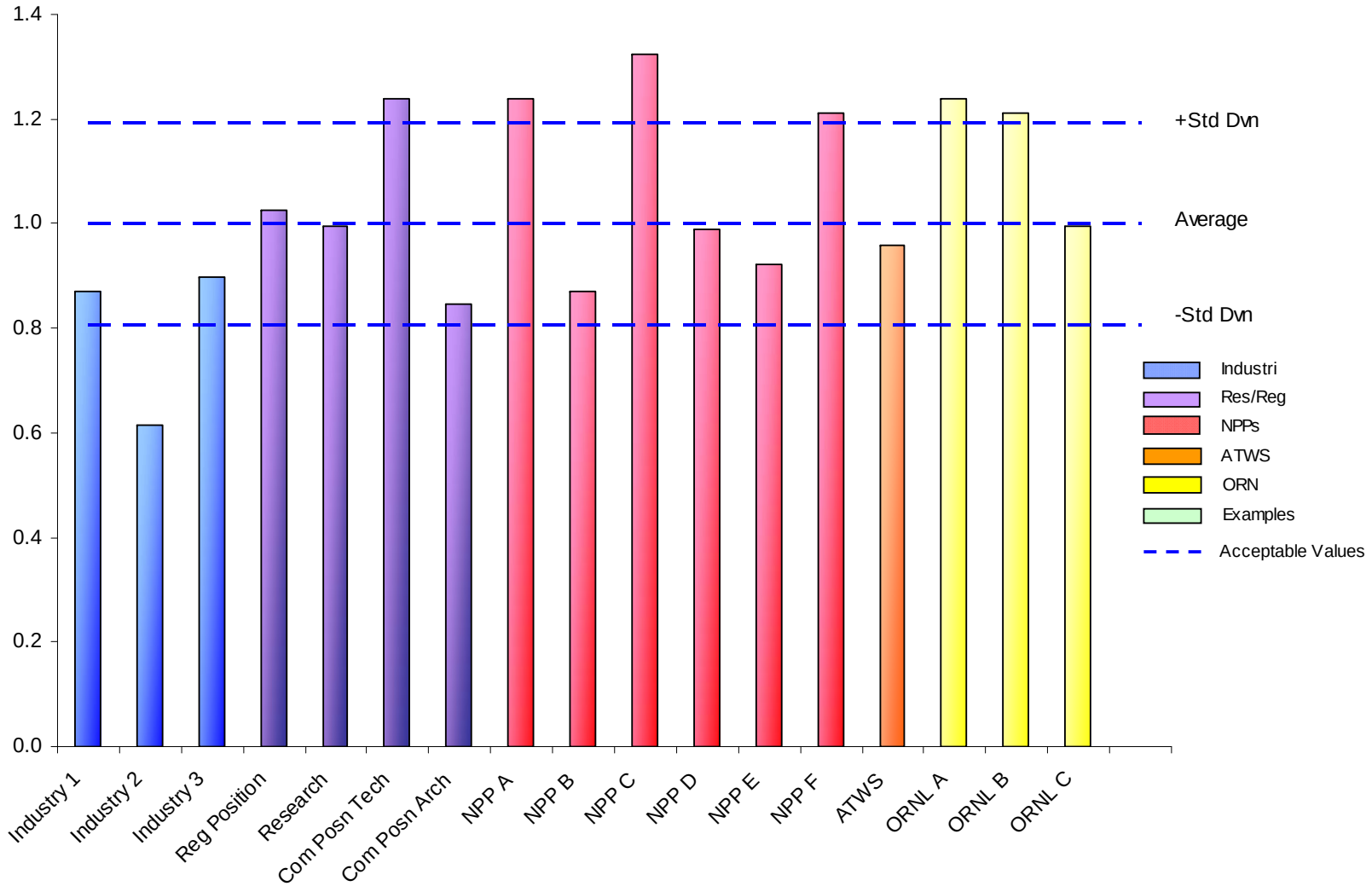
ACCEPTABLE DIVERSE SYSTEM DESIGN APPROACHES



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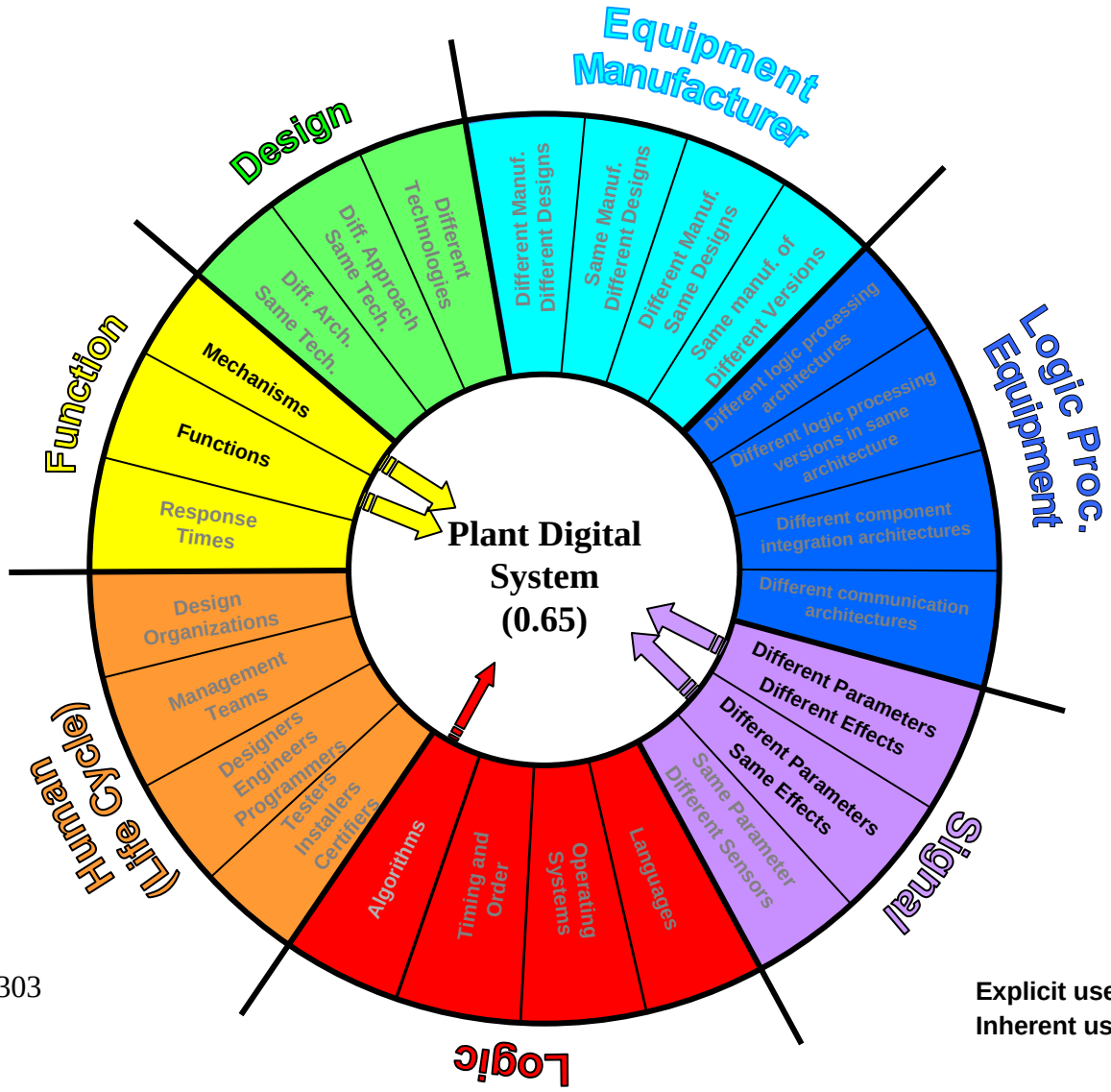
DEVELOPING A DIVERSE FUNCTION OR SYSTEM USING THE SCORING METHOD

EXAMPLE

INITIAL PLANT DIGITAL SYSTEM DESIGN



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Norm = 1.0

Explicit use of Criterion
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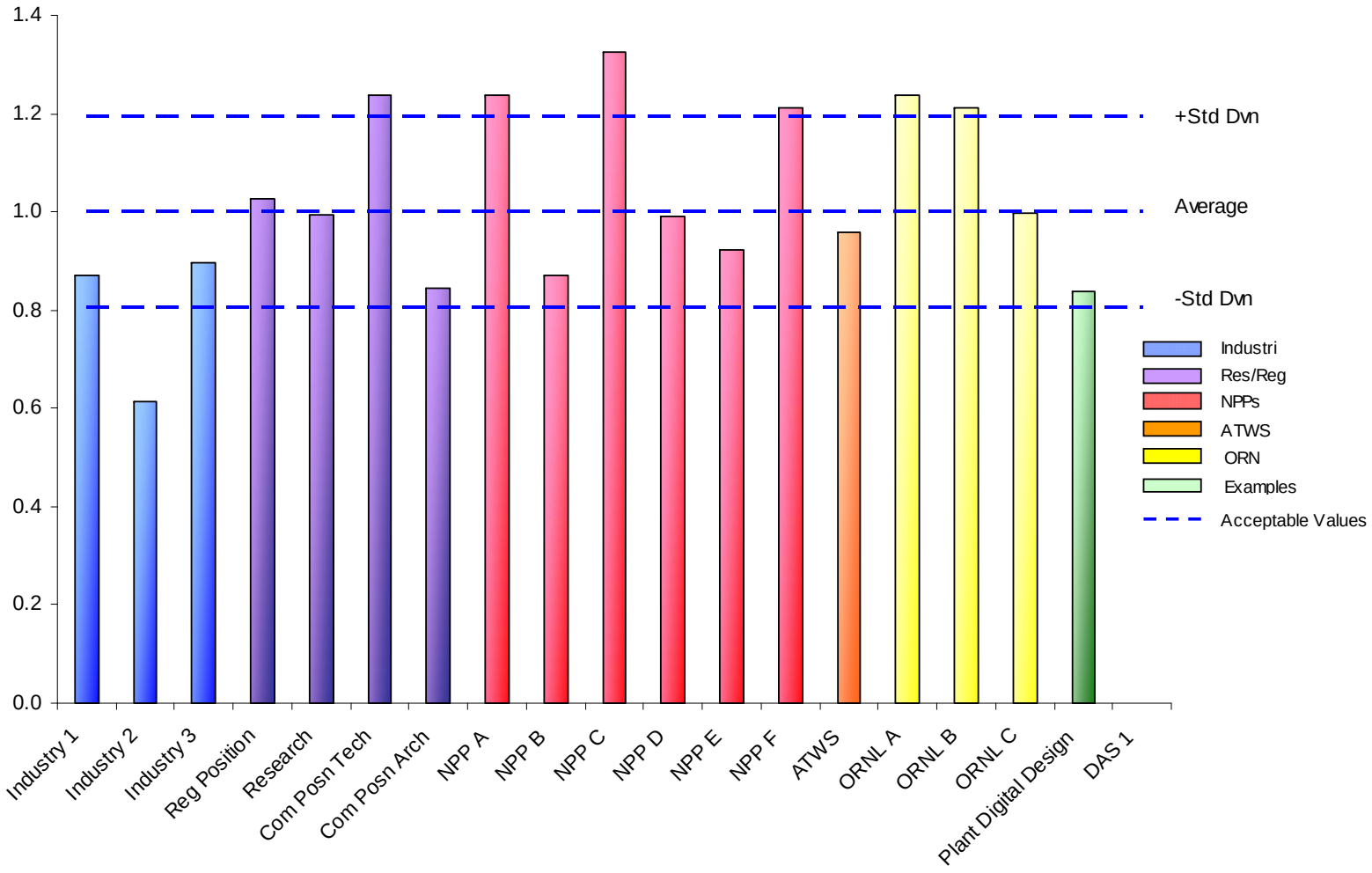
INITIAL PLANT DESIGN



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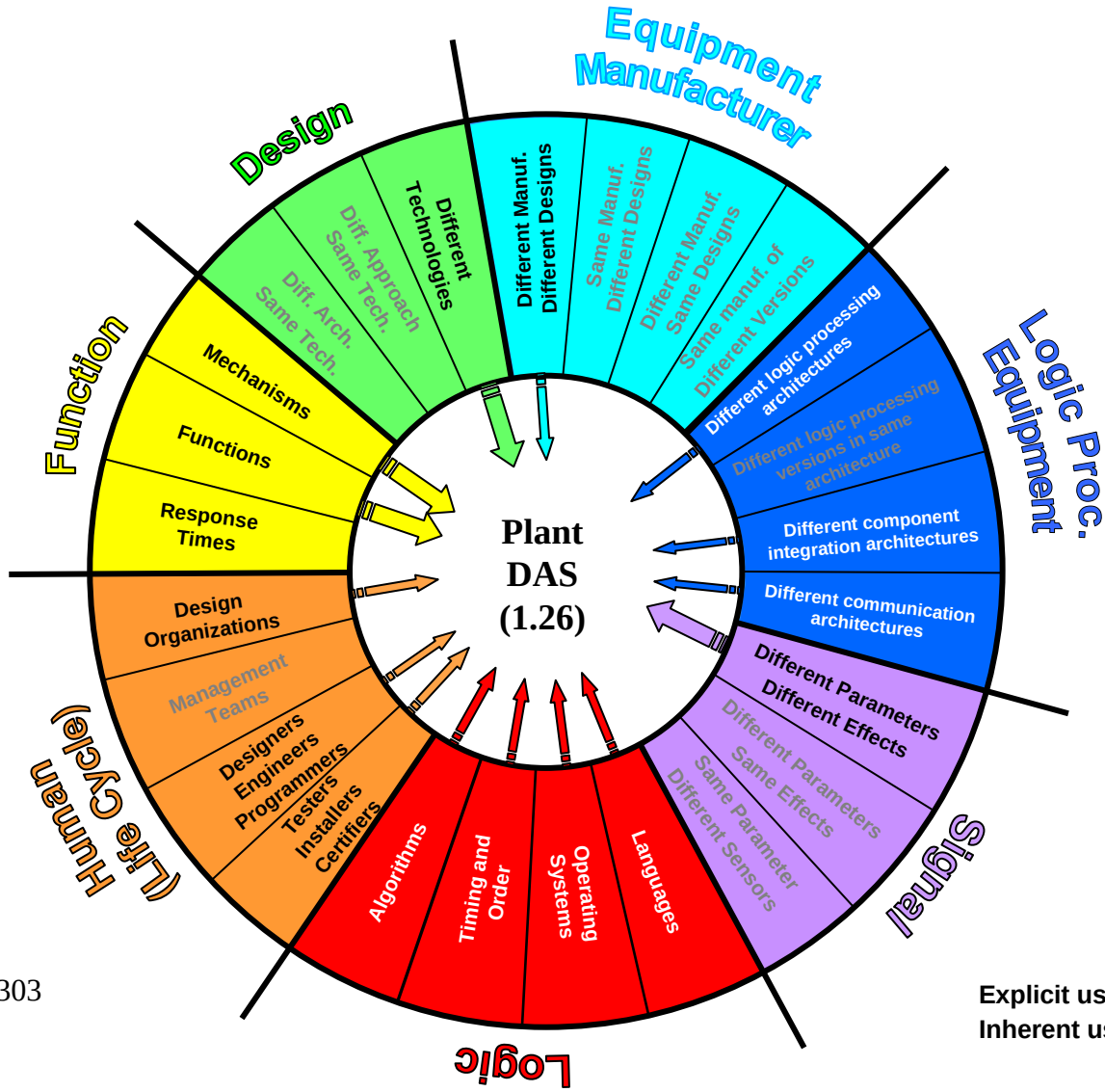
DAS DESIGN



NUREG/CR-6303
Norm = 1.0

Explicit use of Criterion
Inherent use of Criterion

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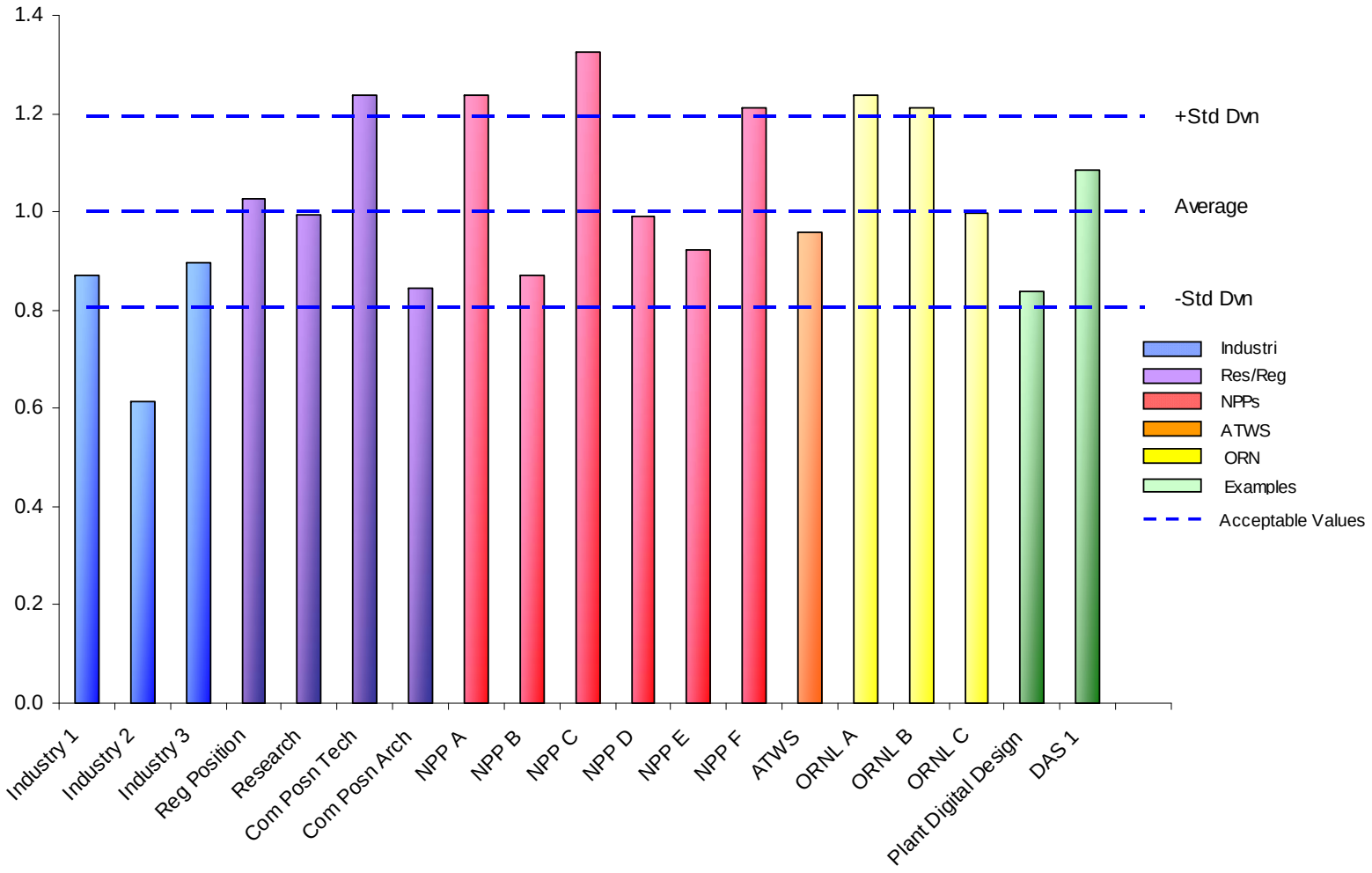
PLANT DESIGN DAS



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DIVERSE SYSTEM DEVELOPMENT CONSTRAINTS

- The set of diversity attributes in the diverse system design should address the postulated CCF mechanisms
  - Example: If a Software CCF, a Function CCF, and a Logic Processing CCF are postulated, criteria from these attributes should be included in the diverse system design
- The diverse system should include design diversity attribute criteria; however, adequate diversity strategies can be developed without the Design attribute
- The threshold value (1.0) must be achieved

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SUMMARY

- World-wide experience has been correlated with NUREG/CR-6303 diversity attribute criteria
- The correlation process is flexible enough to accommodate future data
- The correlated data can be used to evaluate proposed diverse system designs quantitatively
- An initial acceptance threshold has been determined on the basis of the relative effectiveness of NUREG/CR-6303 diversity attribute criteria and experience
- An acceptance threshold can be derived on the basis of data

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NEXT STEPS

- Stakeholder feedback
  - Determine appropriate acceptance threshold value
- Review and incorporate comments into NUREG and process
- Develop systematic process for evaluating proposed diverse safety system designs
- Incorporate acceptance criteria and evaluation process into licensing process
  - Revise NRC guidance to reference process
  - Evaluation procedures supporting SRP

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BACKGROUND INFORMATION

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DIVERSITY CRITERIA SCORING

- Criterion Effectiveness Ranking in Attribute
  - NUREG/6303 inverse rank/sum of the ranks in attribute
- Frequency of Usage
  - Number of diverse safety system designs using criterion/total number of diverse safety system designs
- Relationship Between Ranking and Frequency
  - Score = Weight * Ranking + (1-Weight) * Frequency
- Scores normalized by average score minus one std deviation
- Average score minus one std deviation used as threshold value for acceptable diversity

RANKING WEIGHT W_{Rij}

- **Ranking weighting factor for Criterion *i* in Attribute *j***

$$W_{Rij} = \frac{(N_{cj} - M_{cij} + 1)}{\sum_{i=1}^{M_{cj}} M_{cij}}$$

$$N_{cj} = \text{Number of Criteria in Attribute } j$$

$$M_{cij} = \text{Rank of Criterion } i \text{ in Attribute } j \ ^{*}$$

* Criterion rank specified in NUREG/CR-6303

FREQUENCY WEIGHT W_{Fij}

- **Frequency of usage weighting factor for Criterion *i* in Attribute *j***

$$W_{Fij} = \frac{N_{Sij}}{N_s}$$

N_{Sij} = Number of system designs using Criterion i of Attribute j

N_s = Number of system designs used to determine average score

CRITERION IMPORTANCE WEIGHT W_{ij}

- **Weight applied to Criterion *i* used in Attribute *j* for a diverse safety system design**

$$W_{ij} = W_I * W_{Rij} + (1 - W_I) * W_{Fij}$$

$W_I =$ Importance of Ranking weight relative to Frequency weight

$W_{Rij} =$ Ranking weight for Criterion i in Attribute j

$W_{Fij} =$ Frequency weight for Criterion i in Attribute j

ATTRIBUTE IMPORTANCE WEIGHT w_{ij}

- **Weight applied to Criterion *i* used in Attribute *j* for a diverse safety system design**

$$W_k = \frac{N_{ik}}{N_{ij}}$$

W_k = Importance of Attribute k relative to other diversity attributes

N_{ik} = Number of Criteria i used Attribute k

N_{ij} = Total number of criteria used in all Strategies

SCORING

- **Scoring a diversity strategy**

$$S_l = \left(\sum_{j=1}^{7} \sum_{i=1}^{Nij} (W_j * W_{ij} \times k) \right) \times 1000^*$$

$k = 1$ if Criterion i is used

$k = 0$ if Criterion i is not used

N_{ij} = Total number of Criteria i in Attribute j

W_{ij} = Weight applied to Criteria i in Attribute j

W_k = Weight of Attribute j

S_l = Non-normalized Diversity score for Strategy l

*Scaled by 1000 for readability

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Example Normalizing Value

- **Normalizing value, S_n**

$$S_n = \bar{S} - \sqrt{\frac{\sum_{l=1}^{N_s} \left(S_l - \bar{S}\right)^2}{\left(N_s - 1\right)}}$$

$$\bar{S} = \frac{1}{N_s} \sum_{l=1}^{N_s} S_l$$

$S_l =$ Non – normalized score for Strategy l

$N_s =$ Number of Diversity Strategies used to calculate average score

SCORING

- **Normalized Diversity Strategy score, S_m**

$$S_m = \frac{S_l}{S_n}$$

$$S_l = \text{Non} - \text{normalized score for Strategy } l$$

$$S_n = \text{Normalizing constant}$$

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ASSESSMENT TOOL

	ATTRIBUTE CRITERIA	NUREG/CR-6303	Rank Wt 0.8		Diverse RPS		
	DESIGN	**CRIT. #**	**WT**				
DESIGN	Different technologies	1	1.771		x		1.771
DESIGN	Different approaches within a technology	2	1.181				0.000
DESIGN	Different architectures	3	0.990				0.000
DESIGN	SUBTOTAL			0.101	1		0.179
	EQUIPMENT MANUFACTURER	**CRIT. #**	**WT**				
EQUIPMENT MANUF.	Different manufacturers of fundamentally different equipment designs	1	1.131			i	1.131
EQUIPMENT MANUF.	Same manufacturer of fundamentally different equipment designs	2	0.763				0.000
EQUIPMENT MANUF.	Different manufacturers of same equipment design	3	0.737				0.000
EQUIPMENT MANUF.	Same manufacturer of different versions of the same equipment design	4	0.326				0.000
EQUIPMENT MANUF.	SUBTOTAL			0.101	0		0.114
	LOGIC PROCESSING EQUIPMENT	**CRIT. #**	**WT**				
LOGIC PROCESSING	Different logic processing equipment architectures	1	1.303			i	1.303
LOGIC PROCESSING	Different logic processing versions in same equipment architecture	2	0.806				0.000
LOGIC PROCESSING	Different logic processing equipment integration architectures	3	0.694			i	0.694
LOGIC PROCESSING	Different communication architectures	4	0.326			i	0.326
LOGIC PROCESSING	SUBTOTAL			0.132	0		0.306
	FUNCTION	**CRIT. #**	**WT**