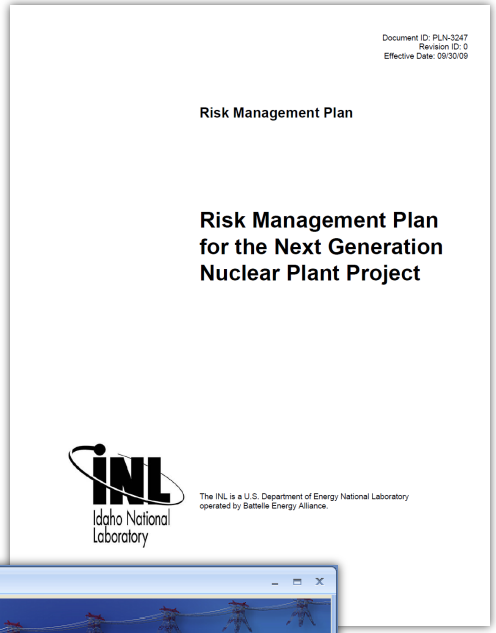
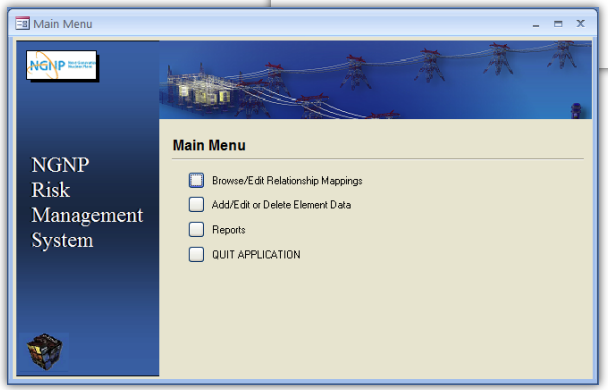
NGNP – A Brief History

- The earliest developments of NGNP are based on research, design, and deployments of High Temperature Gas Reactors
- Early 2000's formulation of NGNP started
  - Various studies and GEN IV start defining NGNP
  - DOE, reactor suppliers, and industrial end users started collaborative activities
- *Energy Policy Act of 2005* formally outlined the NGNP as a federal project with specific project requirements
  - Generate **electricity**, or produce **hydrogen**, or **both**
  - Efficient and safe source for the product streams; process heat
  - Formalized as a DOE project in FY2006
- INL leads and directs the NGNP Project and Systems Engineering is an integral part of the project

NGNP Risks Reduction

- Risk Management Plan
  - Method to manage NGNP risks
  - Integrated risk reduction via the use of:
    - Technology Readiness Assessment (TRA)
    - Technology Readiness Levels (TRLs)
    - Technology Development Roadmaps (TDRMs)
- Risk Management System
  - Risk Register
  - Risk reduction tasks
  - Risk waterfalls
  - Risk mitigation strategies
- Risk Decision Analysis
  - Multi-Attribute Utility Theory
  - Analytic Hierarchy Process





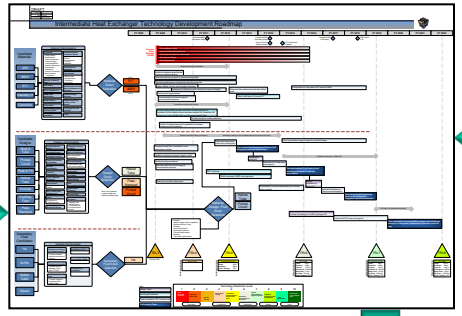
NGNP Next Generation Nuclear Plant

Risk Reduction – An Iterative Process

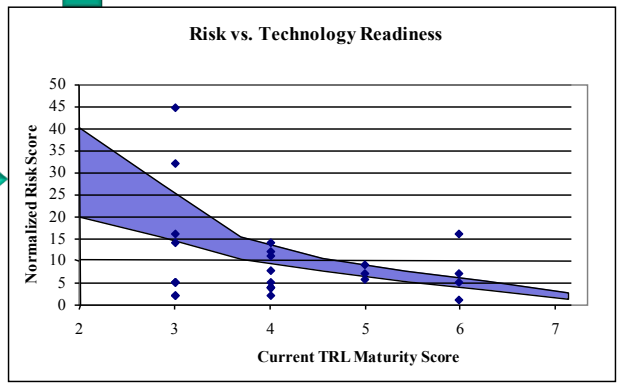
Assess Technology Maturity

NGNP Area System	Min TRL
NGNP	3
Nuclear Heat Supply System (NHSS)	4
Reactor Pressure Vessel	4
Reactor Vessel Internals	4
Reactor Core and Core Structure	4
Fuel Elements	4
Reserve Shutdown System	5
Reactivity Control System	4
Core Conditioning System	4
Reactor Cavity Cooling System	4
Heat Transfer System (HTS)	3
Circulators	5
Intermediate Heat Exchanger	3
Cross Vessel Piping	4
High Temperature Valves - Flapper	6
High Temperature Valves - Iso, Relief	4
Power Conversion System (PCS)	4
Steam Generator	4
Balance of Plant (BOP)	3
Fuel Handling System - Prismatic	4
Fuel Handling System - Pebble Bed	5
Instrumentation & Control	3

Build the Roadmap & Define Path Forward



Advance TRLs & Reduce Risk



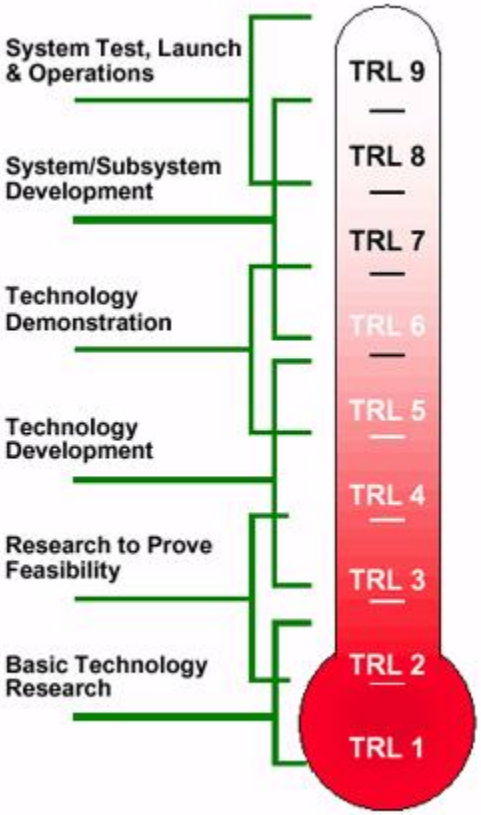
Evaluate the Roadmap & Refine Path Forward

NGNP Next Generation Nuclear Plant

Technology Readiness Assessment

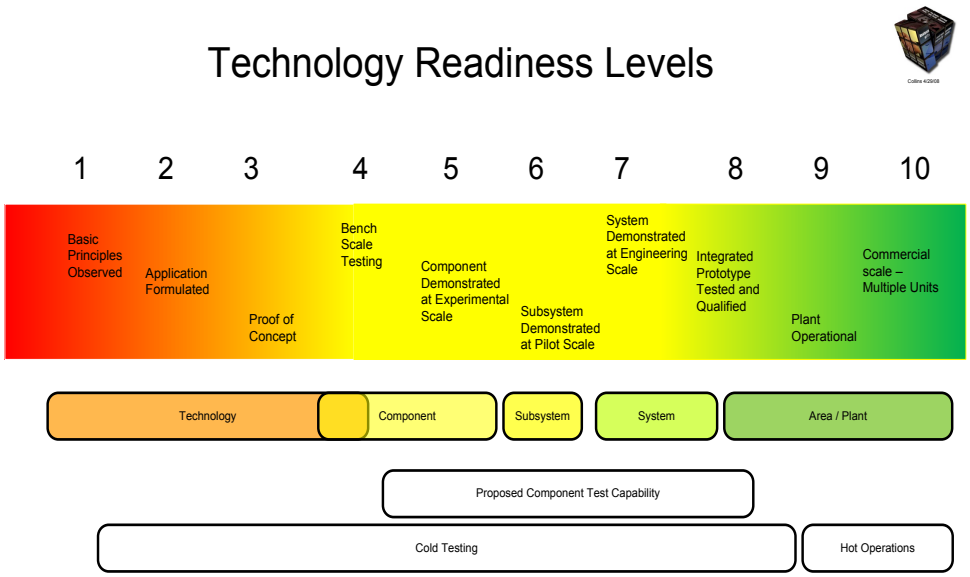
- NGNP TRA based upon a modified version of the DOD and NASA TRA/TRL processes
- Crucial to risk reduction activities to the project
  - Identifies technology development needs, technology development path forward, and risk reduction identification
- NGNP TRA initiated prior to development, acceptance, and implementation of DOE Guide 413.3-4 by the DOE
- DOE Guide 413.3-4
  - Outlines the technology assessment to be used in DOE projects
  - Input from the NGNP experiences with TRAs and TRLs
- Technology Development Roadmaps

Technology Readiness Levels



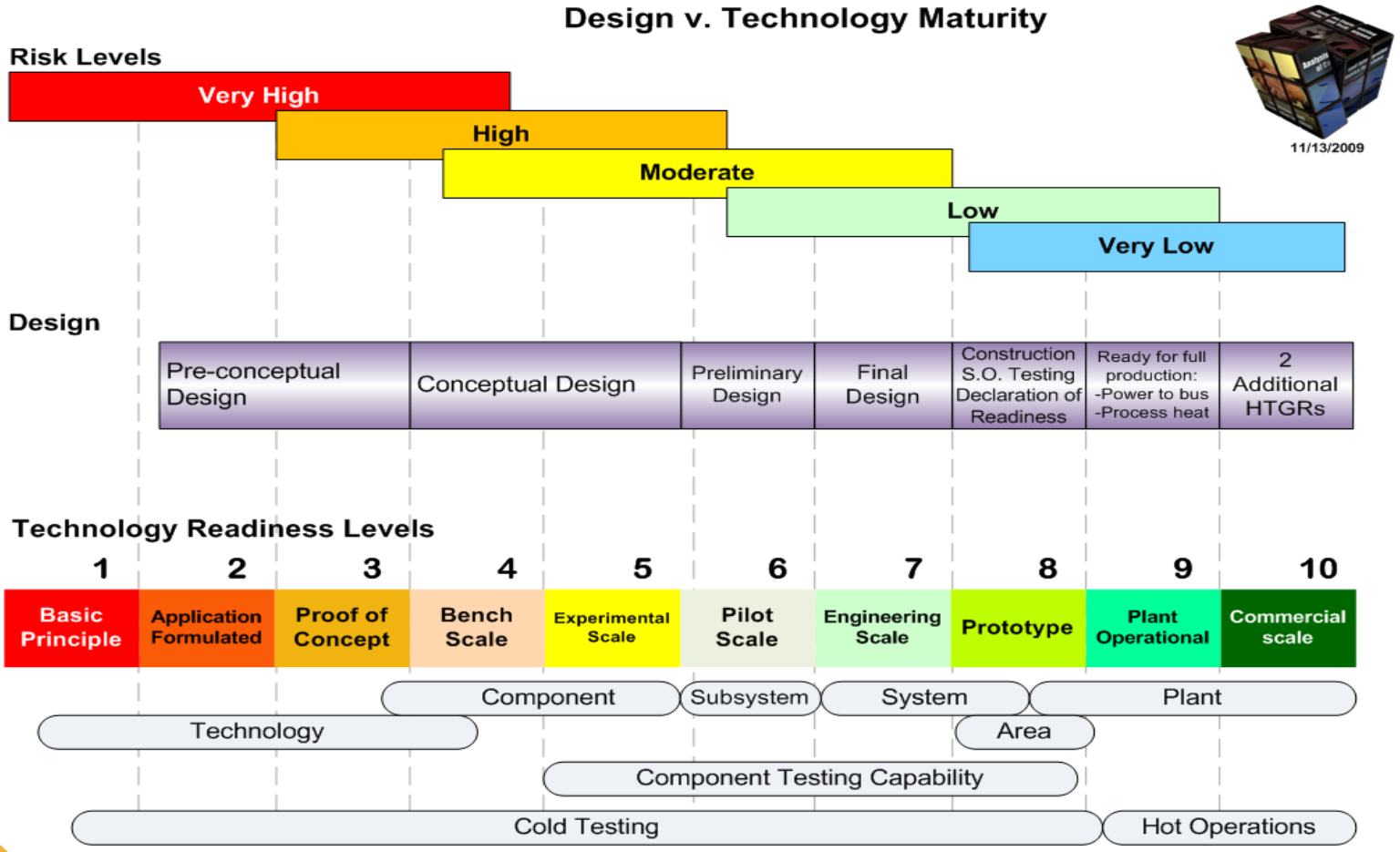
DOD and NASA use a 9-point scale

NGNP has adopted a **10-point scale**



NGNP Next Generation Nuclear Plant

Technology Readiness Levels



NGNP Next Generation Nuclear Plant

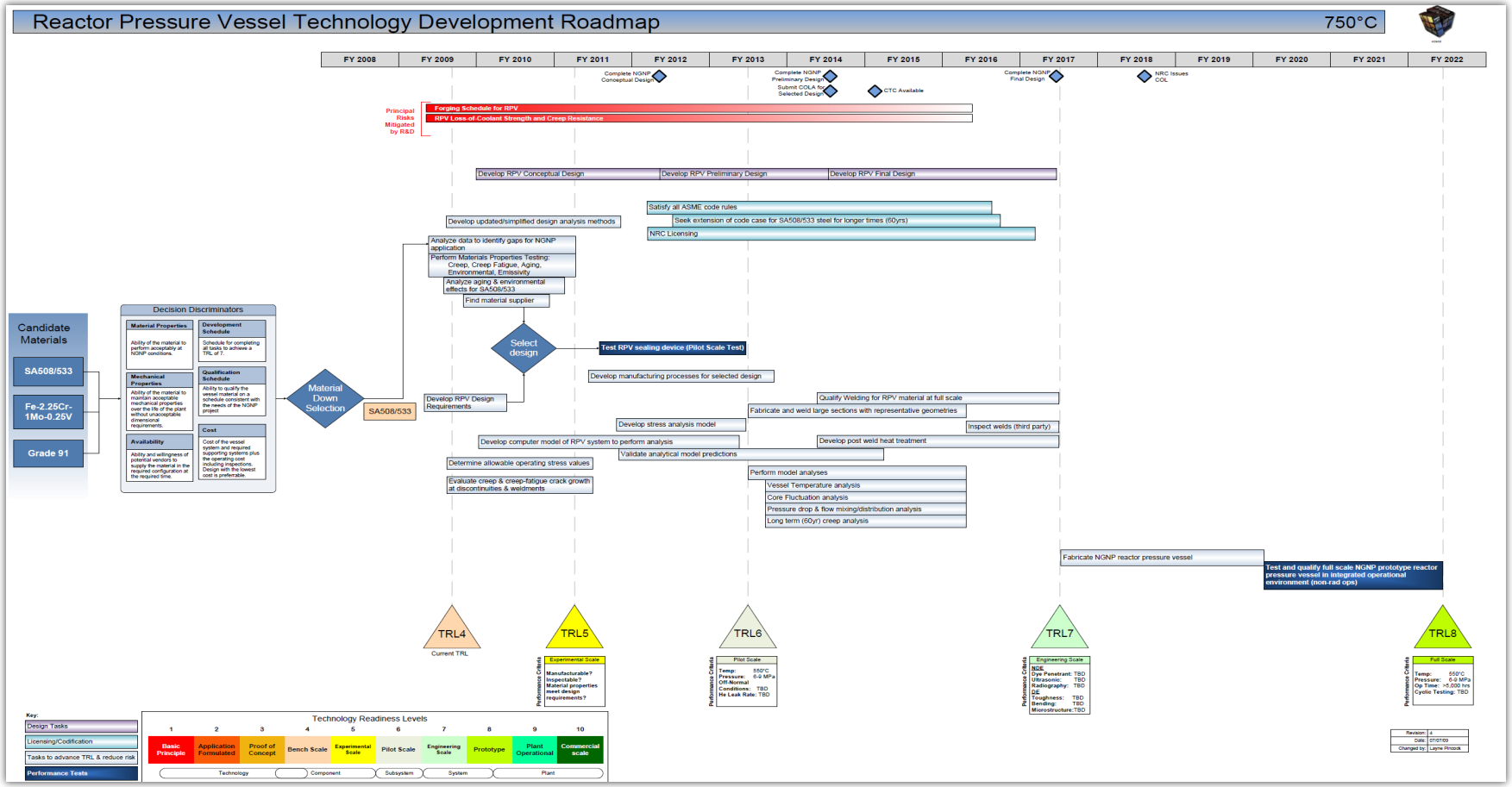
Technology Readiness Levels

- Critical PASSCs
  - Plant
  - Areas
  - Systems
  - Subsystems
  - Components
- Current Technology Readiness Levels for NGNP (at 750°C ROT)

NGNP Area System	Min TRL
NGNP	**3**
Nuclear Heat Supply System (NHSS)	**4**
Reactor Pressure Vessel	**4**
Reactor Vessel Internals	**4**
Reactor Core and Core Structure	**4**
Fuel Elements	**4**
Reserve Shutdown System	**5**
Reactivity Control System	**4**
Core Conditioning System	**4**
Reactor Cavity Cooling System	**4**
Heat Transfer System (HTS)	**3**
Circulators	**5**
Intermediate Heat Exchanger	**3**
Cross Vessel Piping	**4**
High Temperature Valves - Flapper	**6**
High Temperature Valves - Iso, Relief	**4**
Power Conversion System (PCS)	**4**
Steam Generator	**4**
Balance of Plant (BOP)	**3**
Fuel Handling System - Prismatic	**4**
Fuel Handling System - Pebble Bed	**5**
Instrumentation & Control	**3**

NGNP Next Generation Nuclear Plant

Technology Development Roadmaps



Probability Definition

Probabilities	Range	Technology Criteria	Scale Criteria	Use for calculation
Beyond Design Basis	**< 10^{-4}**		Not evaluated since it is beyond the basis of the design	**N/A**
Very Unlikely	**10^{-4} to 0.1%**	Technology are well understood and are routinely used in similar, integrated applications and conditions.	The scale of the system/component needed is similar to existing successful applications.	**0.1**
Unlikely	**0.1% to 1%**	Technology is understood and has been used in applications and conditions close to, but not identical to required conditions. A small amount of development needed before deployment.	Majority of the components are similar in scale to existing applications.	**0.3**
Somewhat Likely	**1% to 10%**	Technology needs a moderate amount of research, development, and design before deployment at required operating conditions.	About half of components are similar in scale to existing applications.	**0.5**
Likely	**10% to 50%**	Technology needs a major amount of research, development, and design before deployment at required operating conditions.	Some of the components are scaled similar to existing applications, with the remainder needing significant design changes to achieve deployment.	**0.7**
Very Likely	**> 50%**	Low maturity; complex, unclear development path; multiple unproven technologies must work together.	All components needed have never been attempted at the necessary scale.	**0.9**

Consequence Definition

Consequence	Technical	Schedule	Use for calculation (risk units)
Negligible	Minimal or no impact	Schedule delays that do not affect milestones or the critical path	1
Marginal	Small change needed to design or path forward. Minor damage to equipment or facilities. Minor, temporary loss of capabilities.	Schedule delays that may affect external milestones or are threatening a slip along the critical path	3
Significant	Moderate change needed to design or path forward. Moderate, but repairable damage to equipment or facilities. Moderate, temporary loss of capability.	Schedule delays that will slip the critical path end date by up to 6 months	5
Critical	Major change needed to design or path forward, workaround available. Significant, repairable damage to equipment or facilities.	Schedule delays that will slip the critical path end date by more than 6 months but less than 1 year	7
Crisis	Major change needed to design or path forward, no workaround available now. Loss of equipment or facilities.	Schedule delays that will slip the critical path end date 1 year (schedule slips in excess of 1 year are anticipated to cause a loss of the program)	9

How Much Risk is Acceptable?

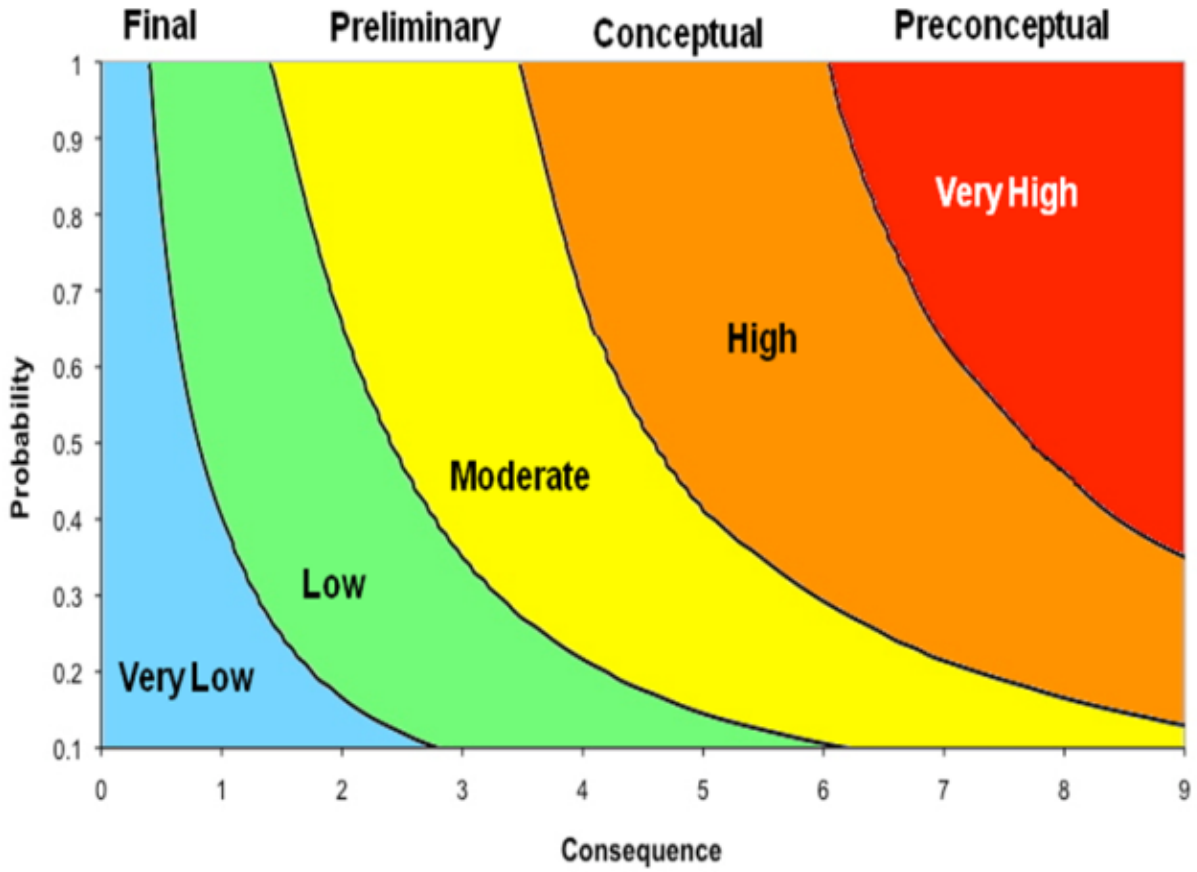
Probability	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7

Consequence

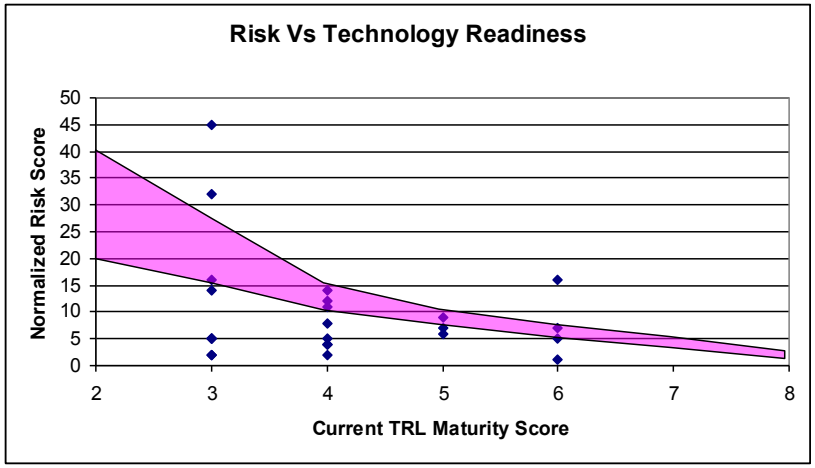
NGNP Next Generation Nuclear Plant

Plan for Risk Reduction

- Acceptable project risk for each design phase



Risk Reduction



- **Risk levels are reduced** as activities are performed to mature technologies
- Activities are measured against established **performance criteria** and how well they **reduce overall risk**

	Risk Score	< 0.4	Very Low
0.4 <=	Risk Score	< 1.4	Low
1.4 <=	Risk Score	< 3.3	Moderate
3.3 <=	Risk Score	< 5.9	High
	Risk Score	> 5.9	Very High

	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1 (S)
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1 (1)	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3 (2)	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2 (3)	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0 (4)	Moderate 1.8	Moderate 2.7

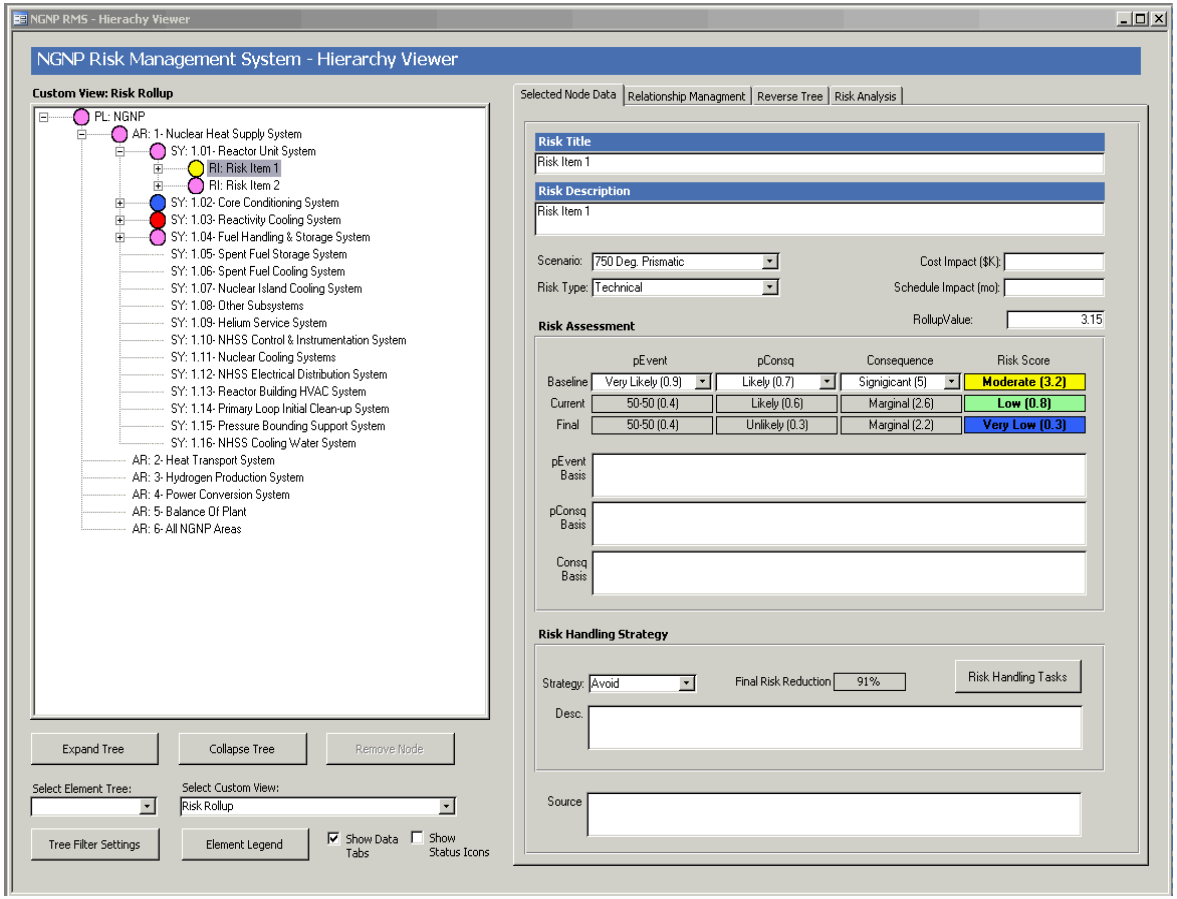
NGNP Next Generation Nuclear Plant

Risk Management System

- Risk Register
  - Risk identification
  - Risk classification – technical versus programmatic
- Risk Assessment Capability
  - Risk reduction tasks development
  - Risk reduction tasks assignments
  - Risk strawman scoring
  - Risk validation
  - Risk final scoring with input from Project Risk Analysis Tool
  - RMS is the Risk Model
  - Incorporate and collaborate with TRA and TDRM activities
  - Provide baseline for Risk Decision Making Analyses — QuickCompare™

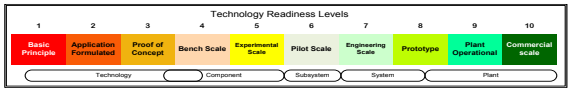
Risk Model

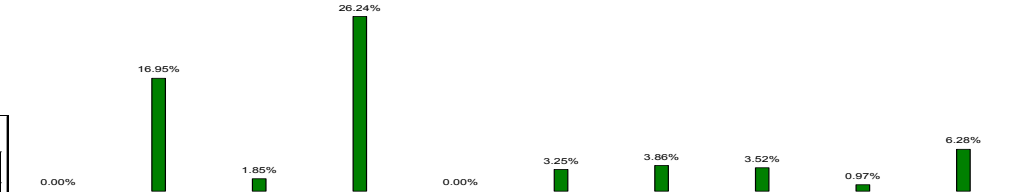
- Establishes risk baseline
- Documents risk reduction plan
- Tracks current risk reduction status
- Tracks risk by reference configuration
- Tracks risk by PASSC and area
- Informs decision making



PRAT – Project Risk Analysis Tool

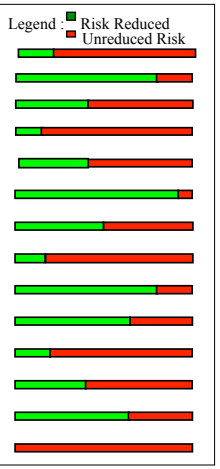
	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.4	High 4.4	Very High 6.1	Very High 7.9
Somewhat Likely	Low 0.5	Moderate 1.9	High 3.8	High 5.3	Very High 6.8
UnLikely	Very Low 0.3	Low 1.2	Moderate 2.6	High 4.2	High 5.4
Very Unlikely	Very Low 0.1	Low 0.5	Low 1.0	Moderate 1.8	Moderate 2.7





ID	RPV TECHNICAL RISKS	BASELINE C	Pc	Pe	Risk Score After Task Completion	Residual risk (ΔR) at 2016
35	RPV Emissivity vs. Power Level - INL/EXT- 05 - 00952(PLN-2489) Revision 3	9.00	1.00	0.70	5.04	
78	Weldments and postweld heat treatment of Modified 9Cr-1Mo- INL PLN-2674	9.00	1.00	0.70	1.26	
48	RPV Loss-of-Coolant Strength and Creep Resistance - INL/EXT-07-12967 Revision 1	9.00	1.00	0.50	2.66	
79	Effects of Sulfur on RPV Wall - INL PLN-2674	5.00	1.00	0.50	2.13	
102	Micro Structural Stability-INEEL/EXT-04-01816	9.00	1.00	0.70	3.78	
105	RPV: Vessel Size/Fabrication- INEEL/EXT-04-01816	9.00	1.00	0.70	0.50	
9	Inspection of Thick Sections and Weldments - INL/EXT - 08-15148	9.00	1.00	0.70	3.15	
76	Thermal Aging Effects - PLN-2803 NGNP RPV Materials R&D Plan	7.00	1.00	0.50	2.91	
132	Irradiation Effects On Fracture Performance -PLN-2803 NGNP RPV Materials R&D Plan	7.00	1.00	0.70	0.98	
133	Temperature Effects On Mechanical Properties of Grade 91 - PLN-2803 NGNP RPV Materials R&D Plan	5.00	1.00	0.50	0.88	
225	Verification & Validation of Analytical Methods to Support Design Development - INL/EXT- 07- 12967	5.00	1.00	0.50	2.00	
226	Uncertainty in Extrapolated Data to Higher Temperatures - INEEL/EXT-04-01816	7.00	1.00	0.70	2.94	
227	Temperature of Pressure Boundary- INEEL/EXT-04-01816	9.00	1.00	0.70	2.27	
228	NRC Issues Identified In PIRT and Not Addressed by Vendors - Phil Mills, et. al	9.00	1.00	0.30	2.70	

	A	B	C	D	E	F	G	H	I	J
	0.00%	16.95%	1.85%	26.24%	0.00%	3.25%	3.86%	3.52%	0.97%	6.28%
	0.00	5.53	0.61	8.56	0.00	1.06	1.26	1.15	0.32	2.05
	Develop updated/simplified design analysis methods - PLN-2803 Rev 0 NGNP RPV Materials R&D Plan April 2008	Collect heavy section material data data Grade 91	Analyze data to identify gaps for NGNP application	Collect data to fill gaps in data for : creep, creep fatigue,aging,irradiation,emissivity	Find material supplier	Evaluate Grade 91 against large scale fossil industry experience	Develop NDE inspection for thick (>200mm) Grade 91microstructure	Analyze aging & environmental effects for SA 508/533	Determine allowable operating stress values - PLN-2803 Rev 0 NGNP RPV Materials R&D Plan April 2008	Evaluate creep creep-fatigue crack growth at discontinuities & weldments -PLN-2803 Rev 0 NGNP RPV Materials R&D Plan April 2008&
	TRL 4 - 5									
35	6.30	6.30	6.30	5.67 (ΔPe 0.10)	5.67	5.67	5.67	5.67	5.67	5.67
78	6.30	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
48	4.50	4.50	4.46 (ΔPe 0.01)	4.01 (ΔPe 0.10)	4.01	4.01	4.01	4.01	4.01	4.01
79	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.38 (ΔPe 0.05)	2.38	2.25 (ΔPe 0.05)
102	6.30	6.30	6.30	5.67 (ΔPe 0.10)	5.67	5.67	5.36 (ΔPe 0.05)	5.04 (ΔPe 0.05)	4.41	4.41 (ΔPe 0.10)
105	6.30	6.30	6.30	6.30	6.30	6.17 (ΔPe 0.02)	6.17	6.17	6.17	6.17
9	6.30	6.30	6.30	6.30	6.30	6.30	6.17 (ΔPe 0.15)	6.17	6.17	6.17
76	3.50	3.50	3.50	3.50	3.50	3.50	3.50	5.36 (ΔPe 0.07)	5.36	5.36 (ΔPe 0.10)
132	4.90	4.90	4.90	0.98 (ΔPe 0.80)	0.98	0.98	0.98	0.98	0.98	0.98
133	2.50	2.50	2.50	1.25 (ΔPe 0.50)	1.25	0.88 (ΔPe 0.15)	0.88	0.88	0.88	0.88
225	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
226	4.90	4.41 (ΔPe 0.10)	4.17 (ΔPe 0.05)	3.43 (ΔPe 0.15)	3.43	3.19 (ΔPe 0.05)	3.19	3.04 (ΔPe 0.03)	3.04	3.04
227	6.30	6.30	5.99 (ΔPe 0.05)	5.04 (ΔPe 0.15)	5.04	4.73 (ΔPe 0.05)	4.73	4.41 (ΔPe 0.05)	4.10 (ΔPe 0.05)	3.15 (ΔPe 0.15)
228	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70



NGNP Next Generation Nuclear Plant

Risk Reduction

Bimetallic Weld Qualification			Demonstrate manufacturability			Computer Modeling: Structural Evaluation of tubes and supports			Computer Modeling: Evaluate Steady state pressure drop			Computer Modeling: Thermal Sizing			Structural Tests of Materials			Perform Trade Studies		
						TRL 4-5														
ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe
		0.10									0.05						0.05			0.05
3.78			4.20			4.20			4.20			4.42			4.42			4.66		
ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe
4.90			4.90			4.90			4.90			4.90			4.90			4.90		
ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe	ΔC	ΔPc	ΔPe
											0.05									0.05
4.42			4.42			4.42			4.42			4.66			4.66			4.66		

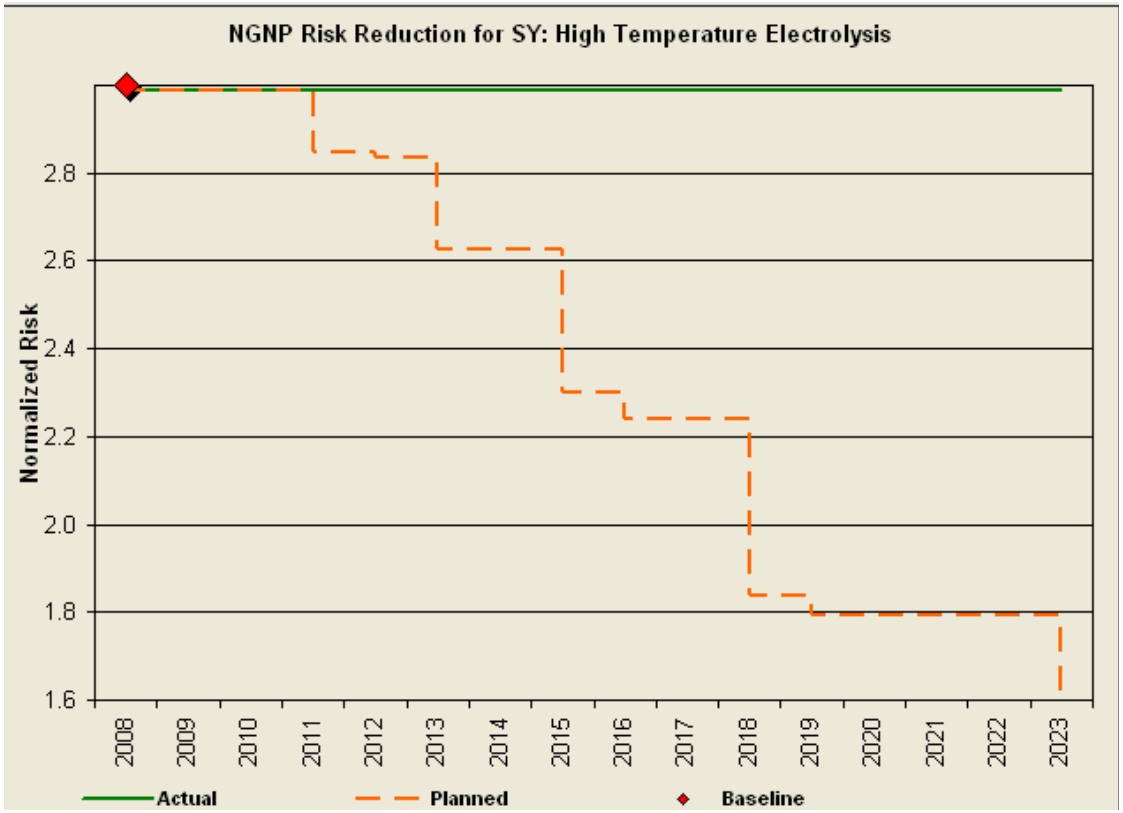
	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 0.9	Moderate 2.7	High 4.5	Very High 6.3	Very High 8.1
Likely	Low 0.7	Moderate 2.1	High 3.5	High 4.9	Very High 6.3
50 - 50	Low 0.5	Moderate 1.5	Moderate 2.5	High 3.5	High 4.5
UnLikely	Very Low 0.3	Low 0.9	Moderate 1.5	Moderate 2.1	Moderate 2.7
Very Unlikely	Very Low 0.1	Very Low 0.3	Low 0.5	Low 0.7	Low 0.9

STEAM GENERATOR TECHNICAL RISKS	BASELINE C	BASELINE Pc	BASELINE Pe	Residual risk at Present	Risk % Reduction (from baseline)	Residual risk at 2016
Corrosion and Wear Issues in SG - TDRM doc_01_09	7.00	1.00	0.70	4.42	10%	2.49
	4.90					
High Pressure Seal Performance in SG - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.90	0%	3.43
	4.90					
Fouling or Plugging in SG - INL/EXT - 08 - 15148	7.00	1.00	0.70	4.66	5%	1.30
	4.90					

R & D, Engineering, & Licensing Tasks Reduce the Probability or Consequence of Risks

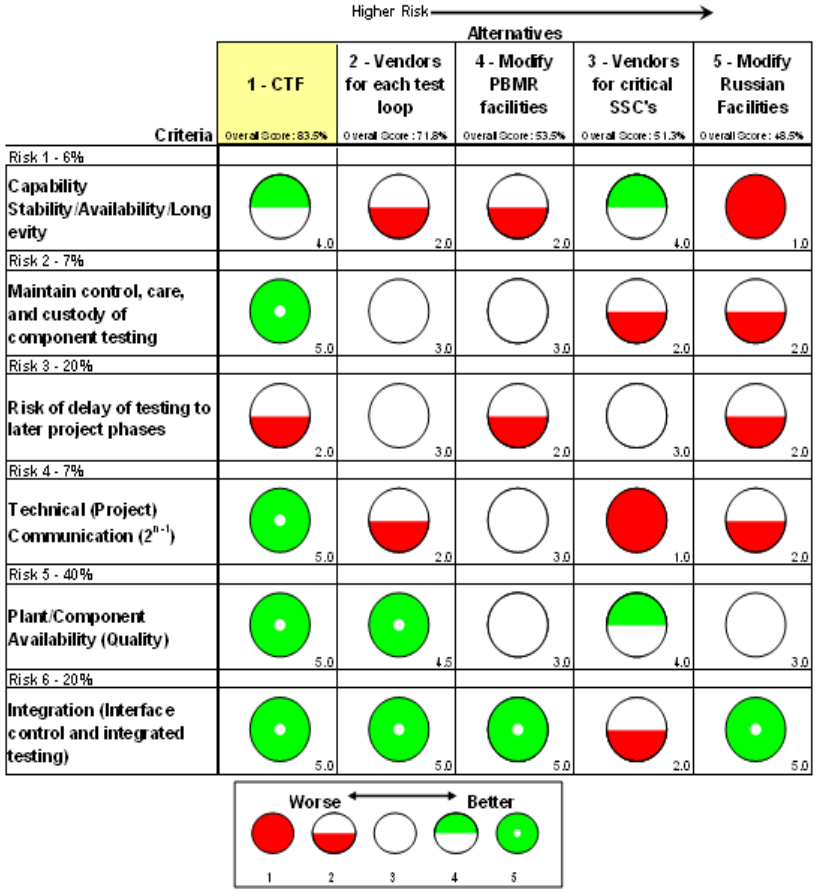
Verify Reductions, Replan

- Evaluates the Task for Actual Risk Reduction verses Planned Risk Reduction
- Replan as Needed



Decision Analysis

- QuickCompare™
  - Developed by INL for decision analysis
- Comparative analysis techniques
  - Provides prioritization of alternatives against risks
  - Assists in decision making for the decision makers
- Multi-Attribute Utility Theory
- Analytic Hierarchy Process



NGNP Next Generation Nuclear Plant

Questions?

Thank you!

www.nextgenerationnuclearplant.com

www.inl.gov

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