Evolution of a Unique Systems Engineering Capability

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Idaho National Laboratory

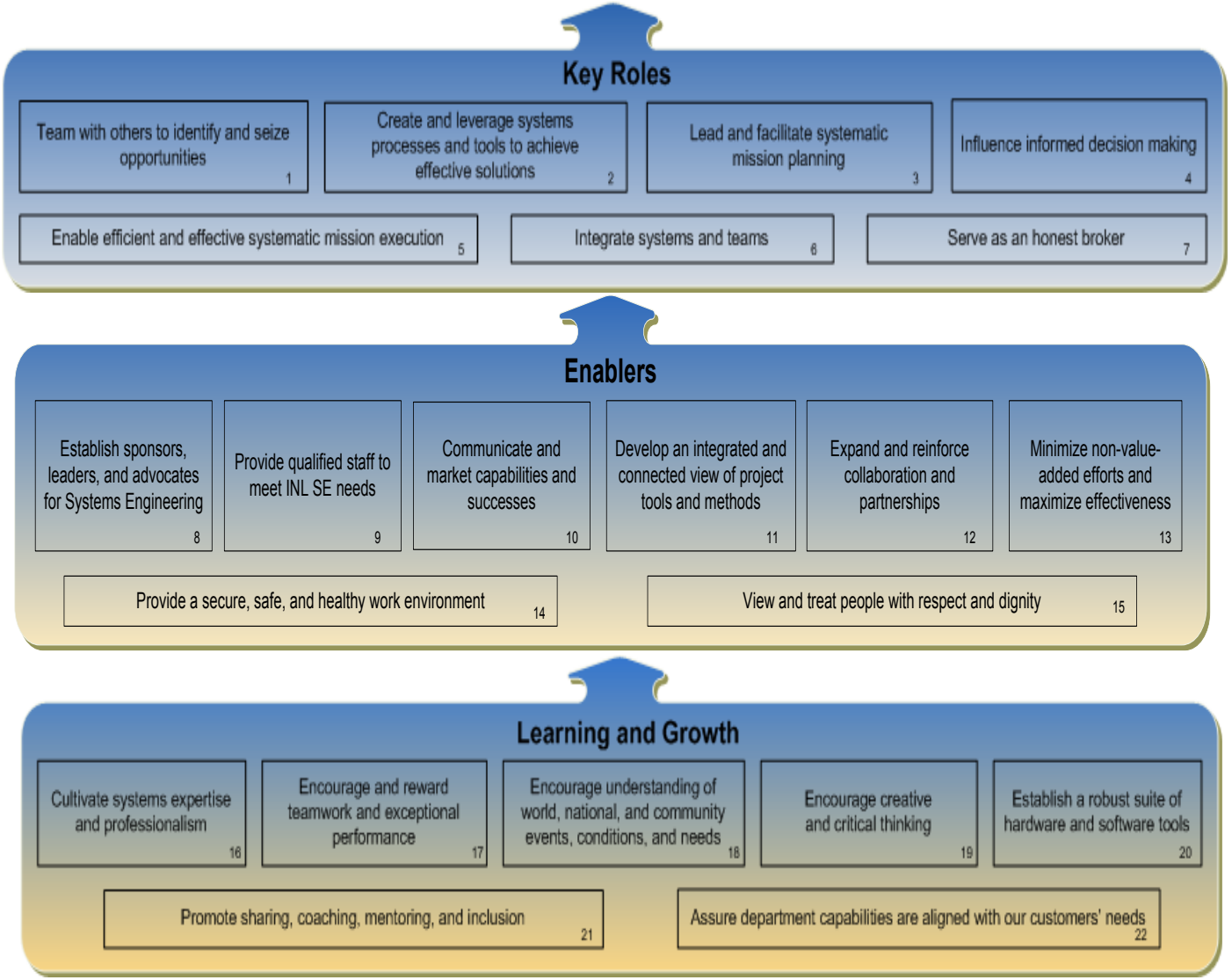
Organization Dilemma

- Should the organization pursue:
  - operational excellence
  - product leadership
  - customer intimacy
- Extremely difficult to excel or achieve best-in-class at all three
- Resulted in the demise of a number of organizations given the very intricate balancing act that is necessary
- What do we want to be when we grow up?

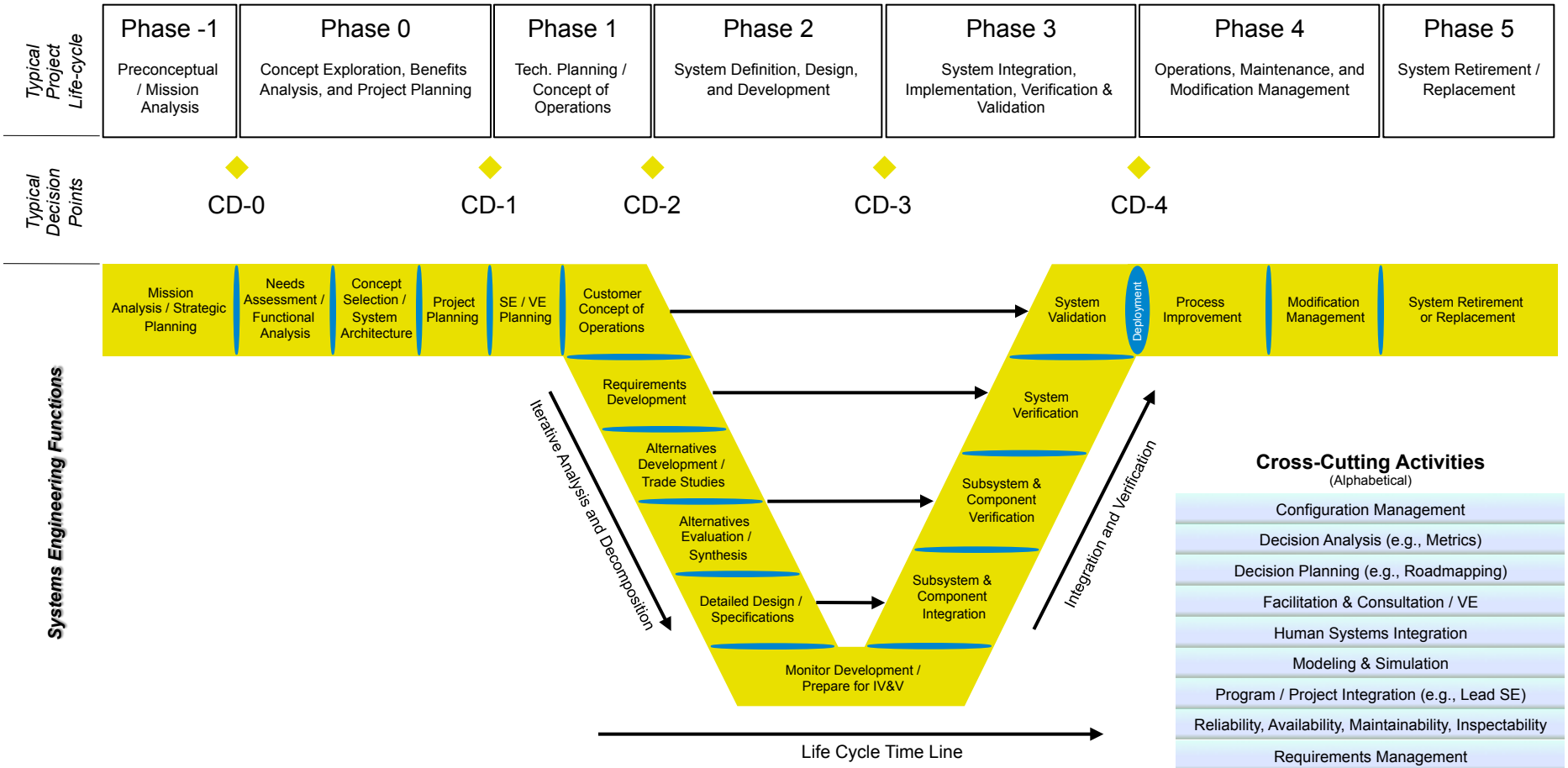
SE Capability Enhanced By Tools that Manage Complexity

- Internal and external projects:
  - Offer broad application of the SE discipline
  - Provide a rich environment to develop tools that increase our ability to manage complexity
- To be invited to help solve big problems:
  - Must differentiate ourselves from other engineering organizations (internal)
  - Stay on the cutting edge between systems science and systems engineering to avoid competition with industry (external)
- Opportunity to leverage accomplishments on behalf of new challenges

Strategy Mapping



Systems Engineering Capabilities Enhance the Entire Project Lifecycle



Cross-Cutting Activities
(Alphabetical)

- Configuration Management
- Decision Analysis (e.g., Metrics)
- Decision Planning (e.g., Roadmapping)
- Facilitation & Consultation / VE
- Human Systems Integration
- Modeling & Simulation
- Program / Project Integration (e.g., Lead SE)
- Reliability, Availability, Maintainability, Inspectability
- Requirements Management
- Risk Management
- Stakeholder Analysis / Elicitation
- System Life Cycle Management

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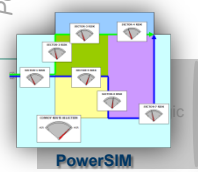
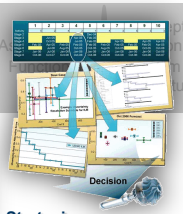
Systems Engineering Tools and Techniques Support Informed Decision-Making

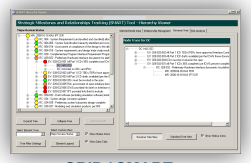
Typical Project Life-cycle	Phase -1	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	Preconceptual / Mission Analysis	Concept Exploration, Benefits Analysis, and Project Planning	Tech. Planning / Concept of Operations	System Definition, Design, and Development	System Integration, Implementation, Verification & Validation	Operations, Maintenance, and Modification Management	System Retirement / Replacement
Typical Decision Points	CD-0		CD-1	CD-2	CD-3	CD-4	

Systems Engineering Tools and Techniques


PowerSIM
FlexSIM

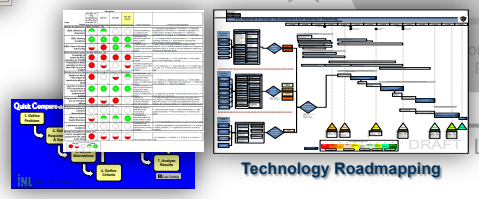
Zoned Analysis


Strategic Roadmapping


GRIP / SMART Relationship Mapping

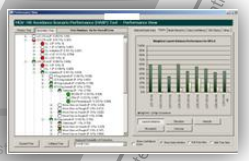
Risk Modeling

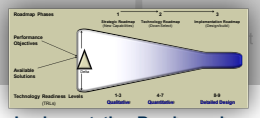
Technology Readiness Assessment


QuickCompare
Technology Roadmapping

Customer Concept of Operations
Requirements Development
Alternatives Development / Analysis / Synthesis
Detailed Design / Specifications
Monitor Development / Prepare for IV&V
Subsystem / Component Integration
System Validation
System Verification
System Retirement or Replacement
Life Cycle Time Line

DOORS RequisitePro


Scenario Performance Modeling


Implementation Roadmapping

Six Sigma

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(Alphabetical)

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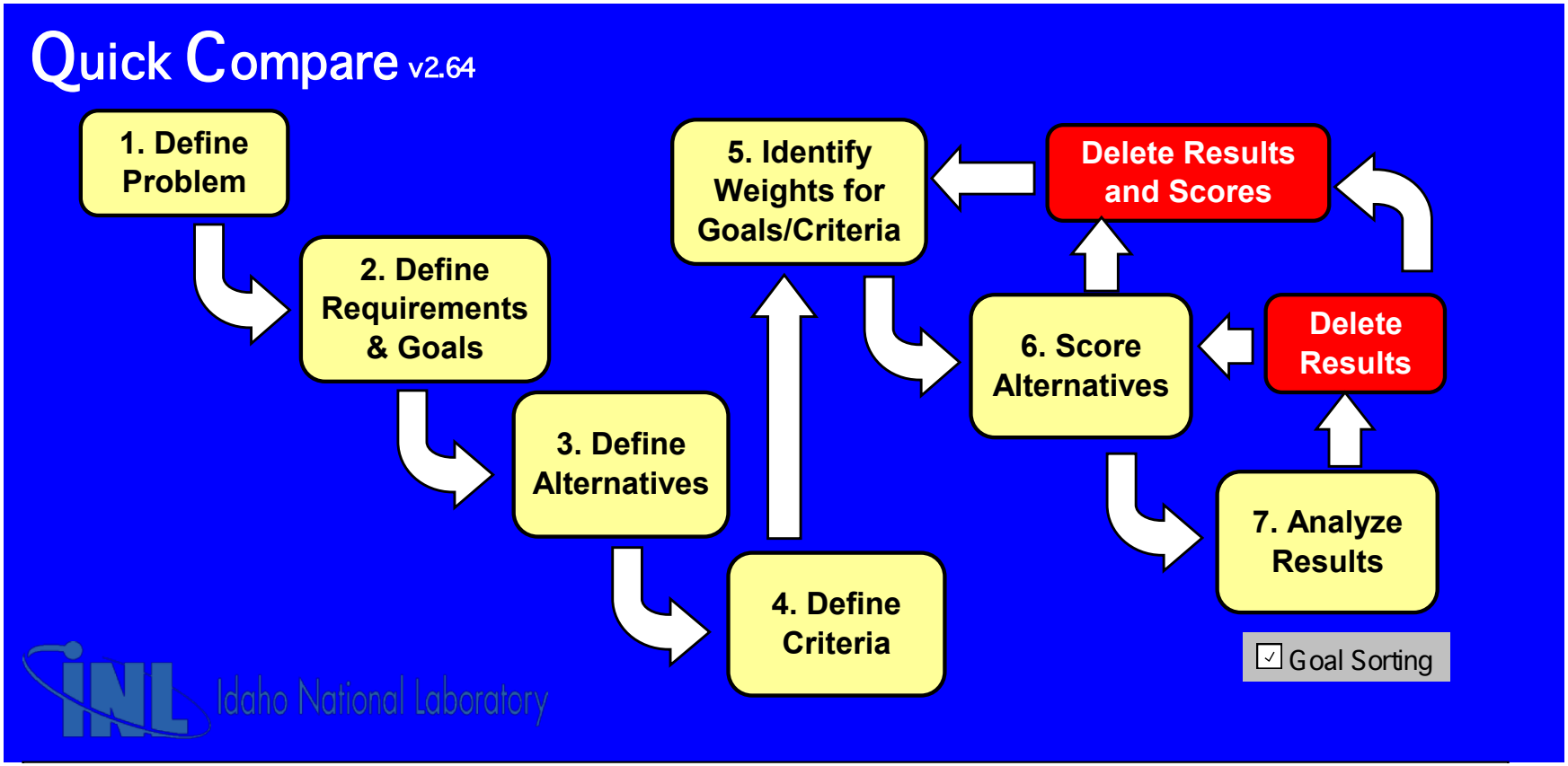
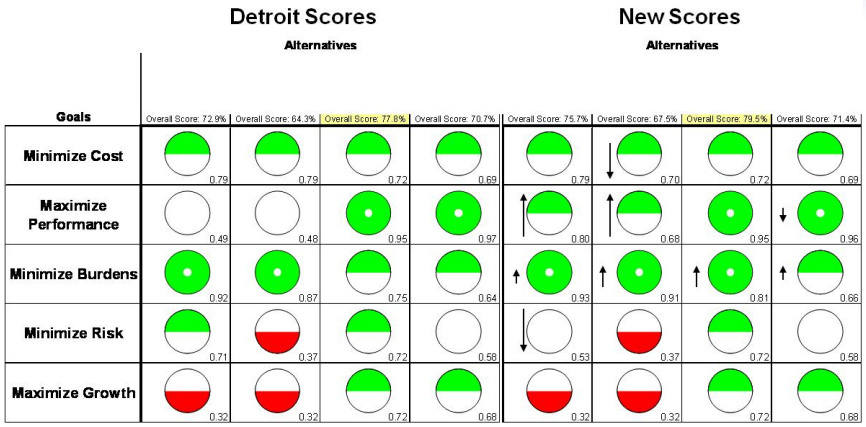
Customers Can Make Uninformed Decisions

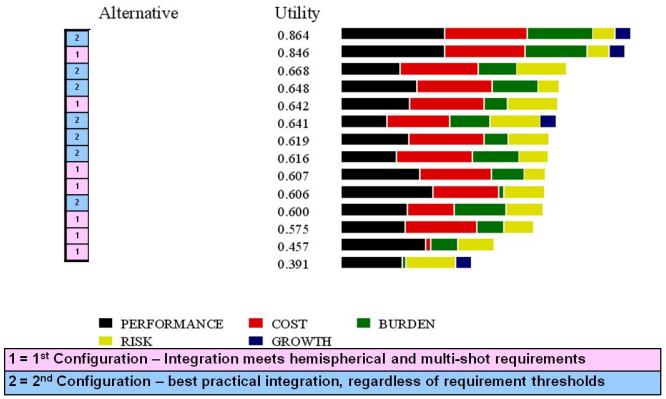
- No methodology to make an informed decision
- Poor mission analysis and problem definition
- Biased participants drive a biased analysis
- Alternatives analysis became an exercise in defending the customer's preferred (upfront) solution

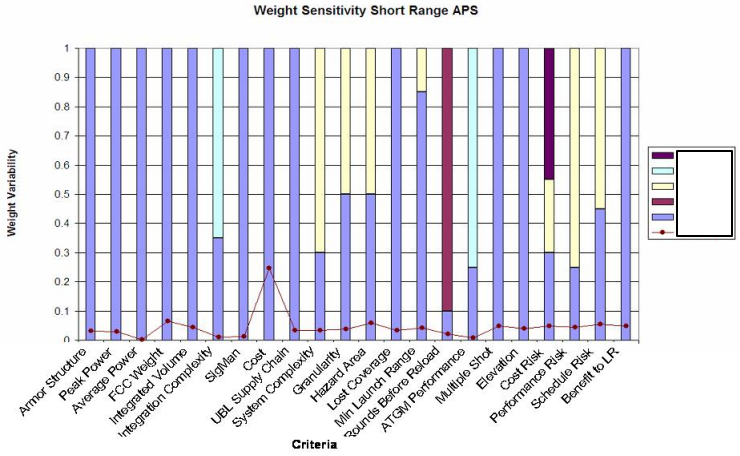
The Genesis of SE Tool Development

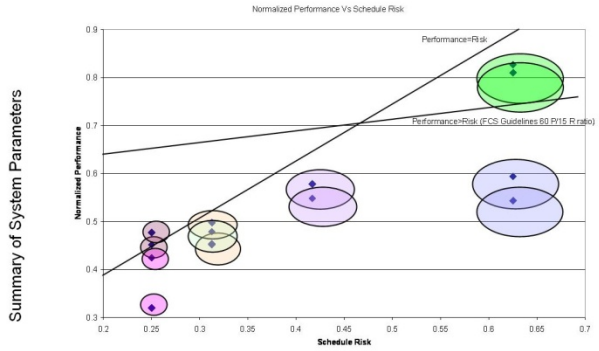


Quick Compare Example Charts









Tool, methodology, and reports continue to improve even after 17 years

Seeing the Big Picture - Not

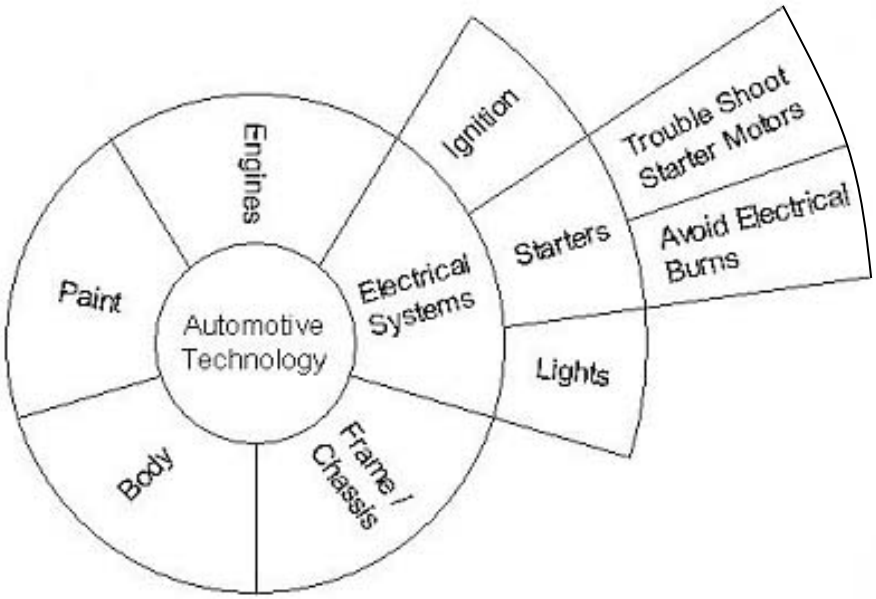
- Mission analysis ends up being “shelfware”
- Poor collaboration and planning of project activities
- Project personnel unable to see their place and how they fit into the project whole
- Functional requirements not well identified
- Deliverables not linked back to the requirements

Zoned Analysis as a Systems Engineering Tool

- Adapted by Larry Zirker as a way to capture and analyze all aspects of the project
- Reflects the “Big Picture” of the project on one sheet of paper
- Conveys information and understanding of project interfaces and dependencies
- Facilitates gap analysis - top down/bottom up
- Links/validates deliverables to the project
- Provides data for subsequent SE tools

Academic Example

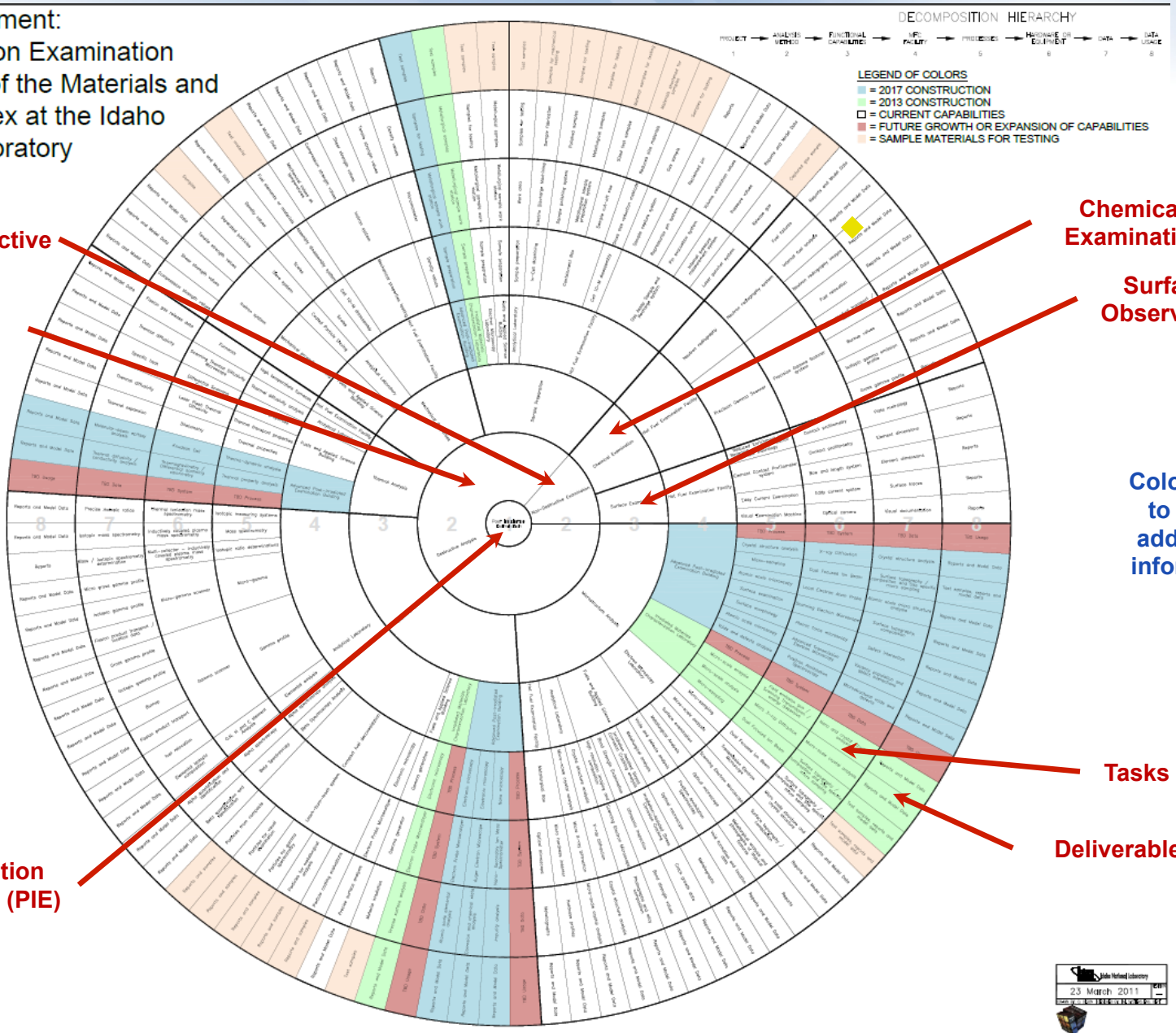
- Automotive Technology (as a discipline) is at the center
- Decomposes into major aspects (fields of study)—electrical systems, engines, body, frame/chassis, and paint
- Decomposes into parts (units in a course)—starters, ignition, lights
- Decomposes into lesson plans—Trouble Shoot Starter Motors and Avoid Electrical Burns



Idaho National Laboratory

Initial Assessment: Post-Irradiation Examination Capabilities of the Materials and Fuels Complex at the Idaho National Laboratory

3/21/2011 DRAFT



Non-Destructive

Destructive

Post-Irradiation Examination (PIE)

Chemical Examination

Surface Observation

Color Code to show additional information

Tasks

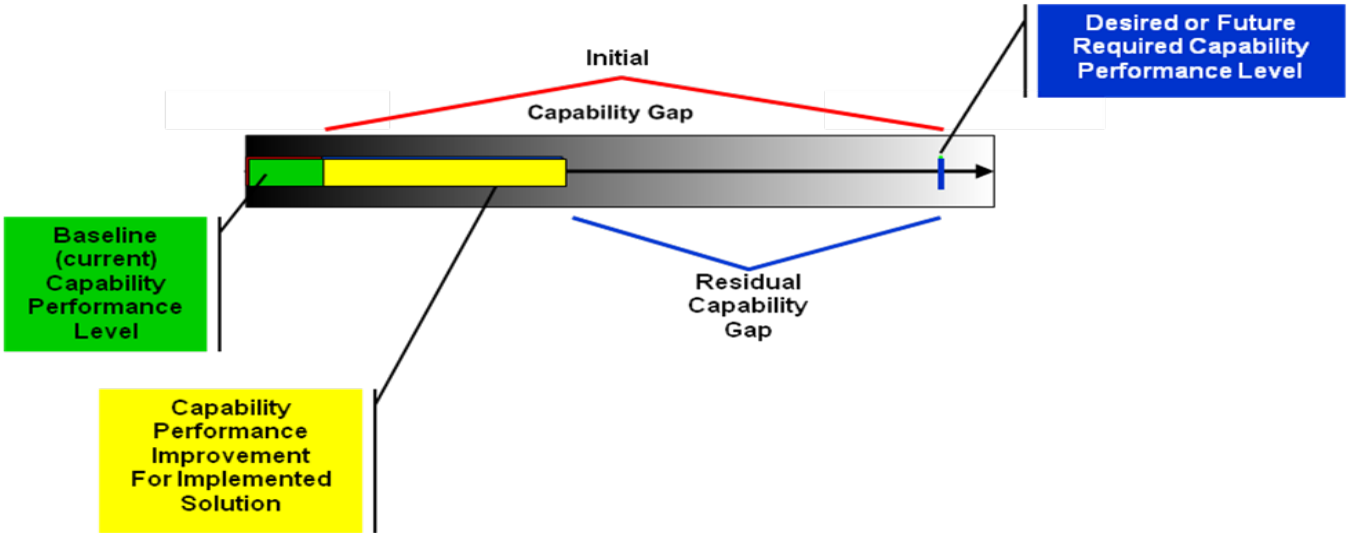
Deliverables

Tool Development Continues to Evolve

- Leveraging tool development - each improvement is a relatively minor cost to the particular customer who needed changes
- Tools today are very different from even a few years ago and are a representation of the underlying SE process
- The tool is still just a tool without an SE knowledgeable about the process and how to properly use the tool
  - A fool with a tool is still a fool

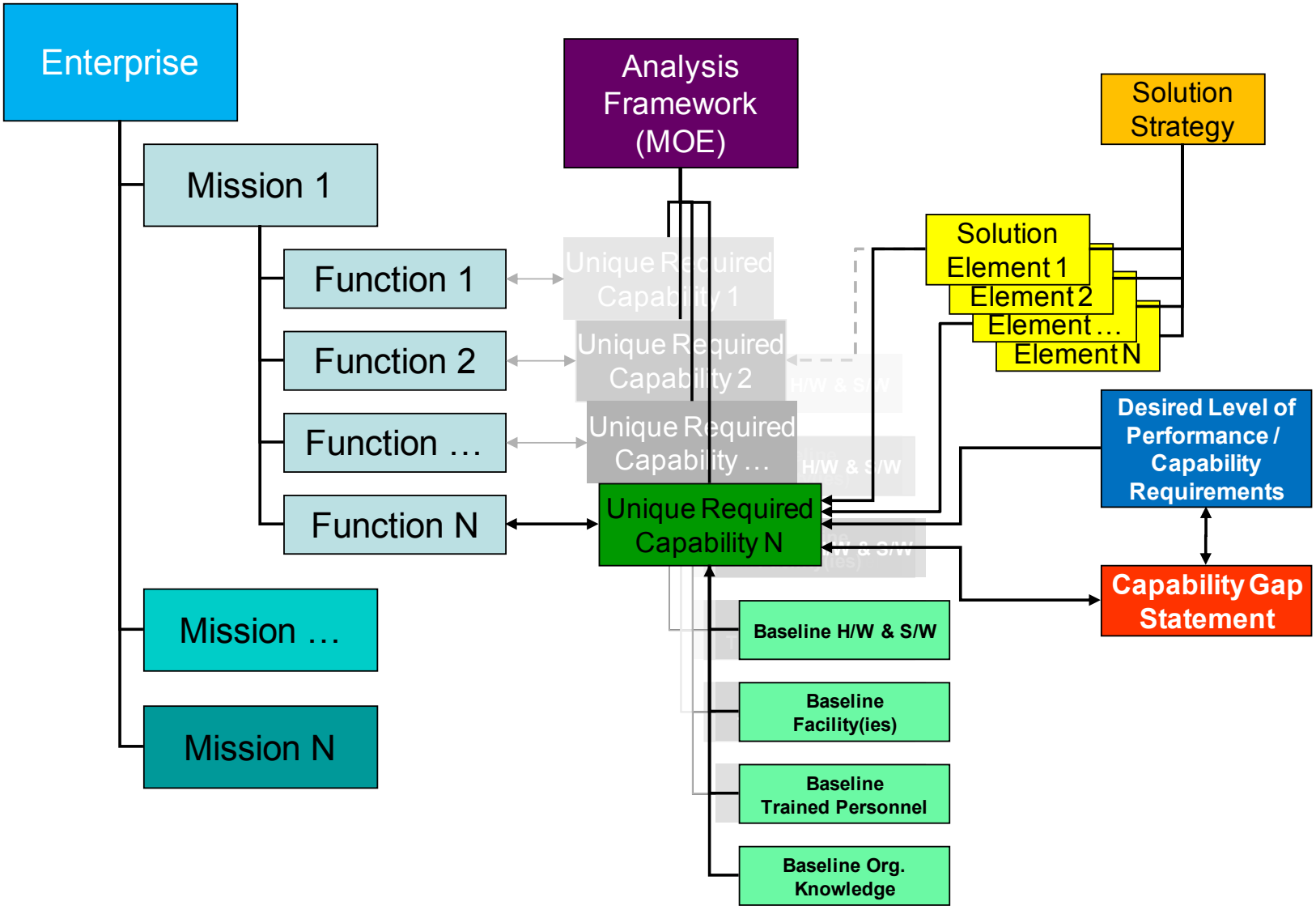
Another Customer's Challenge

- Ability to identify and measure capability gaps
  - In order to more effectively adapt to changing conditions
  - Improve performance toward completing the mission



- What's needed:
  - Analysis framework in the context of a mission
    - Organizing and representing the challenge/problem
    - Common language

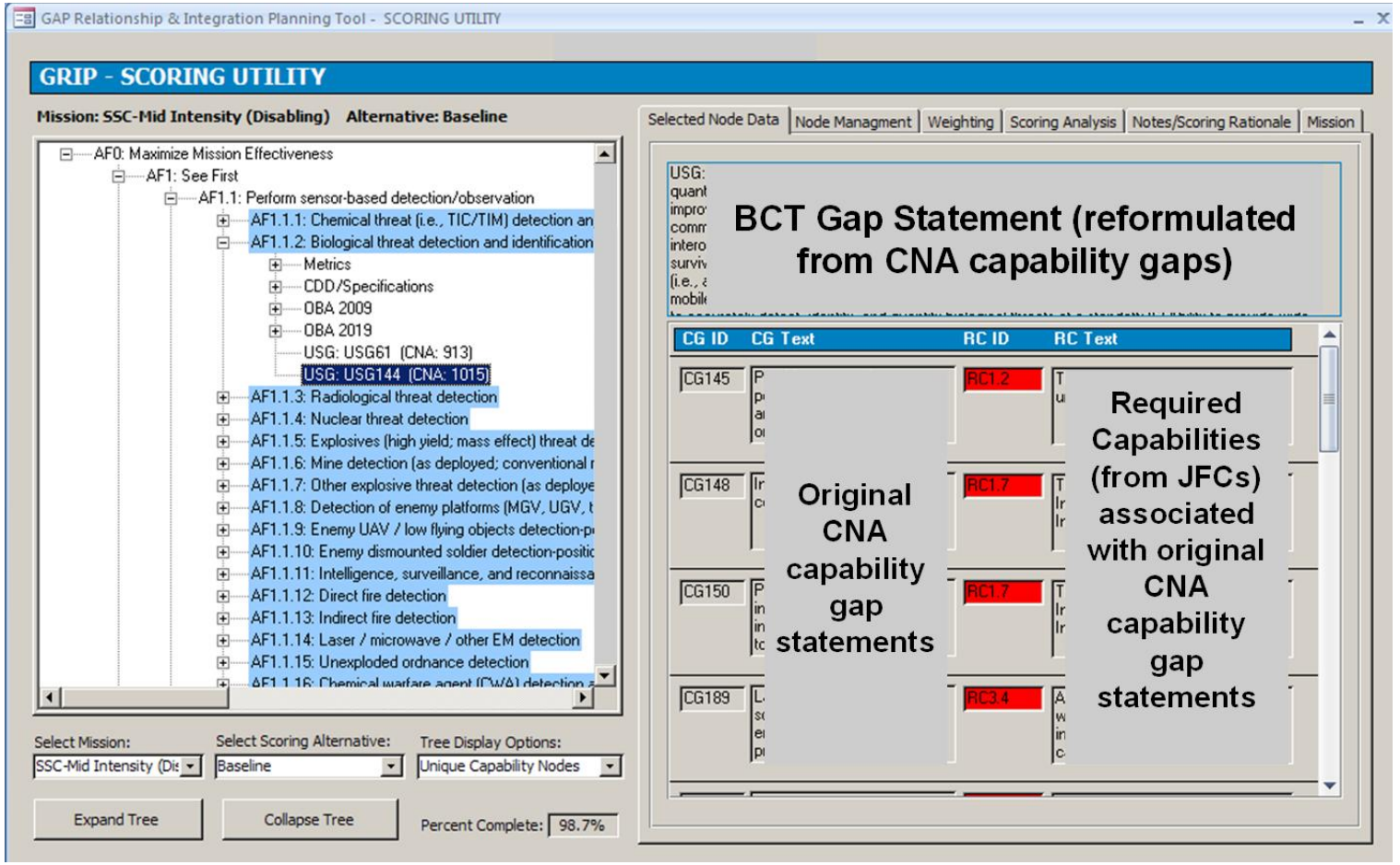
Notional Context for Enterprise Capability Gap Assessment



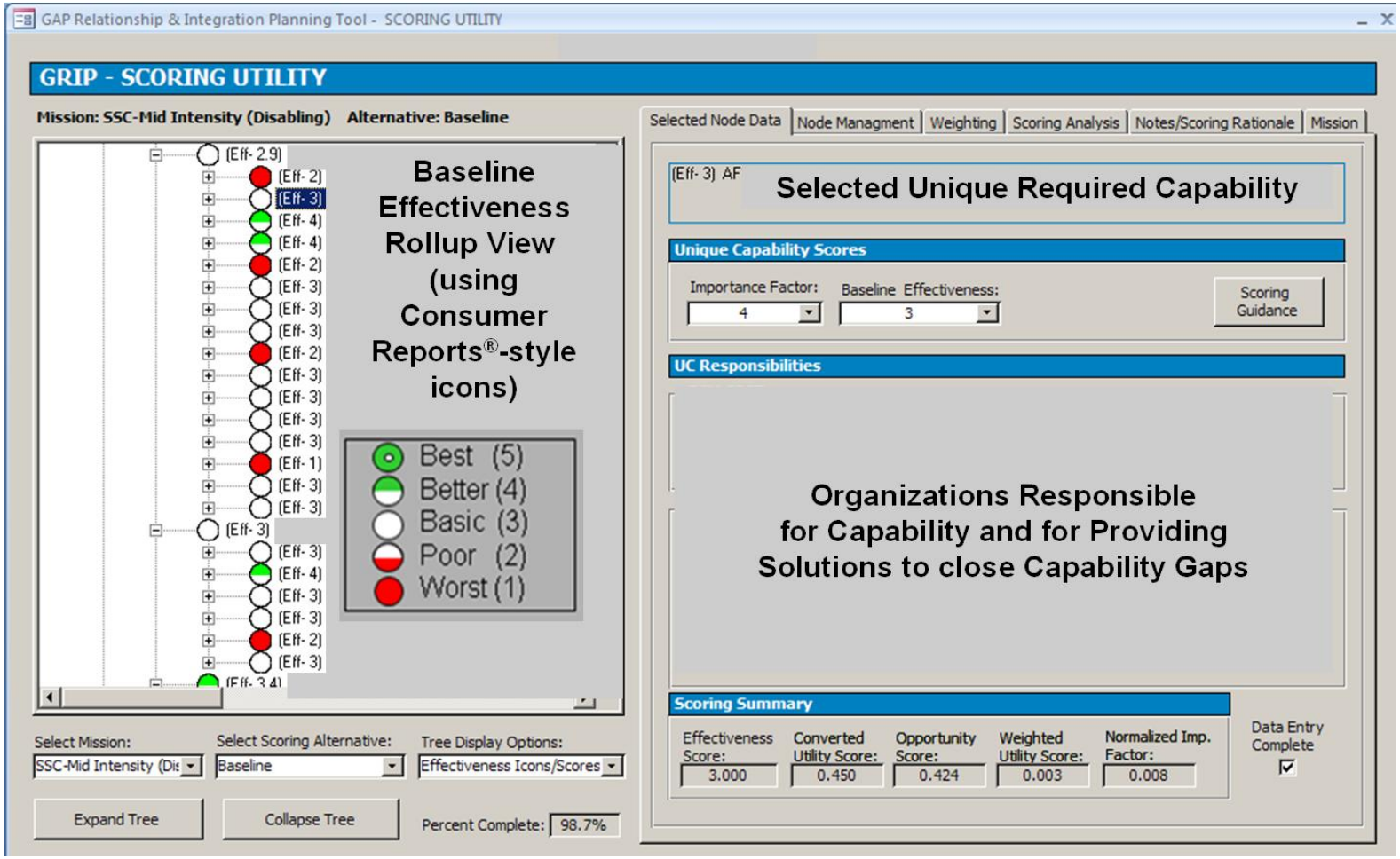
Gap Relationship and Integrated Planning (GRIP)

- This capability assessment and prioritization approach can be applied to almost any enterprise
- Provides the ability to:
  - Identify and measure capability gaps in the context of a mission
  - Evaluate and prioritize solutions
  - Produce analysis results to support a deliberate path forward
- GRIP
  - Cross-correlates and helps to integrate formerly disparate data
  - Enables aggressive and productive workshops
  - Contains the algorithms necessary to apply utility theory
  - Produces reports that underpin the enterprise's investment decisions
- Programmed in Visual Basic for Applications (VBA) which provides a graphical user interface for working with the Microsoft Access® database

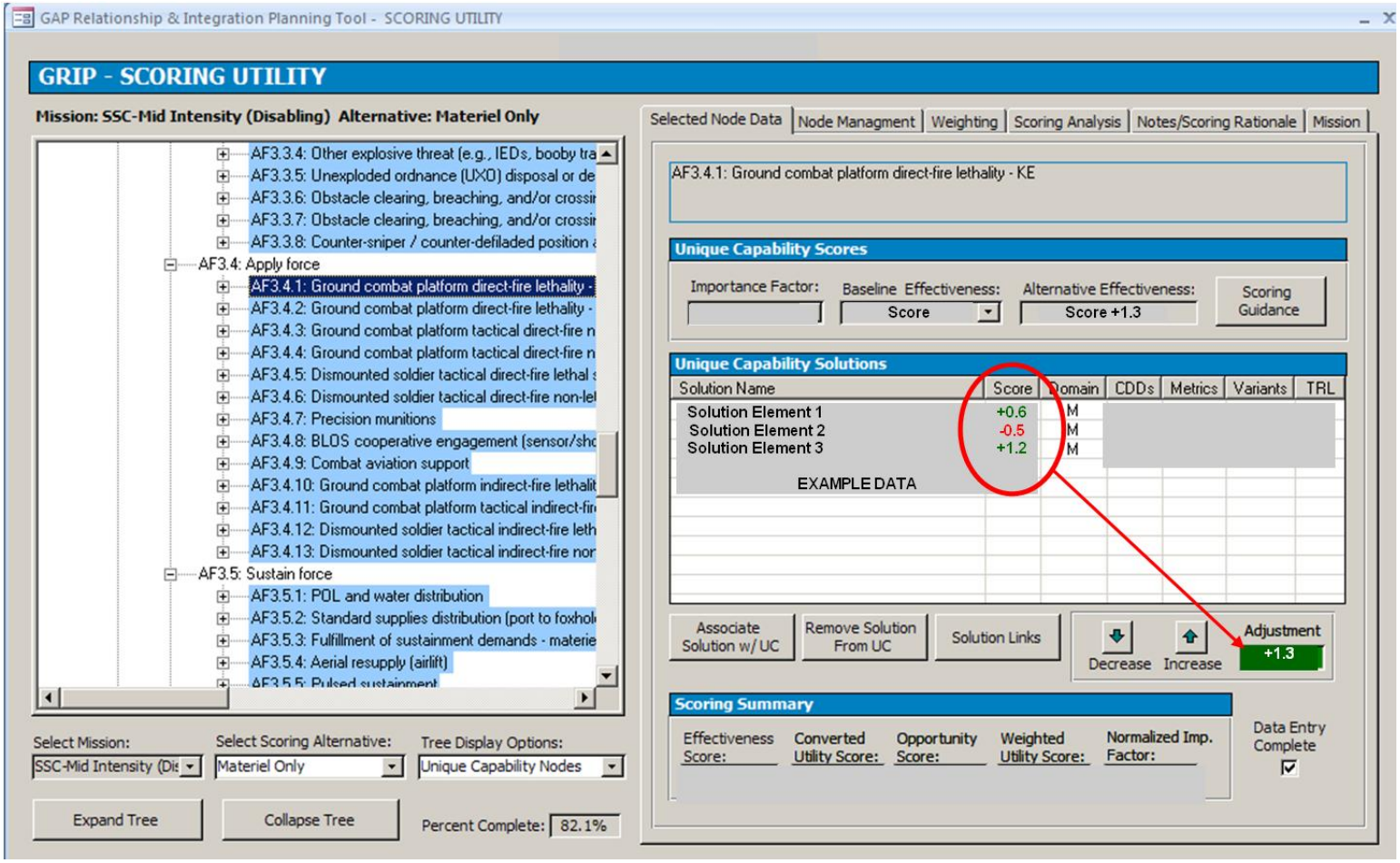
Gap Statement Association and Traceability in GRIP



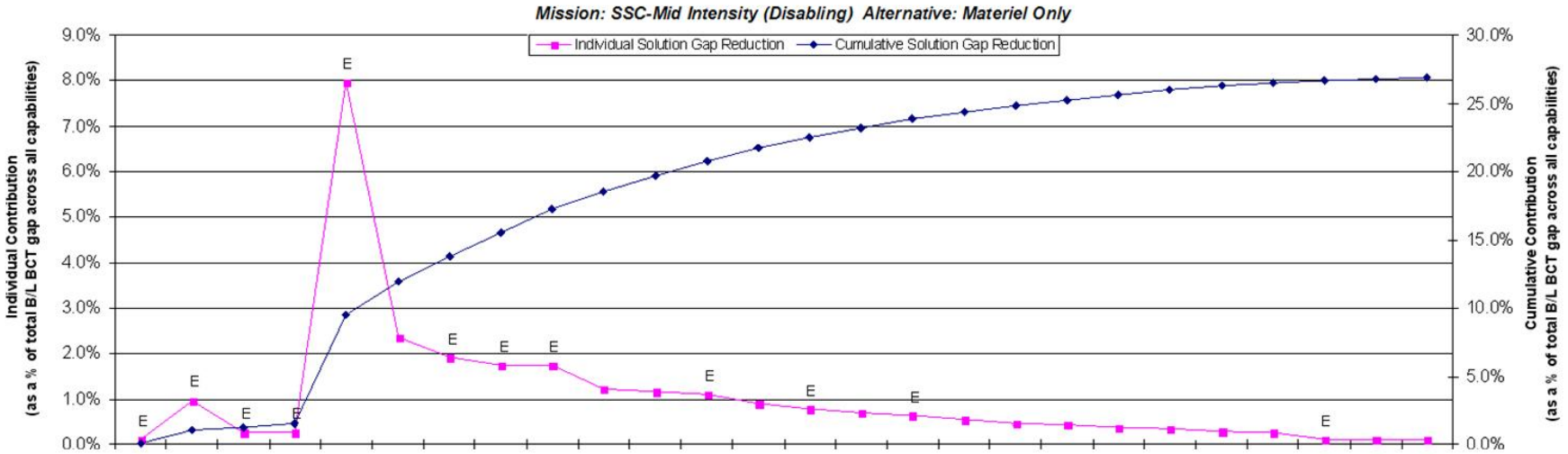
Baseline Results with Rollup Icons



Solution Element Association and Scoring of Impact on Capability



Solution Ranking Accounting for Precedence Relationships



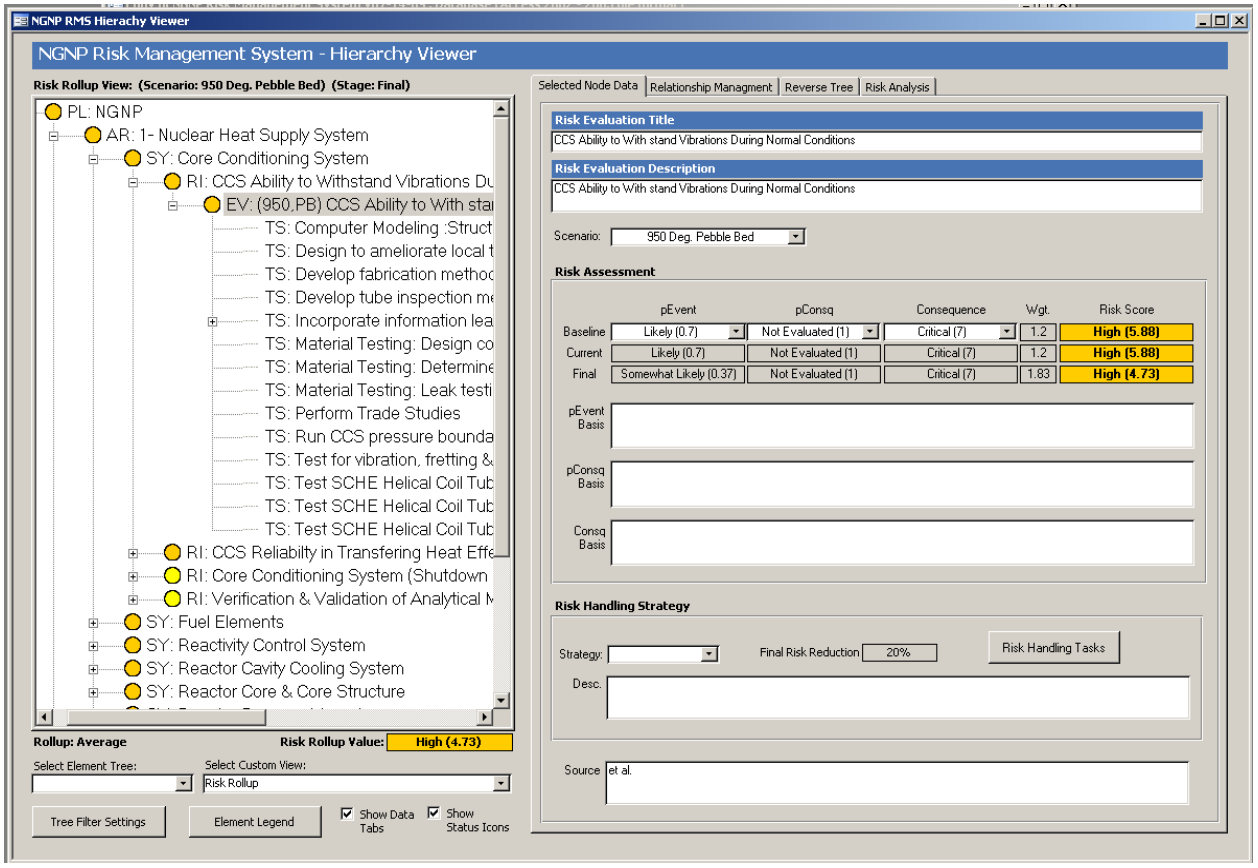
Solution Elements →

Note: "E" denotes that this solution is an enabler for another solution in the chart.

Risk Management Process – In General…

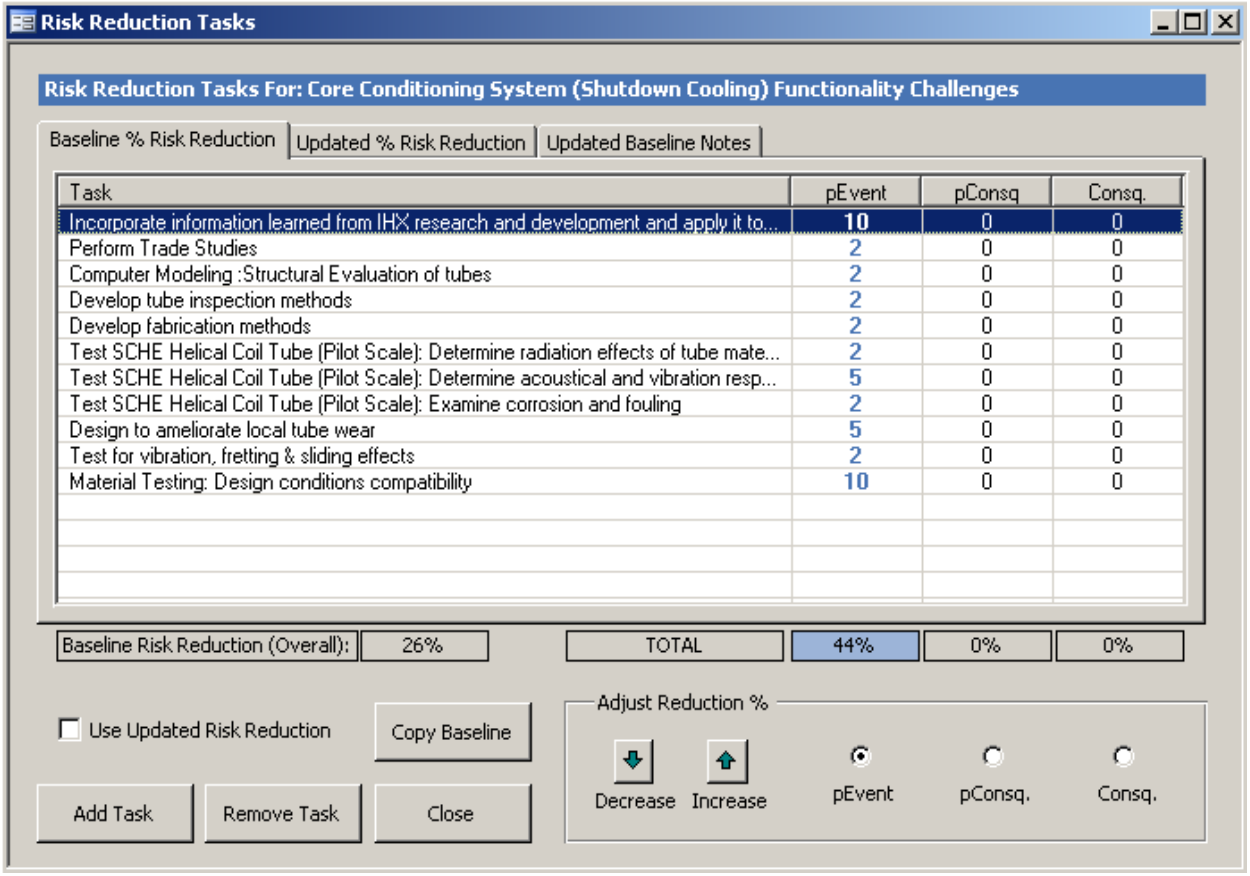
- **Risk Management Planning**
  - Includes initial project risk screening, process tailoring, and self-assessments
- **Risk Assessment**
  - Risk Identification – incl. ID of threats/opportunities, create risk log/register
  - Risk Analysis – incl. classification, qualitative/quantitative evaluation of Pe/Pc/C
  - Risk Level Assignment/Rating/Ranking – i.e., basis for treatment under RMP
- **Risk Handling/Treatment**
  - Response Strategy Selection
    - For threats – avoid, reduce/mitigate, transfer/spread, and accept
    - For opportunities – exploit, enhance, and share
  - Response Plan Development – including reassessment after assumed implementation of response plan actions (i.e., residual and secondary risks)
- **Risk Monitoring**
  - Includes tracking and control activities, periodic reassessment
- **Risk Reporting and Documentation**
  - Includes project risk report/profile (all active risks); response plan effectiveness (e.g., stop light chart, waterfalls), risk response action status, etc.
- **Risk Feedback & Continuous Improvement**

Risk Management System (RMS) Hierarchy Viewer



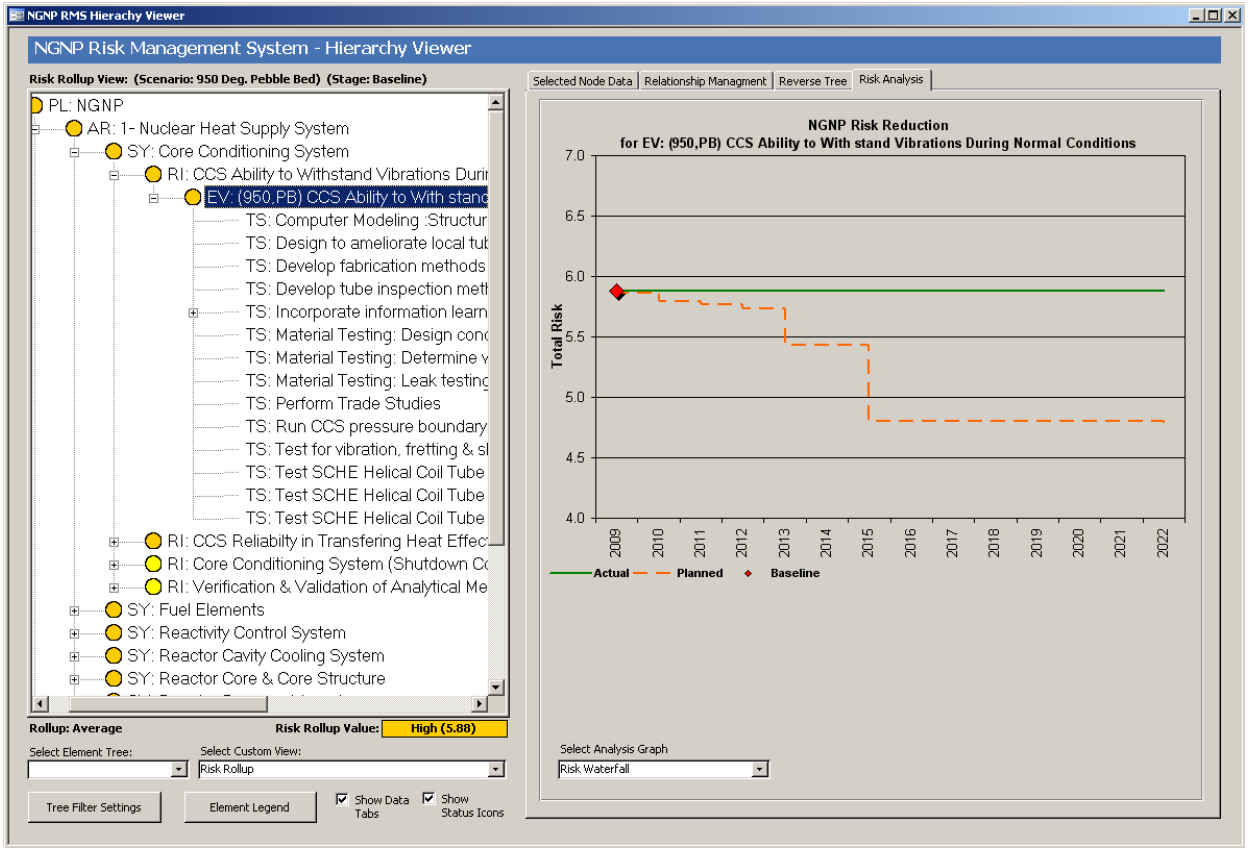
- Provides a rollup /drilldown analysis capability that summarizes quantitative risk scores at various levels of granularity
- Risk scores can be displayed for either the baseline, current status or the final projected risk

RMS - Risk Reduction Tasks



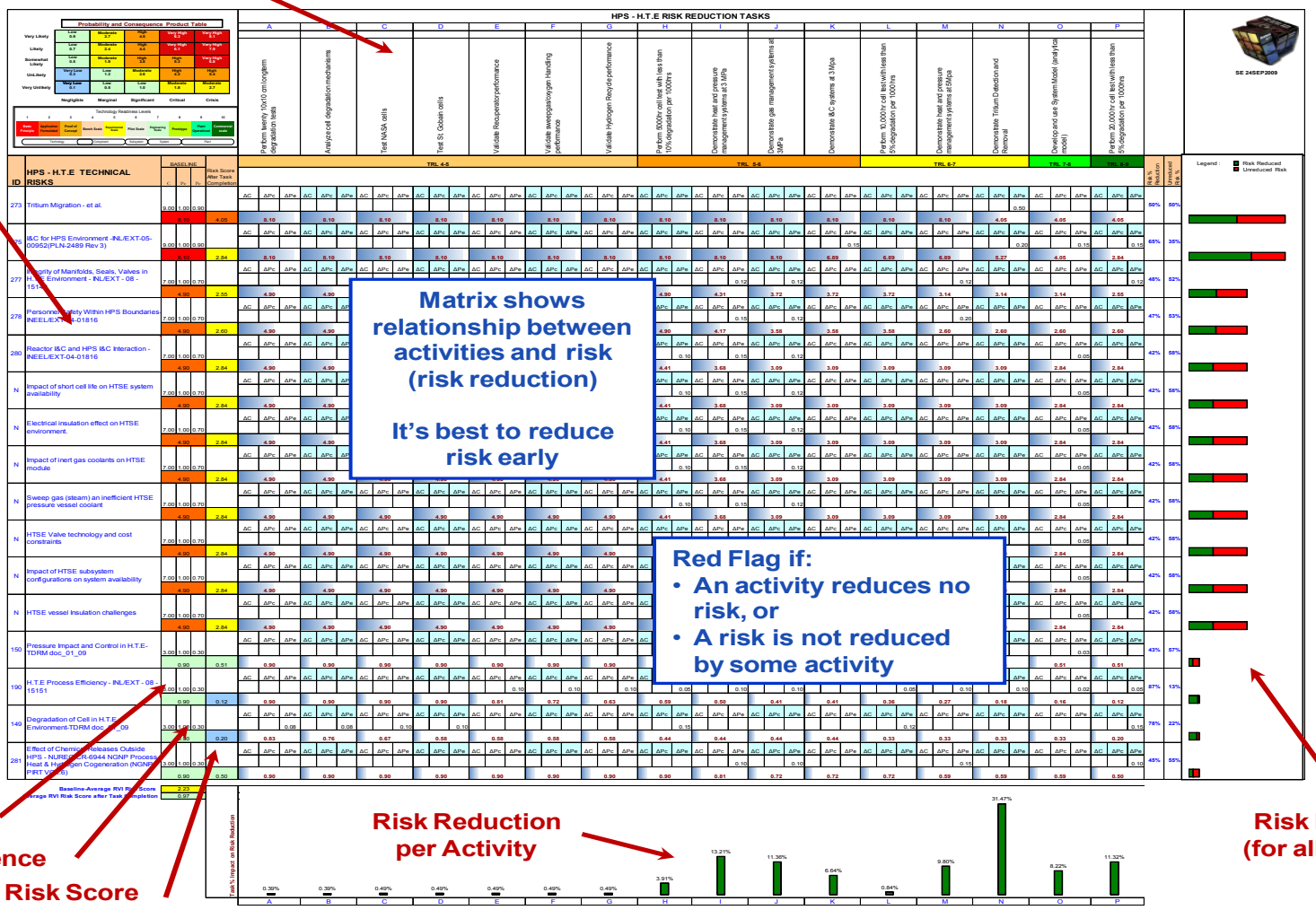
- Provides the capability to outline and status a risk handling strategy for each identified risk
- Risk reduction tasks are assigned to each risk item and the magnitude of risk reduction estimated for each associated task can be specified

RMS - Risk Waterfall



- Displays the actual /current risk reduction versus the planned risk reduction over time
- Capability makes it possible to rank order tasks by the magnitude of risk reduction provided for the entire project

Risk Reduction



DRAFT

Revision:	11
Date:	12/12/08
Changed by:	Layne Pincock

Intermediate Heat Exchanger Technology Development Roadmap

FY 2008 | FY 2009 | FY 2010 | FY 2011 | FY 2012 | FY 2013 | FY 2014 | FY 2015 | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 | FY 2022

- Complete NGNP Conceptual Design (FY 2011)
- Complete NGNP Preliminary Design (FY 2014)
- Submit COLA for Selected Design (FY 2014)
- CTF Construction Complete (FY 2015)
- Complete NGNP Final Design (FY 2017)
- NRC issues COL (FY 2018)

Candidate Materials

- 230
- 800H
- 617
- Hastelloy X
- Ceramics

Decision Discriminators

Properties: -Creep Fatigue -Embrittlement -Thermal Expansion -Thermal Fatigue -Crack Resistance -Oxidation Resistance -Carburization Resistance -Thermal Conductivity -Max Operating Temperature	Adequate Data for Prediction Effects: Effects, Environmental, Thermal, Radiation
Maturity of Material Data	Performance in Impure He
R&D Status	Performance: -Steady State -Depressurized -Conduction -Cool Down
Service Experience	Models/tests to Predict Max Life Reduction at Weld Site
ASME Code Qualification	Fusion of Large Sections
Cobalt Scaling	Diffusion Bonding / Joining of Thin Sheets
Fabricability	Can be put into use by 2021?
Licensing Risks	Cost
Availability	

Material Down Selection

- IHX A: 617
- IHX B: 800H

Principal Risks Mitigated by R&D

- Fouling effects on IHX
- Absence of IHX qualification plan
- IHX design and materials stress issues
- IHX creep and fatigue
- IHX alloy thickness

- Material qualification/codification
- Establish reference specifications & procure mat'ls for testing
- Determine thermal, physical & mechanical properties
- Determine performance of weldments and discontinuities
- Assess effects of grain size & section thickness
- Determine the effects of cyclic loading on creep and fatigue
- Determine flaw assessment and leak before break
- Extrapolation of creep data to 60 years for 800H
- Develop joining procedures
- Evaluate effects of thermal aging & environmental exposure
- Obtain codification of Inconel 617
- Constitutive modeling and analysis
- Provide experimentally based constitutive models that are the foundation of the inelastic design analyses required by Subsection NH of Section III of the ASME Boiler and Pressure Vessel Code
- Validate analytical model predictions
- Assist in the development of a guideline for inelastic analysis and life prediction

Candidate Designs

- Shell & Tube
- Printed Circuit
- Plate & Fin
- Helical Tube
- Involute
- Capillary Tube
- Plate Stamped

Decision Discriminators

Localized Stress/ Strain	Can be put into use by 2021?
Localized Erosion	Ease of Codification: Manufacturability to section III
Localized Corrosion	Ease of Licensing: Performance under off-normal conditions
Transient Condition Acceptability	Repairability
Receipt Inspectability	Availability
Inservice Inspectability	Design Margin
Tritium Migration Allowance	Dust Susceptibility(fouling)
Compactness: MW/m^3	Replacement Frequency
Heat Transfer Rate (performance)	Pressure Drop
Costs: Equipment & Operating costs	Integration: -Integration with vessels & piping -Compatibility with multi-stage/module designs
Material Thickness	

Design Down Selection

Note: Can implement multiple designs (for different process loops)

- Helical Tube
- Plate Stamped
- Printed Circuit

- Establish simplified design procedures
- Satisfactory testing of IHX candidate designs at experimental scale
- Develop thermal/fluid, stress/strain, and performance models
- Establish criteria for structural integrity of IHX
- Develop joining procedures
- Evaluate effects of thermal aging & environmental exposure
- Determine corrosion allowances
- Fabricate Experimental Scale heat exchanger(s)
- Test and evaluate Experimental Scale of IHX design(s) in relevant environment
- Design Pilot Scale IHX
- Fabricate Pilot Scale heat exchanger(s)
- Test and evaluate Pilot Scale of heat exchanger design(s) in relevant environment
- NRC Licensing
- Obtain necessary ASME code approvals
- Design Engineering Scale IHX
- Fabricate Engineering Scale heat exchanger(s)
- Test and evaluate Engineering Scale of IHX design(s) in integrated relevant environment
- Develop manufacturing processes for selected design
- Satisfactory testing of 1.2MWt IHX
- Demonstrate in-service inspectability for inelastic design method

Material, Design, Fluid Down Selection

- Helical Tube
- Printed Circuit

Consider:
-Material, design, fluid compatibility
-Required Delivery Temp
-Distance
-User Requirements
-Operating Conditions
-Transient performance
-Bonding
-Thin section performance

- Full Scale IHX operated successfully
- Develop final design for NGNP prototype IHX
- Fabricate NGNP heat exchanger(s)
- Test and qualify full scale NGNP prototype heat exchanger design(s) in integrated operational environment (non-rad ops)

Secondary Fluid Candidates

- He
- N_2/He
- Molten Salts
- Steam

Decision Discriminators

Infiltration to Primary in Accident Scenario: Consider accident scenarios and ease of recovery	Availability of Fluid
Purification Capability: Consider ability to separate Tritium from 2nd Fluid	Inspectability (RAMI)
Cost: Consider mitigation requirements for certain fluids	Piping/Valving Complexity

Secondary Fluid Down Selection

- He

- TRL3 (Current TRL)
- TRL4 — Performance Criteria: Bench Scale
- TRL5 — Performance Criteria: Experimental Scale — Temp: 950°C; Pressure: 9MPa; Cyclic Testing: TBD
- TRL6 — Performance Criteria: Pilot Scale — Temp: 950°C; Pressure: 9MPa; Temp Δ: >250°C; Pressure Δ: <600kPa; Mass Flow: 5 kg/s; Op Time: 500 hrs; Cyclic Testing: TBD
- TRL7 — Performance Criteria: Engineering Scale — Temp: 950°C; Pressure: 9MPa; Temp Δ: >300°C; Pressure Δ: <500kPa; Mass Flow: 10 kg/s; Op Time: 5,000 hrs; Cyclic Testing: TBD
- TRL8 — Performance Criteria: Full Scale — Temp: 950°C; Pressure: 9MPa; Temp Δ: >400°C; Pressure Δ: <200kPa; Mass Flow: 10 kg/s; Op Time: >5,000 hrs; Cyclic Testing: TBD

Key:
- Design Tasks
- Licensing/Codification
- Tasks to advance TRL & reduce risk
- Performance Tests

Technology Readiness Levels

1	2	3	4	5	6	7	8	9	10
Basic Principles Observed	Application Formulated	Proof of Concept	Bench Scale Testing	Component Demonstrated at Experimental Scale	Subsystem Demonstrated at Pilot Scale	System Demonstrated at Engineering Scale	Integrated Prototype Tested and Qualified	Plant Operational	Commercial scale – Multiple Units
Technology			Component		Subsystem		System		Plant

Challenges Drive Additional Tool Development

- ***Strategic Milestones and Relationships Tracking (SMART)*** manages the complex relationships of program artifacts, evidence, reviews, tasks, status, and relationships to other project elements
- ***Performance Rollup Tool (PRT)*** captures and evaluates a number of variables affecting a system's performance across multiple scenarios
- ***INL Portfolio Integration and Prioritization (iPIP)*** provides an ability to easily capture and analyze the interrelationship of organizational elements (called capabilities) that play a role in the overall strategy and tactics of the enterprise

Observations and Lessons Learned

- Don't reinvent the wheel – use COTS whenever appropriate
- Multiple perspectives are essential in a complex environment
- Accurate data relationships must be defined – a cross correlation of data
- Informative customized views and customer-specific reports are critical
- Rapid prototyping is preferred and provided:
  - Immediate customer involvement/engagement which allowed for direct feedback on methodology approaches and specifications
  - Less chance of miscommunication as complicated data and analysis were more instantly visualized
  - More timely delivery of the final product
- Managing complexity in a synergistic manner will lead us to solving more meaningful and challenging problems
- Tool development is an enabler to achieving the SE organization's mission and moving closer to our vision
- The INL SE organization can continue to leverage all the work we do today to create more value for our customers tomorrow

Idaho National Laboratory

Back Up

Risk Management System (RMS)

- Provides the capability to:
  - Establish the risk baseline
  - Document and analyze the risk reduction plan
  - Track the current risk reduction status
  - Organize risks by a reference configuration
  - Inform decision making such as prioritizing risk reduction activities by those that best help the program reduce the largest critical uncertainties
  - Provides a testing basis for the uncertainty reduction/risk reduction by defining the expected outcome of the risk reduction that can be compared to the actual results