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NASA Cost Analysis Workshop

CSPER-C Model and
Weapons Major Modernization Estimates

Charlie Loelius, Division Manager, NA-MB-92
Bill Todd, Senior Cost Analyst, NA-MB-92

NNSA's Office of Programming, Analysis, and Evaluation (PA&E)

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- 2011: Established to focus on cost estimating on early-stage weapons acquisitions
  - Subsequently broadened to other analytical disciplines
- 2019: NNSA centralized cost estimating into two offices and established PA&E to lead:
  - Programmatic cost estimation
  - Execution of all Analysis of Alternatives (AoAs)
  - Programming process of annual Planning, Programming, Budgeting, and Evaluation (PPBE)
- PA&E provides decision support throughout acquisition and budgeting
  - Promotes data-driven decisions and managing portfolio risk
  - Promotes credibility in cost estimating and long-term planning through objective, unbiased, and technically sound analyses and tools.
- PA&E leads:
  - Agency's programmatic cost community which includes 8 labs and production sites
  - Continuous improvement and innovation in analytical models, tools, and processes
  - Hosting annual Cost Estimating Community of Practice (CECOP) symposium
  - Active collaboration with external cost communities (NASA, DoD's CCRG, ICEAA, AACE)

Decision Support · PPBE · Cost Assessment · Strategic Communication · NA-14

CEAG
COST ESTIMATING ANALYSIS GROUP

6th Annual Cost Estimating Community of Practice (CECOP) Symposium
August 2 – 3, 2022 in the Washington, DC Metro Area
CECOP@nnsa.doe.gov

National Nuclear Security Administration

Protect the Nation by maintaining **a safe, secure, and effective** nuclear weapons stockpile

Reduce global **nuclear threats**

Provides the U.S. Navy with militarily effective **nuclear propulsion**

The NNSA is an agency within the U.S. Department of Energy responsible for enhancing national security through the military application of nuclear science

NNSA Labs, Plants, and Sites

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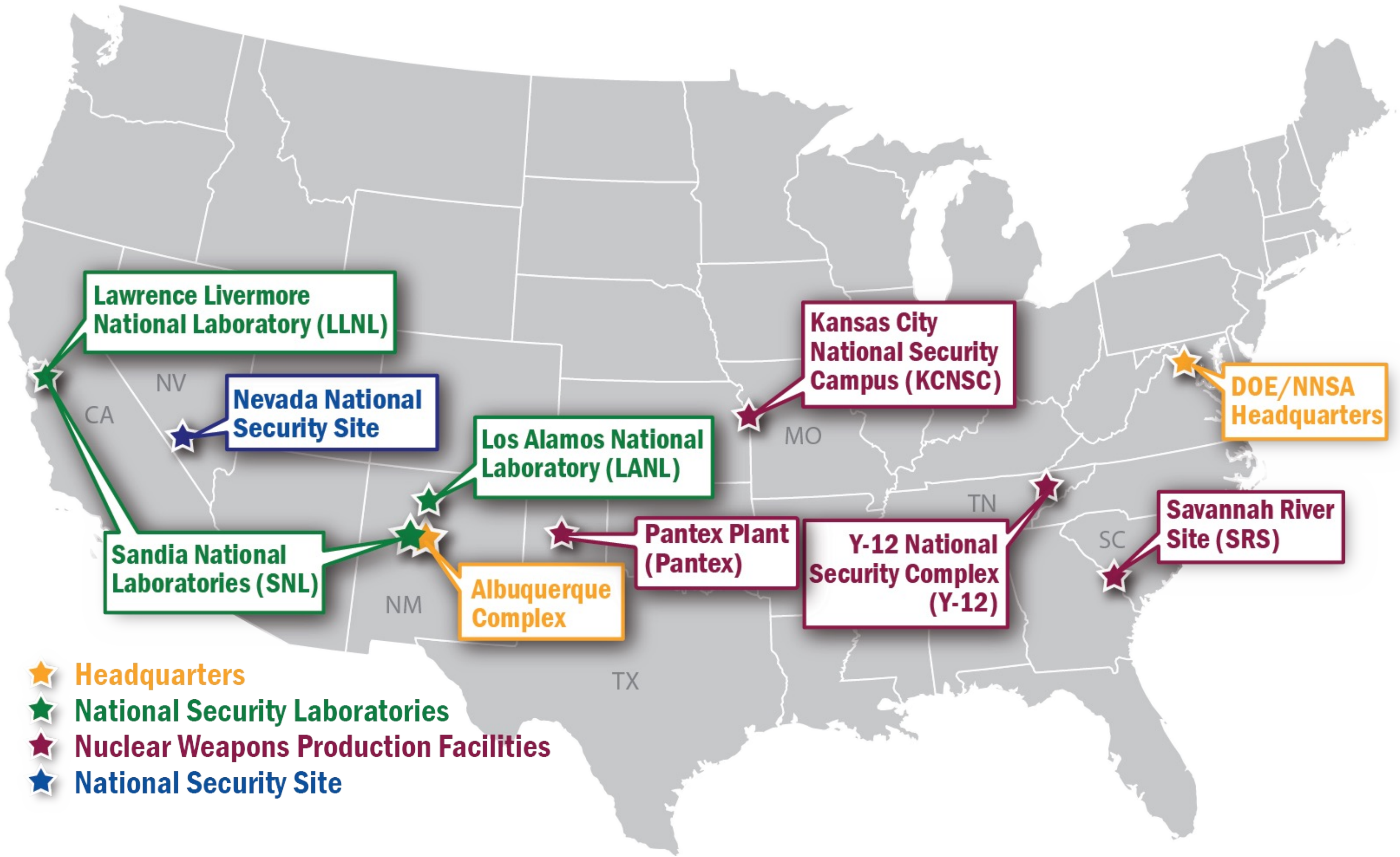

NNSA Infrastructure

- The majority of facilities are **over 40 years old**, nearly 30% date to the Manhattan project era, and nearly two-thirds are in less than adequate condition
  - This age and condition creates a challenge to safely operate and meet mission demands
- Projects include:
  - Cutting-edge research laboratories
  - Safe and secure weapon assembly plants
  - Nuclear and non-nuclear component manufacturing
  - Office facilities

NNSA Capital Projects range from office buildings to the National Ignition Facility (Pictured Above)

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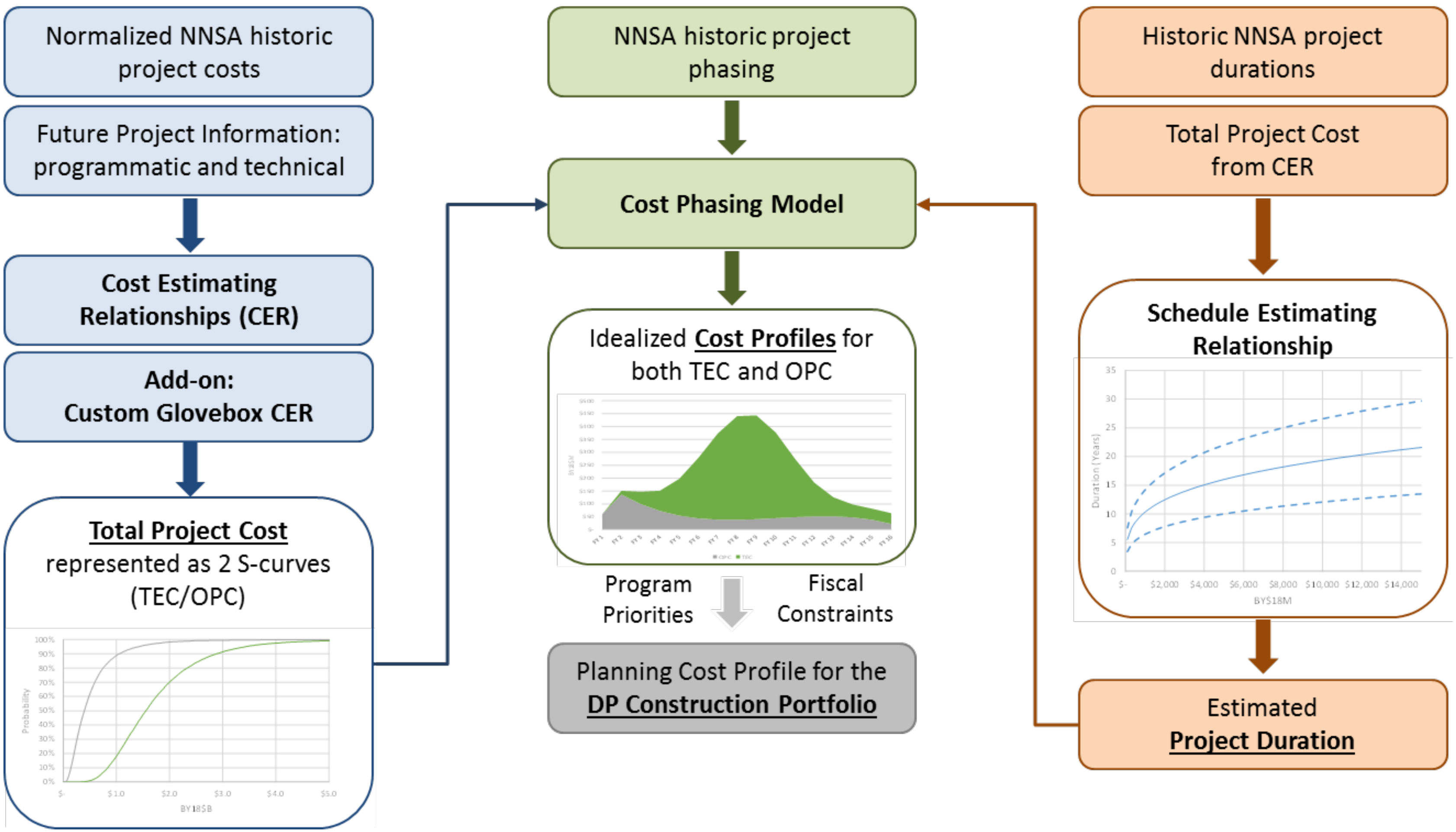
Cost Model Overview



PA&E CSPER-C model produces parametric cost, schedule, and phasing estimates ***based on historic NNSA data***

Cost Estimating Relationship

Example Multiplicative Functional Form Cost Estimating Relationship (CER)

Independent Variables

$$\text{TEC in BY\$/GSF} = a\,GSF^{b}\,Hazcat^{c}\,EquipComp^{d}$$

$$\text{OPC as \% TEC} = d\,GSF^{e}\,Hazcat^{f}\,EquipComp^{g}$$

Technical Cost Drivers

GSF – Gross Square Feet
Hazcat – Hazard Category Bin
*EquipComp – Equipment Complexity**

**Only for New Construction with or without Process Equipment*

- Total Estimated Cost (TEC) is calculated using the first equation
- Other Project Cost (OPC) is calculated from TEC as a percent using the next equation
- Total Project Cost (TPC) is calculated by summing TEC and OPC

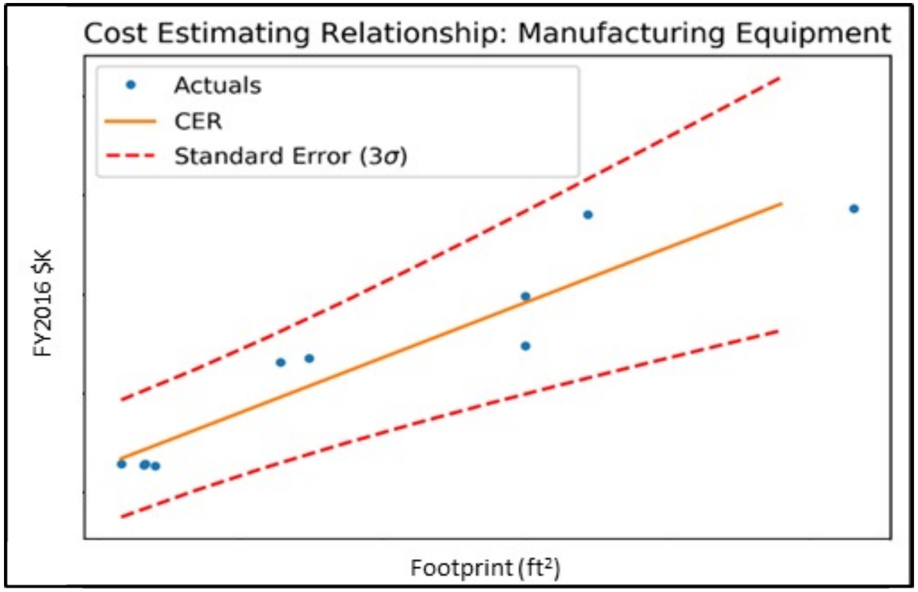
- Output estimate range driven by:
  - **Technical uncertainty** based on per project subject matter expert input (GSF range from 3 points – low, most likely, high)
  - Underlying **cost uncertainty** based on historic NNSA project actuals

Add On: Cost Estimating Relationship (CER) for Highly Complex Gloveboxes

- **Issue**: Cost model does not estimate complex custom gloveboxes due to lack of historic data
  - *However, custom gloveboxes are a known significant cost driver*

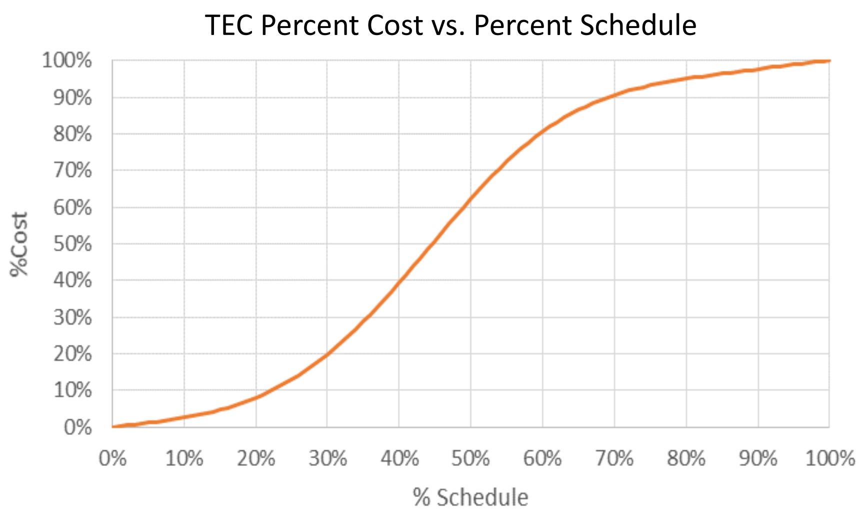
- **Approach:** Leverage glovebox cost model developed by office in prior analyses
  - SME provided technical parameters (quantity & footprint)
  - Applied to proposed projects that anticipate glovebox space

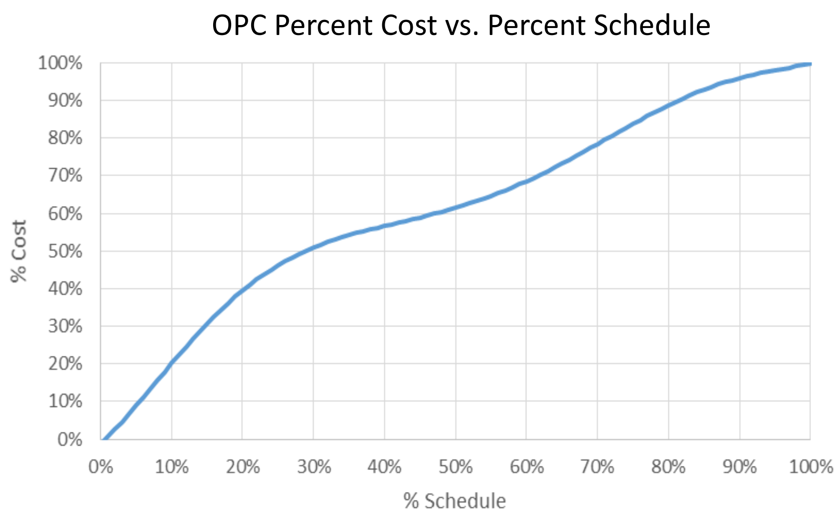
- **Result**:



Cost Phasing Model

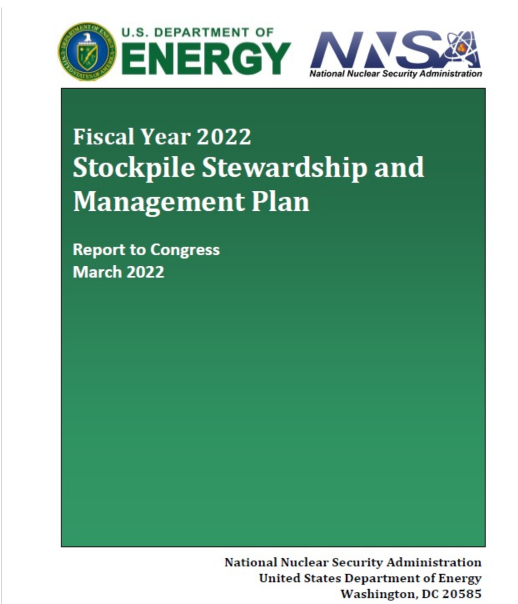
- The last step in producing the cost profile is to phase the estimated cost over the estimated schedule
- Two phasing estimating relationships are needed as TEC and OPC dollars cover different project scope and are budgeted separately
  - TEC costs follow a Weibull distribution, a common spending profile for construction projects
  - OPC funds follow a polynomial*





CSPER-C Conclusion

- NNSA develops early stage phased cost profiles using the CSPER-C model
  - Model entirely based on historic data
  - Inputs can be identified even pre-conceptual design
- Cost profiles are developed for individual projects *and* NNSA portfolios
  - Early-stage ROM cost/schedule range published in SSMP


U.S. DEPARTMENT OF ENERGY
National Nuclear Security Administration

Fiscal Year 2022
Stockpile Stewardship and Management Plan

Report to Congress
March 2022

National Nuclear Security Administration
United States Department of Energy
Washington, DC 20585

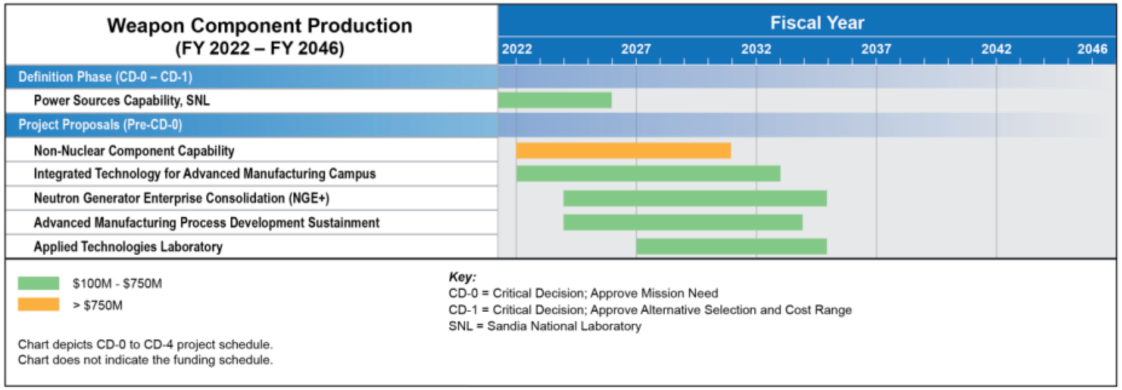


Table 8–15. Weapons Activities programmatic construction estimated costs, FY 2022 – FY 2046

Then-Year Dollars, in Billions	*Low* [a]	*High* [b]
Weapons Activities capital acquisition estimated costs	63.7	73.7

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Weapon Systems Major Modernizations

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What Do We Estimate? Life Extension Programs (LEP), Major Alts, and Major Modernizations

Examples of U.S. nuclear weapons and delivery systems

- Completed Systems:
  - W76-1 and W76-2
- Systems in Production:
  - B61-12 and W88 Alt370
- Systems in Development:
  - W80-4, W87-1 and W93
- Future Programs:
  - FSWs, B61 follow-on

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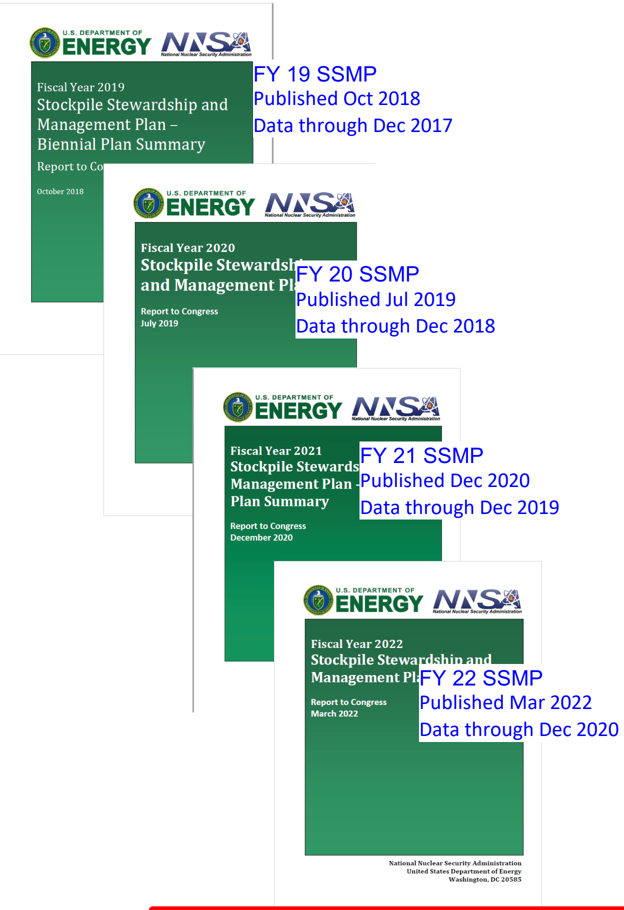
Product – The Annual SSMP

- NNSA Mission: to sustain a safe, secure, and effective nuclear arsenal…*without underground testing*

- Stockpile Stewardship and Management Plan (SSMP)
  - Mandated annual report to Congress, including costs for each nuclear warhead/bomb program

- SSMP is a **25-year Program of Record with Costs** for Defense Programs

- SSMP Cost Estimating process is a flexible tool that has also been **used to answer many 'WHAT-IF's' in short time periods**



FY 2023 SSMP
Currently in Revision/Concurrence
Data through Dec 2021

Estimate Methodology Summary

- **Two Separate Models**

Development (RDT&E)

- TOTAL development costs are **based on W76-1, B61-12 and W88 Alt370 cost actuals to date** adjusted using Subject Matter Expert (SME) developed WBS Complexity Factors
  - A High-Most Likely-Low Scope complexity range compared against a reference system's scope is produced for each WBS element by M&O and Program Office SMEs.
  - These Complexity Scores are rolled up to provide Complexity Factors, based against the B61-12 through the EMAC SCORE model.
- The TOTAL development cost is spread annually **based on the standard Rayleigh development profile**

Production (Procurement)

- Annual production costs are **based on a Learning Curve model** derived from the W76-1 actual production quantities and costs.

Schedule for FY 2023 SSMP, One Year of Activity

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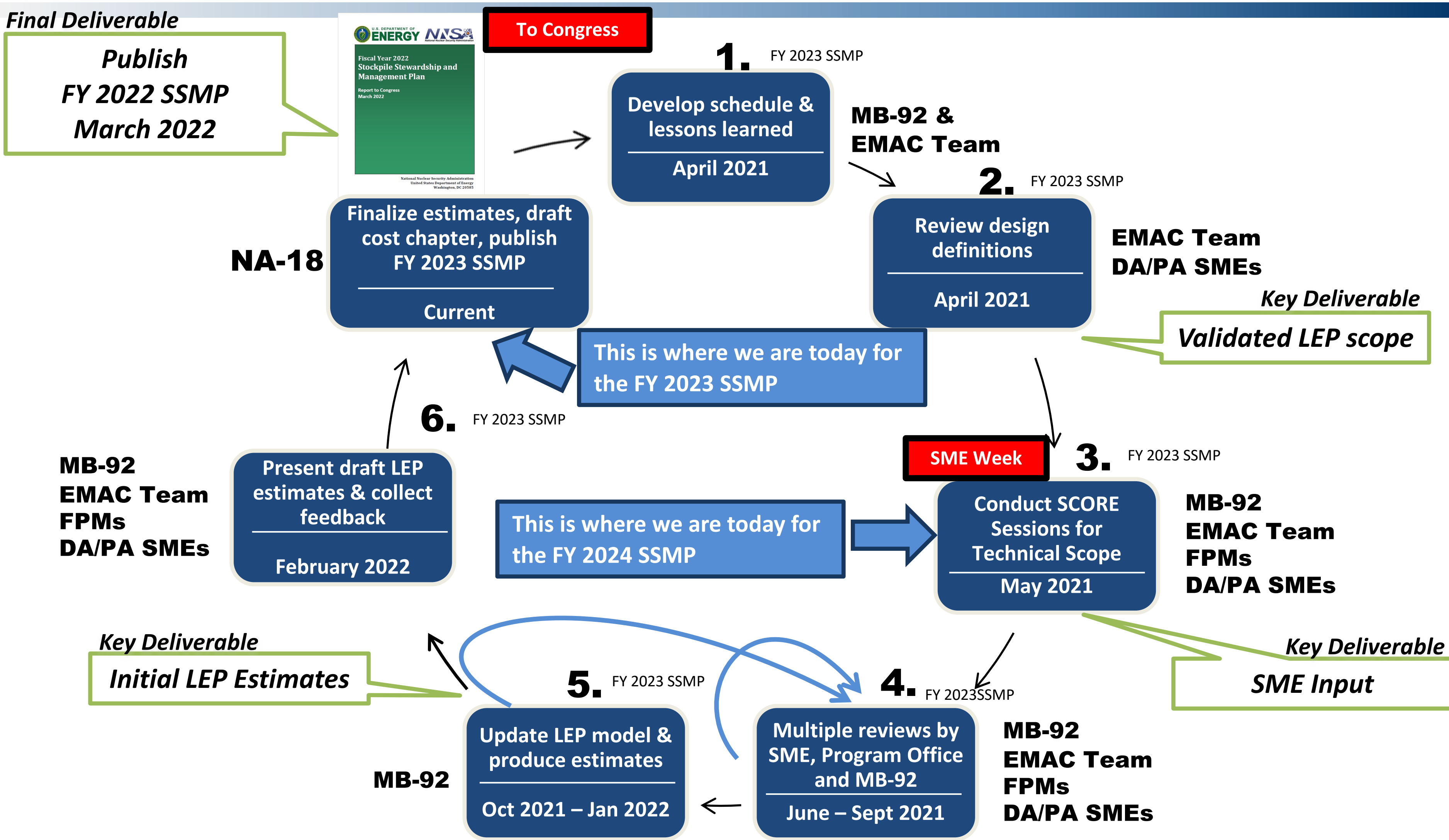


EMAC/SCORE Process Overview

Multiple rounds of review

Establish Design Definitions

The program office in coordination with the NWC and the design labs establish the design features, quantities and time frame, for all the options they would like to estimate

↓

Set Reference Systems Provide Complexity Estimates

The SMEs choose the most applicable reference system for a particular WBS element (W76-1, B61-12, W88 Alt 370, or less desirable W80-4 WDCR and SME input cost estimate). SME then estimates the most likely, high and low complexity of that WBS element compared to the chosen reference system

↓

Calculate Scores and Factors

The EMAC SCORE team uses the SCORE model to calculate Complexity Factors for each option against the B61-12

Additional information and answers on the EMAC/SCORE process can be provided by Andrea Dorado (ameller@sandia.gov) and Jonell Samberson (jnsmith@sandia.gov)

Total Development Cost Model

- Weapon System Development (RDT&E)
  - TOTAL development costs are based on analogies to W76-1, B61-12 & W88 Alt370 actual costs to date adjusted using SME derived complexity factors (CF) for each WBS element
  - System level CF calculated as the weighted average of WBS level CFs using B61-12 cost percentages for weightings
  - Individual Monte Carlo runs pull from triangular distributions of the WBS level CF.
    - High and low WBS level CF are expanded 30% due to SME estimations underestimating ranges, most likely and skew are kept the same[1]
    - All WBS element distributions are correlated at 0.3
    - The weighted sum is then used to calculate system level CF for each Monte Carlo run

RDT&E Cost = (B61-12 RDT&E Cost) x (System Level CF)

B61-12 RDT&E cost = $6,500 M (FY21$)

WBS Element	Name	Factor (mode)
1.1.1.X.1	Systems Engineering and Integration	1.07
1.1.1.X.2	Systems Test and Qualification	1.65
1.1.1.X.3	Systems Surveillance	0.90
1.1.1.X.4	Production Support	0.85
1.1.1.X.5	Nuclear Components	1.42
1.1.1.X.5.1	Primary	1.32
1.1.1.X.5.2	Secondary	1.78
1.1.1.X.5.3	Other Nuclear Explosive Package (NEP) Components	1.36
1.1.1.X.5.4	Gas Transfer System (GTS)	0.92
1.1.1.X.6	Non-Nuclear Components	0.57
1.1.1.X.6.1	Arming	0.05
1.1.1.X.6.2	Fuzing	0.11
1.1.1.X.6.3	Firing	1.72
1.1.1.X.6.4	Neutron Generator (NG)	1.18
1.1.1.X.6.5	Safety Components	1.69
1.1.1.X.6.6	Structural Components	0.51
1.1.1.X.6.7	Power Systems	0.02
1.1.1.X.6.8	Surety	0.45
1.1.1.X.6.9	Other Non-Nuclear Components	0.00
1.1.1.X.7	Systems Program Management	1.92
1.1.1.X.X	Sandia External Production	0.72

	System Level Factor	1.04

[1]See Joint Agency Cost Schedule Risk and Uncertainty Handbook, March 2014, Section 2.5

Methodology – The Development (RDT&E) Cost Profile

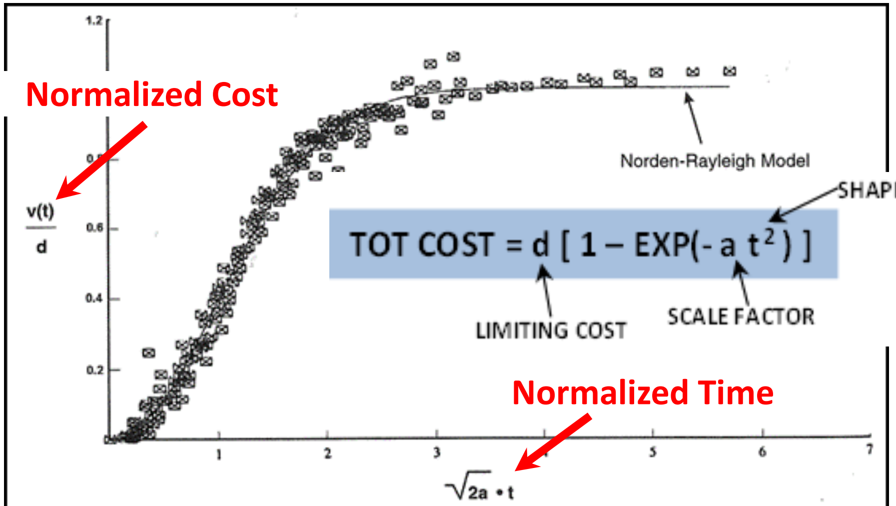
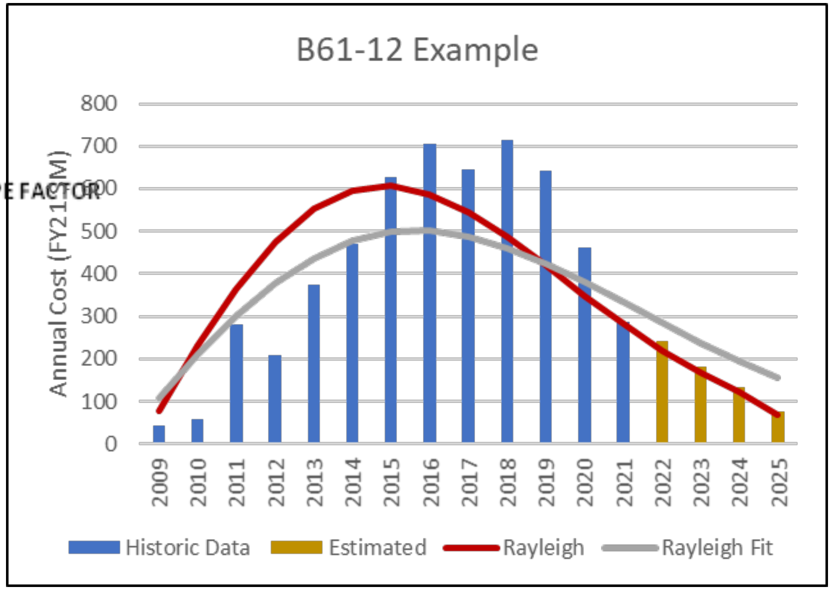


Figure 24. Cost Profiles of Development Programs and Norden-Rayleigh Model



Lee, David A. *The Cost Analyst's Companion.* LMI McLean, VA 1997

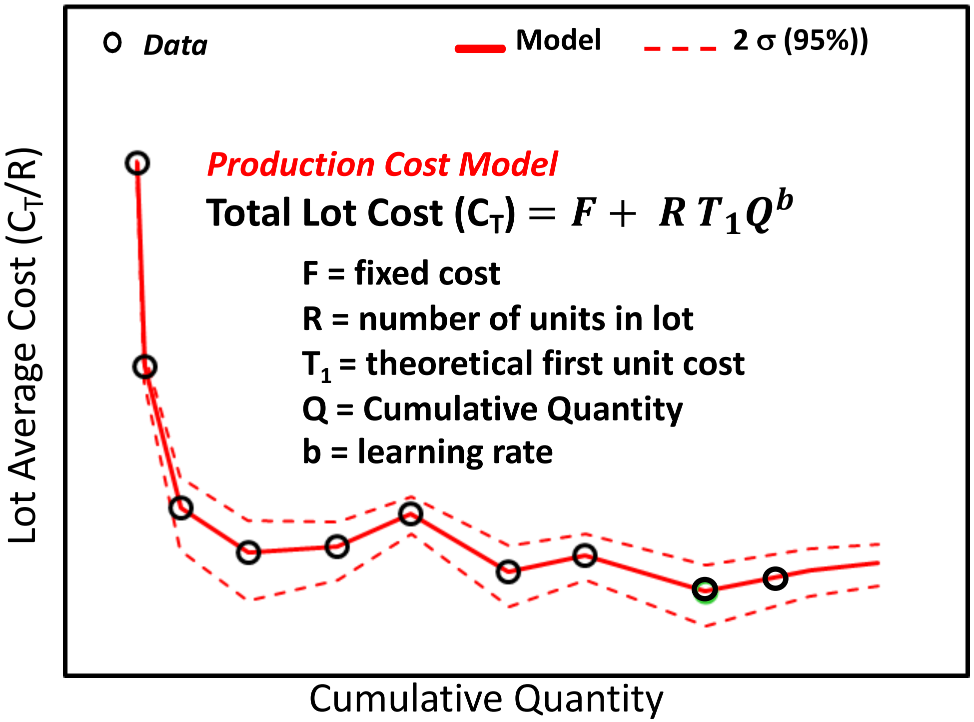
- The TOTAL Development Cost is spread using the well-known **Rayleigh distribution,** a subset of the Weibel distribution
- A Rayleigh distribution is often used to **determine or evaluate annual funding** for high complexity development projects
- The left chart shows the actual cost over time for several dozen real DOD development programs compared to a generic Rayleigh profile, the right chart shows the B61-12.

Methodology, Production Cost Profile

- Production costs are based on standard learning curve modeling methodology based on the W76-1 production profile

W76-1 LEP Production Costs and Quantities

* Chart depicts data that represents a similar trend, rather than actual W76-1 data



- Production cost & quantity are modeled on a fiscal year basis.
- Annual production costs are a function of quantity, RDT&E, decreasing costs with time (learning), and a fixed cost.
- Adjustment for production complexity is via (T_1 for W76-1) multiplied by the RDT&E complexity factor determined by SME's.
- Production quantities are based complete systems. Adjustment to production costs for early component production and life of program buys are included prior to FPU (Forward Funding).

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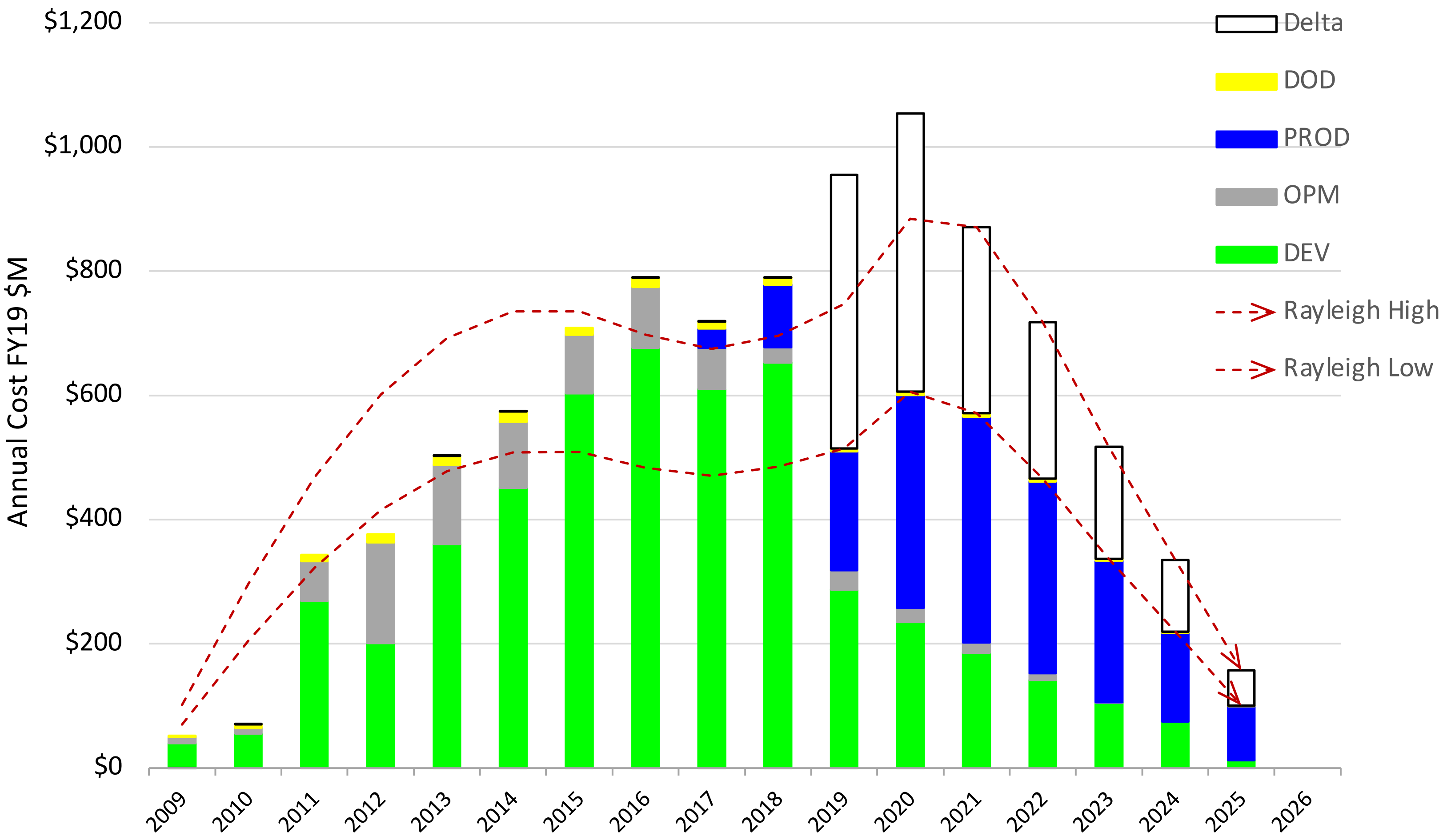
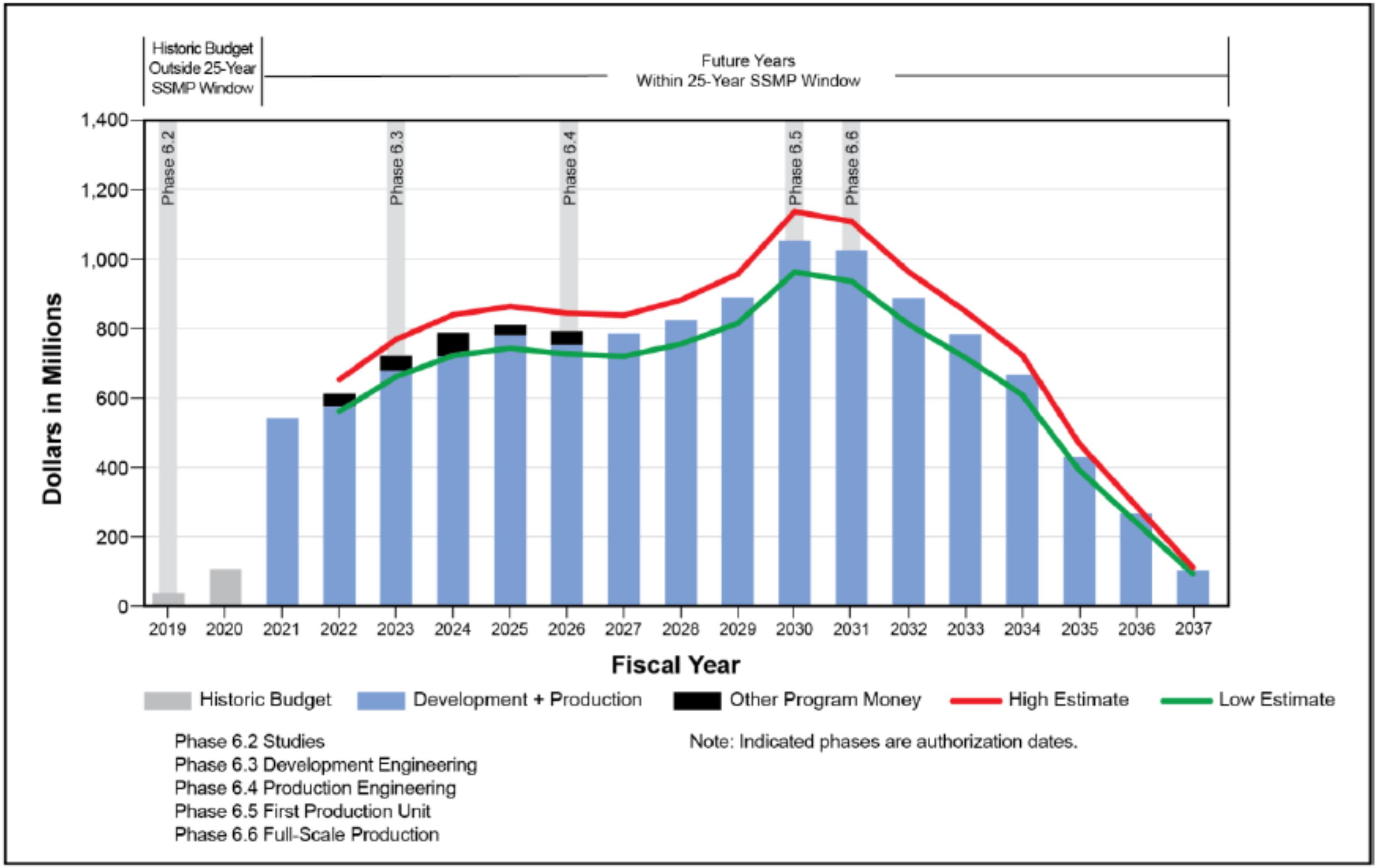
B61-12 LEP



SSMP Presentation – W87-1



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Questions?

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Backup

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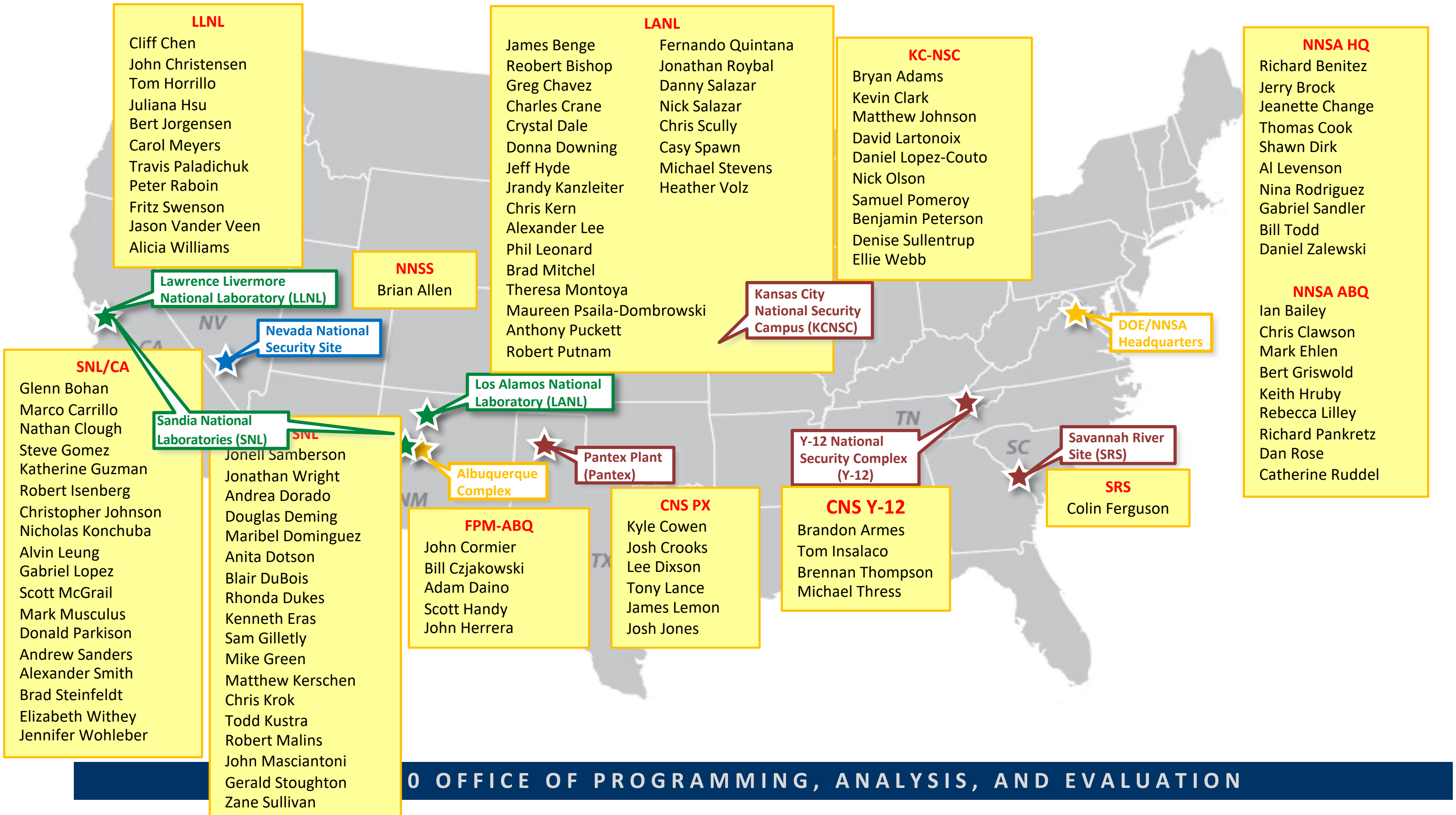
People, All of the Nuclear Security Enterprise

- Annual complexity/technical evaluation occurs during **SME week**
- Stakeholders from HQ, national labs, production plants, and our test site
- Over 100 participants, 2 weeks focused discussion and evaluation, held virtually



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SCORE Model detail

SCORE Input Session Artifacts: What Data Do We Need?

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Analysis Artifact Inputs

1. *WBS Code & Element Mapping*
2. *Reference Cost Data*
3. *Model Input Files*
4. *Design Definitions*
5. *Complexity Estimates*
6. *Assumptions*

WBS Code	Element Name
1.X.1	Systems Engineering and Integration
1.X.2	Systems Test and Qualification
1.X.3	Systems Production
1.X.4	Nuclear Components
1.X.4.1	Component A
1.X.4.2	Component B
1.X.5	Non-Nuclear Components
1.X.5.1	Widget 1

Details provided on subsequent slides

SE&I: Systems Engineering and Integration | T&Q Test and Qualification | PD: Process Development | Prod: Production

WBS Code	Element Name	Reference System	Phase	Design Choices					
				New Design			Reuse Design		
				Low	Mode	High	Low	Mode	High
1.X.5.1	Widget 1	System Alpha	6.2/2a	110	120	180	90	100	110
			6.3	110	120	180	90	100	110
			6.4	100	110	140	60	70	80
			6.5	100	110	140	60	70	80
			6.6	120	160	200	90	100	110

Element Name	Work Scope	Phase	New Design		
			Low	Mode	High
Widget 1	Design requires one additional type A electrical connection	6.3	Minimal challenges	Some challenges	Major challenges

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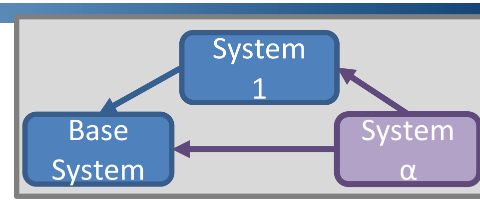
SCORE Model: Calculating Factors

Complexity Score# * **WBS Reference Cost** = **Factor**



WBS Code	Element Name	System α Reference System
1.X.1	Systems Engineering	Base System
1.X.2	Widget A	Base System
1.X.2	Widget B	System 1
1.X.3	Widget 1	N/A
1.X.3	Widget 2	Base System
1.X.4.1	Component A	System 1
1.X.4.1	Component B	System 1
1.X.4.2	Component 1	New Scope

WBS Code	Element Name	Phase	Base System Reference Cost	System α Complexity Estimate Mode	System 1 Complexity Estimate Mode
1.X.2	Widget A	6.2/A	35	120	-
		6.3	15	140	-
		6.4	10	50	-
		6.5	10	50	-
		6.6	*See Understanding Production Complexity Slide*		
1.X.2	Widget B	6.2/A	35	150	180
		6.3	15	140	200
		6.4	15	50	100
		6.5	20	60	110
		6.6	*See Understanding Production Complexity Slide*		
1.X.2 Total			155		

#Both System α and System 1 Complexity Estimates are divided by 100 to account for their reference comparison when calculating factors

$\{1.X.2\ \text{Factor}\} =$

$$\underbrace{1.2 * \frac{35}{155} + 1.4 * \frac{15}{155} + 0.5 * \frac{10}{155} + 0.5 * \frac{10}{155}}_{\text{Widget A}} + \underbrace{1.5 * 1.8 * \frac{35}{155} + 1.4 * 2.0 * \frac{15}{155} + 0.5 * 1.0 * \frac{15}{155} + 0.6 * 1.1 * \frac{20}{155}}_{\text{Widget B}} = \boxed{1.5}$$

*System α is **50** percent more complex than the Base System for WBS 1.X.2.*

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SCORE Model: Calculating Factors with SME Estimate

The previous slide assumed Widget B for System 1 had a Complexity SCORE vs the Base System.

What if Widget B is provided as a SME cost estimate?

- Calculate and Complexity Score from the ratio of the SME cost estimate and the Base System Reference Cost and multiply by 100
- Treat these calculated Complexity Scores the same as in the previous slide, but with the mode for each phase = 100 if the SME Cost is for the system be evaluated

WBS Code	Element Name	Phase	Base System Reference Cost	System α SME Estimate	SME Estimate Complexity Relative to Base System
1.X.2	Widget B	6.2/A	35	63	(63/35)x100 =180
		6.3	15	30	(30/15)x100 = 200
		6.4	15	15	(15/15)x100 =100
		6.5	20	22	(22/20)x100 = 110
		6.6			
1.X.2 Total				130	

Example

- Assume Widget B is the only component of WBS element 1.X.2
- Base System Cost for WBS 1.X.2 = Base System for Widget B = $85
- Total Base System Development Cost (B) = $1000
  - Fraction of total cost due to WBS 1.X.2 ($f_{1.X.2}$) = 85/1000 = 0.085
- Widget B's reference system for System α is a SME cost Estimate ($130)

WBS Code	Element Name	Phase	Base System Reference Cost	System α Complexity Estimate relative to reference	SME Reference Complexity Estimate relative to Base
1.X.2	Widget B	6.2/A	35	100	180
		6.3	15	100	200
		6.4	15	100	100
		6.5	20	100	110
		6.6	*See Understanding Production Complexity Slide*		
1.X.2 Total			**85**		

$$\{1.X.2\ \text{Factor}\} = \mathbf{1.0} * \mathbf{1.8} * \frac{35}{\mathbf{85}} + \mathbf{1.0} * \mathbf{2.0} * \frac{15}{\mathbf{85}} + \mathbf{1.0} * \mathbf{1.0} * \frac{15}{\mathbf{85}} + \mathbf{1.0} * \mathbf{1.1} * \frac{20}{\mathbf{85}} = \boxed{\mathbf{1.53}} = CF_{1.X.2}$$

$WBS_{1.X.2}$ contribution to total System α cost = B x $f_{1.X.2}$ x $CF_{1.X.2}$

=$1000 x 0.085 x 1.53 = $130