Layered Pressure Vessels (LPV)

Validating an Aging, Non-compliant Product

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Outline

- Project scope
- Team membership
- What are they
- Why we're concerned
- Background, history, issues
- Service, materials, construction, inspection
- Risk based approach
- How many vessels, and project funding
- LPV project elements
- Final product
- Opportunities for collaboration

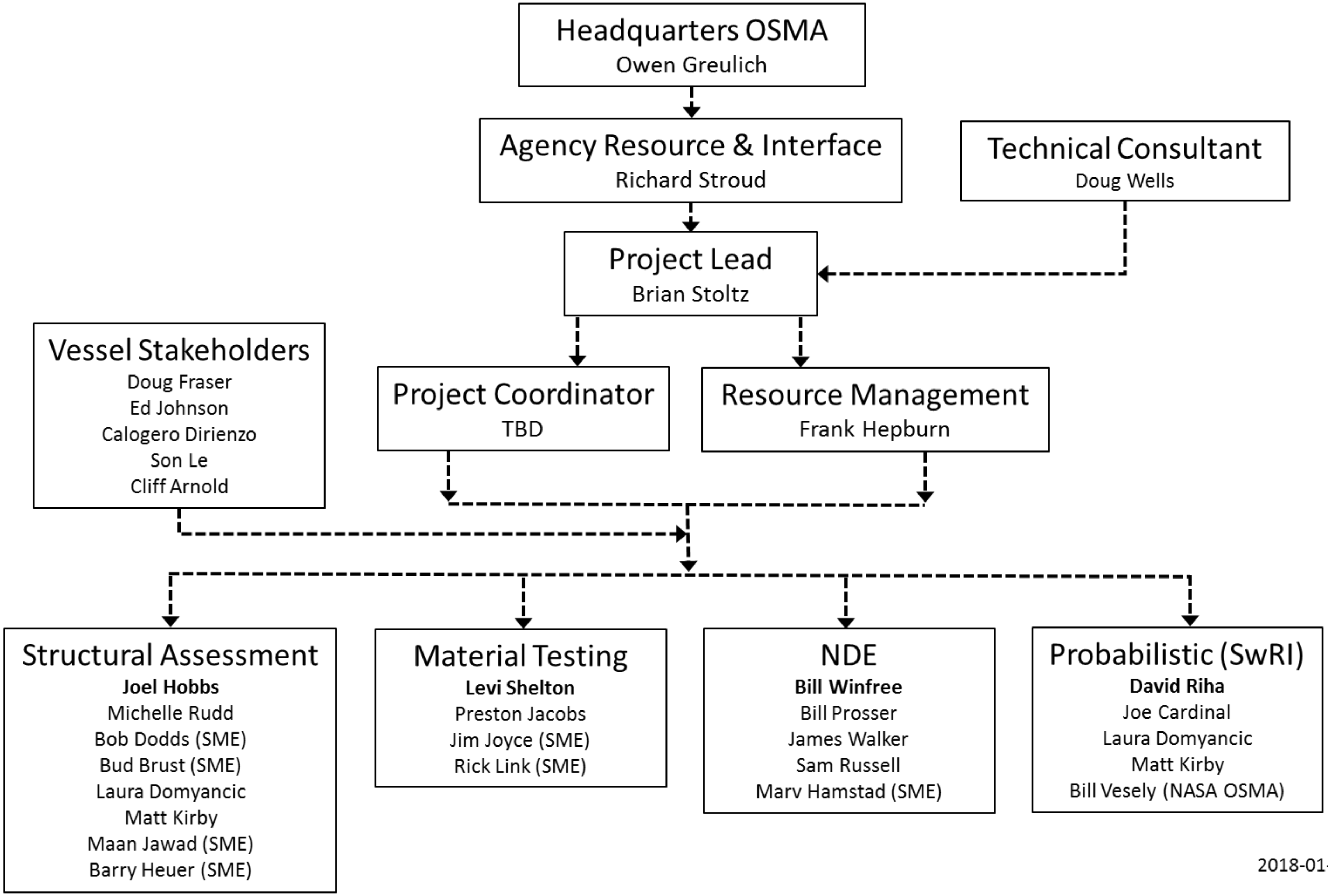
Project Scope

- …To assess and reduce risks associated with LPV, with the goal of developing a standard Agency process for continued usage, maintenance, and inspection of LPV.

- This team will also configure an online repository to document, to the extent practical, LPV design, fabrication, materials, operation, inspection , maintenance, and repair data. This repository will facilitate implementation of a consistent program of minimum maintenance and vessel inspection requirements.

- (Charter letter from Terrence W. Wilcutt, Chief, Safety and Mission Assurance, NASA)

LPV Program Organizational Chart



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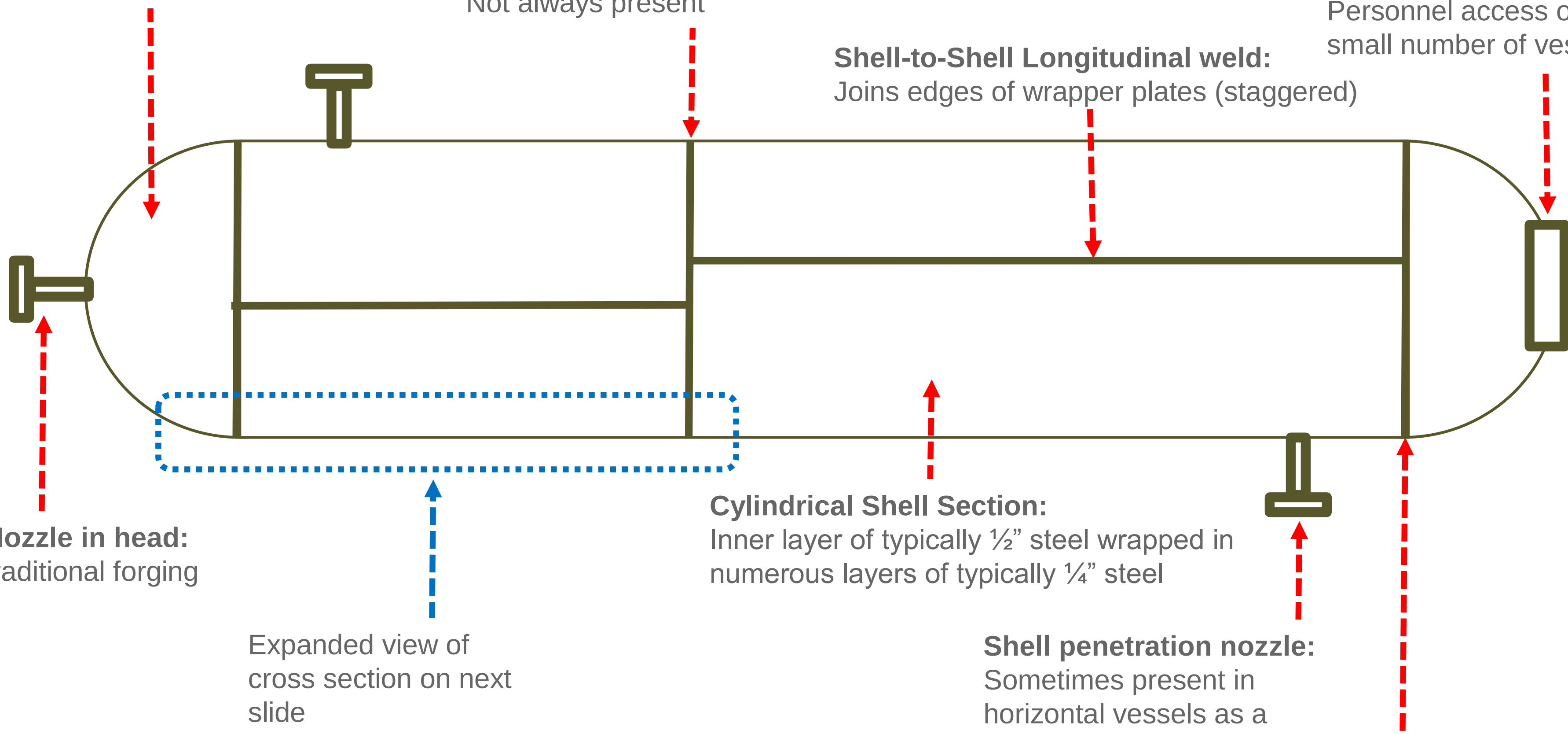
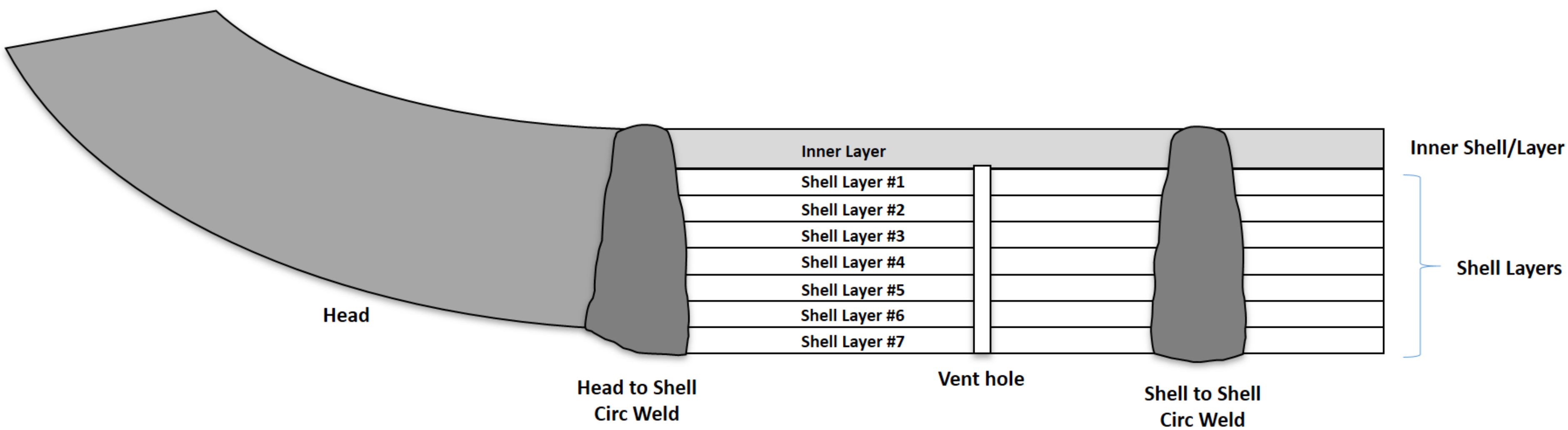
Layered Pressure Vessels – What Are They?

- A pressure vessel using layered construction of relatively thin material to provide pressure retaining capability equivalent to a thicker monolithic vessel.
  - Various constructions are permitted, including concentric layers, coil wound, shrink fit, and spiral wrapped.
  - The ASME Boiler and Pressure Vessel Code has allowed for layered heads as well as shells since 1978.
- NASA vessels:
  - Concentric wrapped layered shells and monolithic heads.
  - Most from late 1950's and early 1960's (prior to inclusion in ASME Code)
  - Material non-code and not well characterized
  - Not inspected in full compliance with code
  - Originally rated by yhe manufacturers based on lower safety factor (not compliant with Code), generally 2.5:1 on UTS vs. 4:1 then, or 3.5:1 today.
  - Mostly 3/8 - 1/2 inch liner and ¼ inch layers
  - 299 out of 302 not code-stamped

Generic LPV Geometry



Generic LPV Geometry



Construction

- Rolled and welded shells
- Formed or forged heads
- Forged nozzles in head and sometimes in shell
- Shell longitudinal welds offset, circumferential welds through-thickness
- Layer gaps and efficiency
- Good construction for the time, but many welding defects

Background

- NASA has approximately 300 layered pressure vessels (LPV)
  - Currently about 200 in service but desirable to return the others to service as well
- Replacement cost $0.5B to $1.0
- Some purchased directly, some acquired from DoD
- High stored energy
- Challenges ensuring safety and reliability, how to mitigate risks
- Not equivalent to ASME Section VIII Division 2 compliant vessels

Regulatory Issues

- OSHA General Industry regulations require ASME Code construction for many pressure vessel applications
- OSHA regulations fail to address some NASA LPV applications
- Most NASA LPV are not ASME Code stamped
- OSHA Basic Program Elements for Federal Employees 29 CFR 1960 requires an Alternate Standard for cases in which an Agency does not comply with regulations.
- 29 CFR 1960 requires a Supplementary Standard for those cases in which an Agency has operations not specifically addressed by the OSHA regulations.
- NASA has operations in both of these categories and intends to develop an Alternate/Supplementary Standard for use of LPV

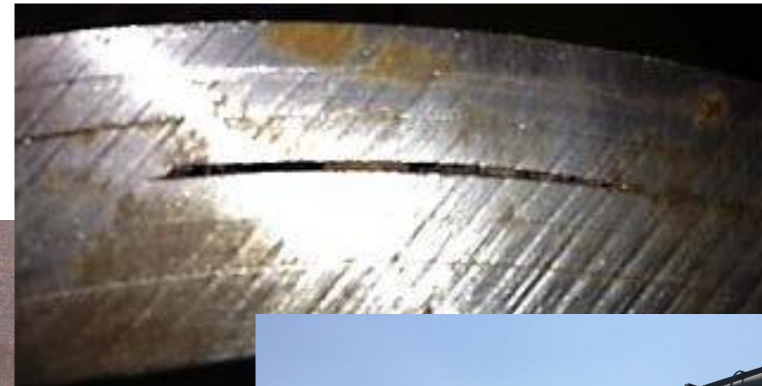
History

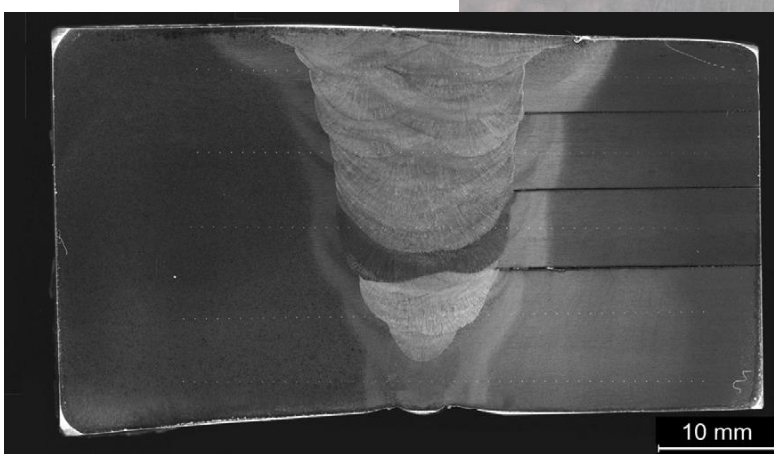
- Manufacturing method developed in 1930's
- Incorporated in ASME Boiler and Pressure Vessel Code in 1978
- Fabrication advantages
- Some purchased directly, some acquired from DoD
- High stored energy
- Some failures in industry (about 10 out of total ~ 23,000 constructed)
- OSHA discussions
- LaRC, DWC and SwRI work

Issues

- **Advantages**
  - Easier to form thin material
  - Less full thickness welding and less total weld
  - More favorable toughness properties in thin material
  - Possible favorable pre-stress
  - Leak detection via vent holes
- **Disadvantages**
  - Non-code material with very limited fracture properties characterization (toughness, crack growth rate, and transition temperature)
  - Layer gaps, possible inconsistent tension, and welding residual stresses make analysis a non-trivial task (particularly for older vessels)
  - Difficult to inspect inner layers and shell to shell welds
  - Very high MDMT for solid heads and full thicknesses welds, typically ~120F per current Code

LPV at NASA





Manufacturers of NASA LPV

- AO Smith
- CBI
- Nooter Corp
- Hahn and Clay
- Struthers Wells
- Consolidated Western Steel
- Others

Service Conditions

- Industry:
  - Urea reactors
  - Low cycles
  - Stress Corrosion Cracking (SCC) potential
  - Often elevated (300-400F) temperature operation, some low temperature
- NASA:
  - Most in air or inert gas service (a few in hydrogen service)
  - Cyclic operation (pressure swings
  - No SCC
  - Ambient temperature operation which is below Code MDMT limits at every NASA Center
  - Some blowdown service resulting in lower temperature at nozzle and surrounding area
  - Often sited in uncontrolled areas with significant staff exposure

Materials

- Frequently proprietary specifications and non-code
- Not well characterized from a fracture perspective
- Frequently fairly high ductile-brittle transition
- 19 material and condition combinations in NASA vessels, reduced for testing purposes:
  - Availability of data
  - Similarities of materials
- AOS 1146, AOS 1135G Gr. B, CBI 1143, AOS 1148B, A225B, A212B, A225C, A302B, SA516-70, SA517F (T-1), A350-LF3, SWC 100302, SA302B SS clad, SA724B

Analysis

- Models and case studies to understand details and criticality
- Incorporation of layered construction
- Layer gaps
- Welding residual stresses
- Development of analysis tools

Inspection

- Original fabrication inspection did not meet 1978 ASME Code
- Head, outer layer, and head to shell weld inspections manageable
- Inspection of intermediate layers difficult
  - Weld locations?
  - UT not effective beyond first layer for plate in intermediate weld inspections
  - RT sensitivity limited by thickness
- Nozzle to head inspections manageable
- Nozzle to shell inspections challenging
- Shell to shell welds currently difficult to inspect

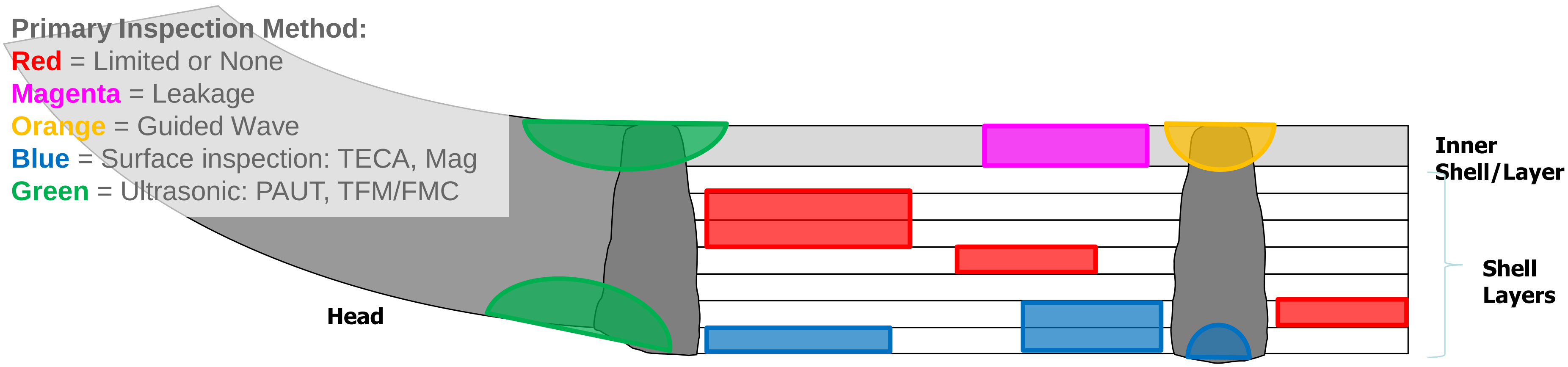
Risk Based Approach

- Understand materials
- Understand physics
- Identify potential defects
- Identify risk associated with each
- Determine critical crack sizes for each flaw based on bounding properties and stresses
- Find/Develop capability to inspect for defects of concern
- Address issues of operational temperature on case by case basis
- All flaws addressed logically in some way – probabilistic, analytic, inspection (e.g., deterministic analytical approach, can reliably find, always LBB, no crack growth)

Potential Hoop Loaded Flaws/Inspection Techniques

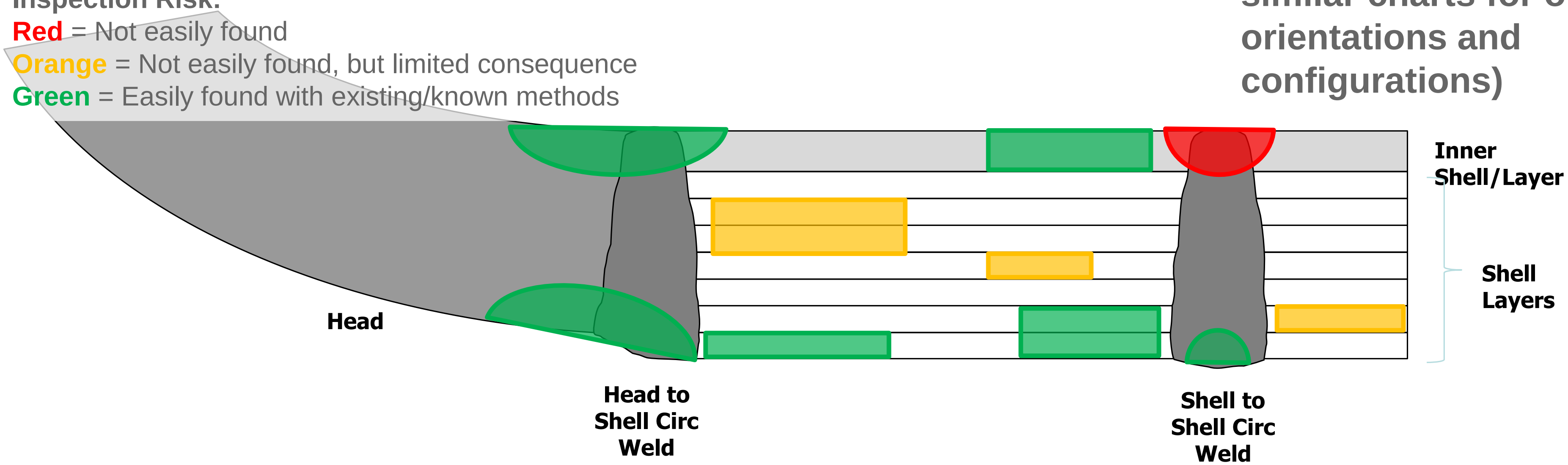
(Current thinking)

Primary Inspection Method:
Red = Limited or None
Magenta = Leakage
Orange = Guided Wave
Blue = Surface inspection: TECA, Mag
Green = Ultrasonic: PAUT, TFM/FMC



(Hoop loaded flaws only – similar charts for other orientations and configurations)

Inspection Risk:
Red = Not easily found
Orange = Not easily found, but limited consequence
Green = Easily found with existing/known methods



OSHA Alternate/Supplemental Standard

Will:

- Be part of NASA-STD-8719.17 NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)
- Address material properties, construction variability, welding residual stress, fabrication defects, analysis, and inspection.
- Define analysis approach
- Defect categories will be identified, then in order to validate operation of a vessel all categories must be addressed and their safety validated.

Flaw Catalog and Inspection Techniques (Tentative)

Name				Risk Cube Classification: 1 (good) — 3 (bad)				Mitigation Method(s): Primary, Secondary, Tertiary, N/A											
Region	Orientation	Flaw Type	Location	Severity	Probability	Detection	**Rank %**	PAUT	TFM/FMC	EMATS	TECA	EC	RT	Mag	AE	Leak	GW	Analyt.	Comments
SS	H	Si	W	3	1	3	29.6	T	S	N/A	N/A	N/A	T	N/A	T	S	P	S	
SS	A	Si	W	2	2	3	11.6	T	P	N/A	N/A	N/A	T	N/A	T	S	S	S	
NH	M	Si	F	1	3	2	2.3	P	P	S	N/A	N/A	N/A	N/A	T	N/A	N/A		
NS	H	Si	H	2	2	2	7.4	P	P	P	N/A	N/A	N/A	N/A	T	N/A	N/A		
NH	M	So	F	1	2	2	1.9	P	P	S	N/A	N/A	N/A	N/A	T	N/A	N/A		
HS	H	Si	A	2	1	2	4.2	P	S	N/A	N/A	N/A	T	N/A	T	S	S		
HS	A	Si	W	2	2	1	4.2	P	S	N/A	N/A	N/A	T	N/A	T	N/A	T		
HS	A	So	A	2	2	1	4.2	P	S	N/A	P	N/A	T	T	T	N/A	N/A		
SS	A	So	A	2	2	1	4.2	T	P	N/A	P	N/A	T	S	T	N/A	N/A		
NS	H	C	P	3	1	1	3.7	T	T	S	S	P	N/A	N/A	T	S	N/A		
SS	H	So	W	3	1	1	3.7	T	S	N/A	P	N/A	T	S	T	N/A	S		
HS	H	So	A	3	1	1	3.7	P	S	N/A	P	N/A	T	S	T	N/A	S		
WP	H	T	P	1	3	3	2.8	N/A	N/A	N/A	N/A	N/A	S	N/A	P	N/A	N/A		
NS	H	E	F	1	3	3	2.8	P	P	S	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
SS	A	E	F	1	3	3	2.8	S	P	N/A	N/A	N/A	T	N/A	N/A	N/A	N/A	P	
LW	H	T	W	1	3	3	2.8	N/A	N/A	N/A	N/A	N/A	S	N/A	P	N/A	N/A	P	Middle
NH	M	E	F	1	3	2	2.3	P	P	S	N/A	N/A	N/A	N/A	T	N/A	N/A		
IP	H	Si	H	1	1	3	1.9	N/A	N/A	N/A	N/A	N/A	T	N/A	S	N/A	N/A	P	Bounded by IP-H-T-A
NS	H	Si	F	1	3	1	1.9	P	P	S	N/A	N/A	N/A	N/A	T	P	N/A		
NP	A	So	H	1	2	3	2.3	P	P	N/A	N/A	N/A	N/A	T	T	N/A	N/A		
LW	H	T	W	1	3	1	1.9	N/A	N/A	N/A	P*	N/A	S	P*	P	N/A	N/A		Outer
NH	C	C	P	2	1	1	1.9	P	T	T	T	S	N/A	N/A	T	N/A	T		
HS	A	E	F	1	3	1	1.9	P	S	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
NP	H	So	F	1	2	2	1.9	P	P	N/A	S	N/A	N/A	T	T	N/A	N/A		
SS	A	Si	F	1	2	1	1.4	T	S	N/A	N/A	N/A	N/A	N/A	T	P	N/A		
HS	A	Si	F	1	2	1	1.4	P	S	N/A	N/A	N/A	T	N/A	T	P	T		
IP	H	T	A	1	1	1	0.9	N/A	N/A	N/A	N/A	N/A	T	N/A	S	P	N/A	P	

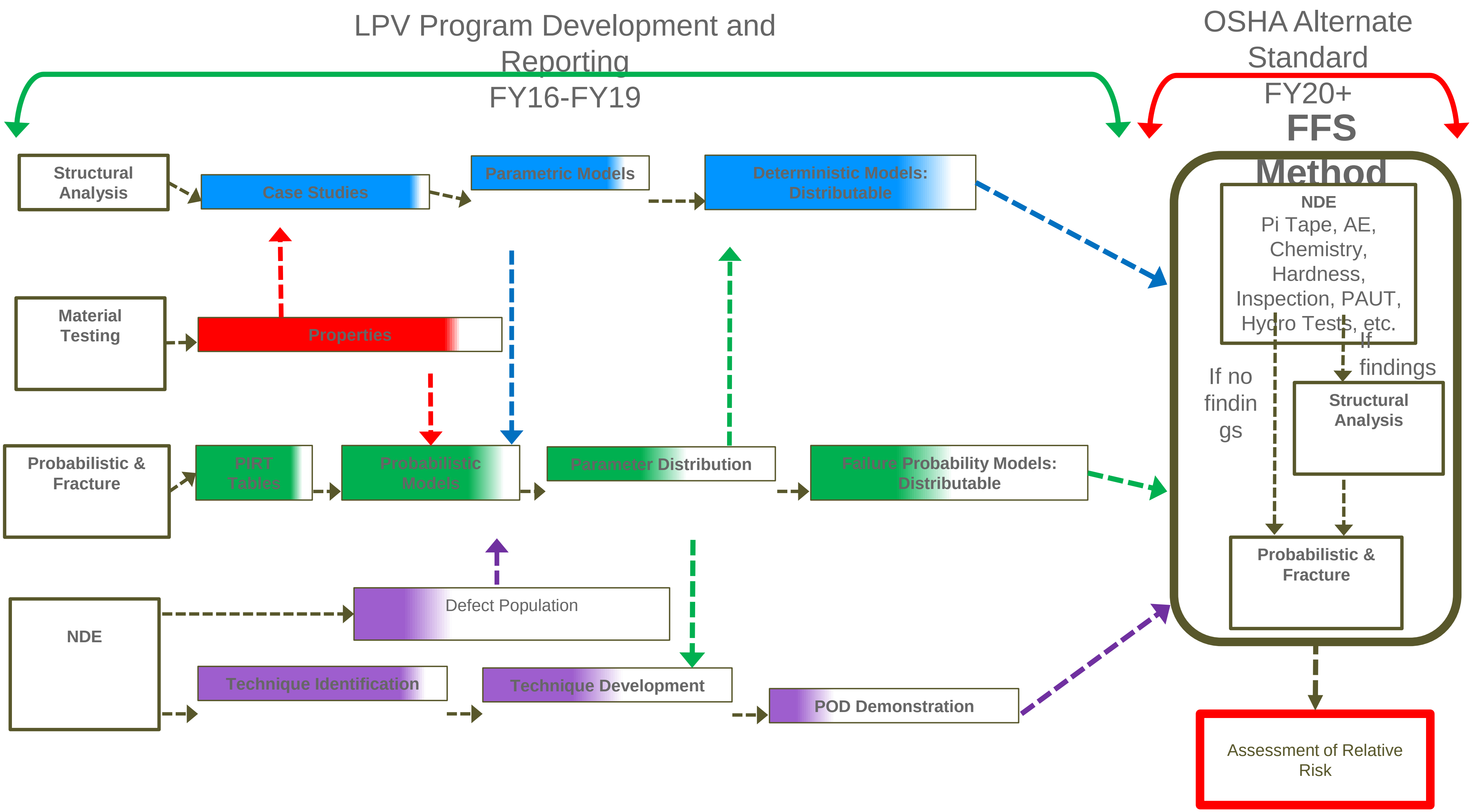
Quantities / Locations

- **NASA**
  - Total of approximately 300 vessels at eight Centers (currently ~200 in service)
- **DoD**
  - AEDC
  - Vandenberg
  - White Oak
  - Others?
- **DOE?**
- **Private Sector**
  - Typically in urea reactors in fertilizer plants
  - Petro-chemical?
  - Other commercial applications

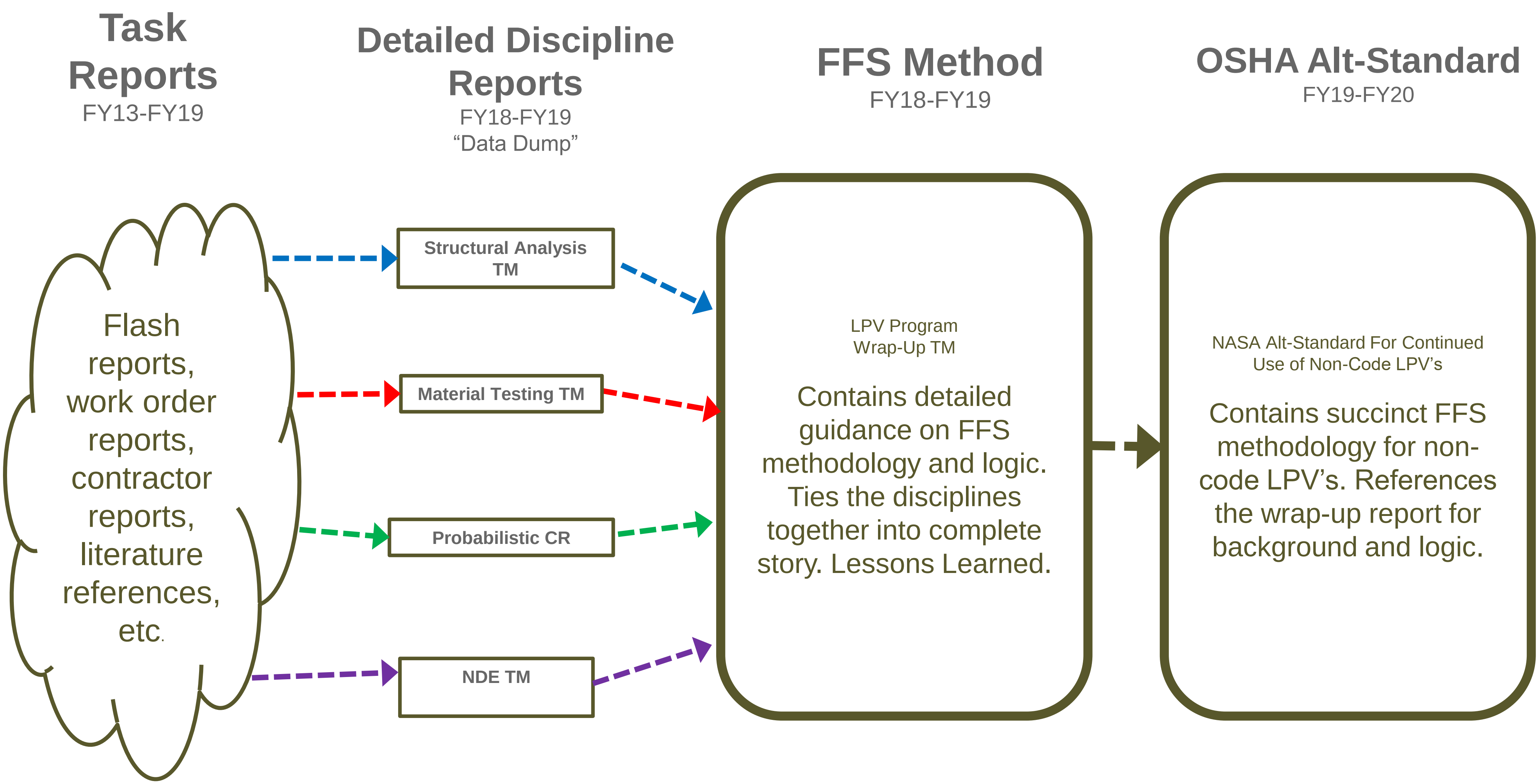
Project Elements (status/schedule next slide)

- Materials studies
- Stress analysis
- NDE
- Probabilistic aspects
- Documentation
- OSHA Alternate and Supplemental Standard

LPV Program Anticipated Technical Path



LPV Program Documentation



NASA Funding, Commitment

- 1975 First material testing
- $1 Million OSMA funding prior to focused Agency effort
  - Cyclic testing
  - NESC effort 2014
- Current $5.2M budget began 2016
  - 2016 $1M
  - 2017 $1.2M
  - 2018 $1.0M
  - 2019 $1.0M (est.)
  - 2020 $1.0M (est.)
- Significant staffing and testing resources at Marshall Space Flight Center

Other Agency Participation

- AEDC – Project F2F meetings
- Vandenberg – Project F2F meetings

Opportunities for Collaboration

- NASA currently “tapped out” on engineering and test resources
- Course to completion fairly well defined
- Opportunities to contribute through testing
  - Improve data fidelity (larger sample size)
  - Test materials outside those in NASA LPV

Questions?