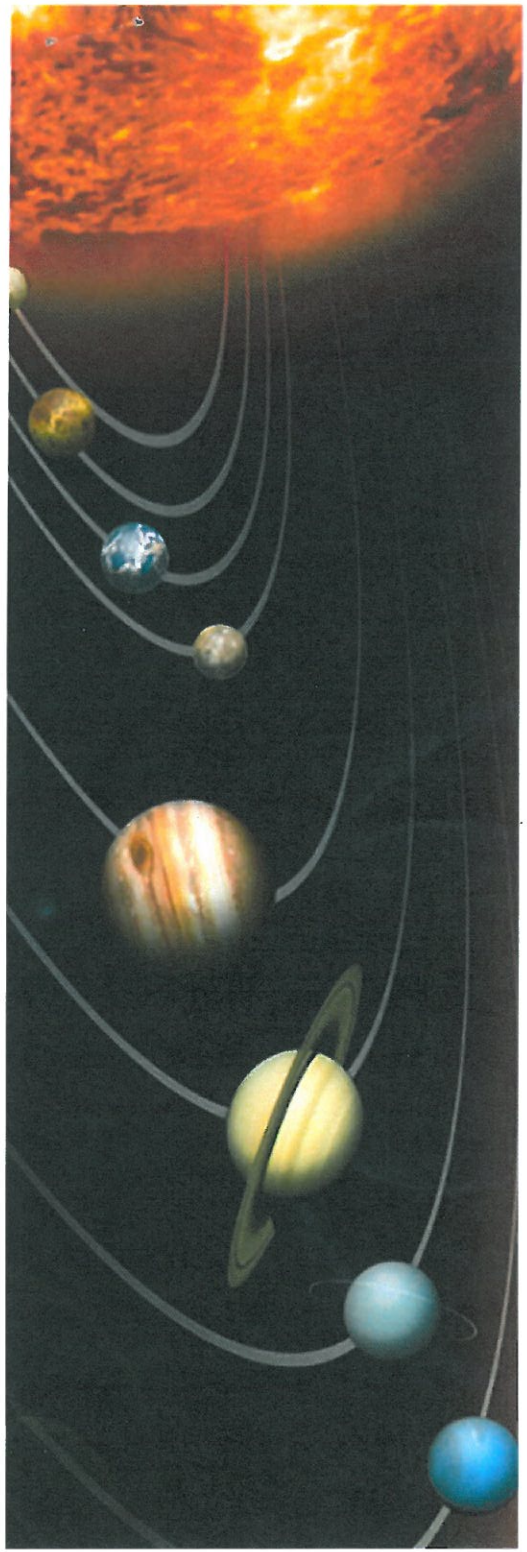


U.S. DEPARTMENT OF ENERGY

Nuclear Energy

National Aeronautics and Space Administration

NASA

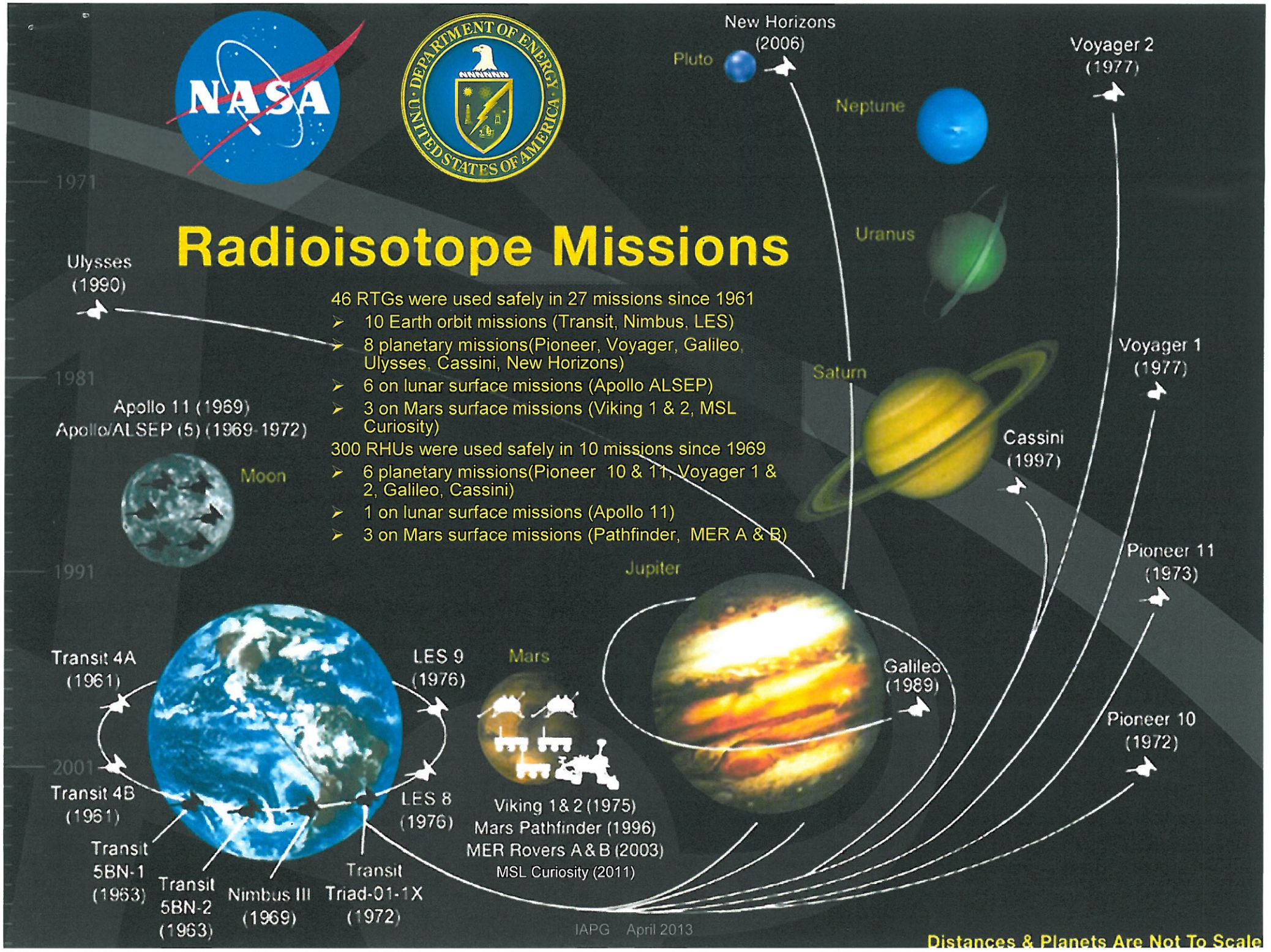
ASRG

ADVANCED STIRLING RADIOISOTOPE GENERATOR
INTEGRATED FEDERAL PROJECT

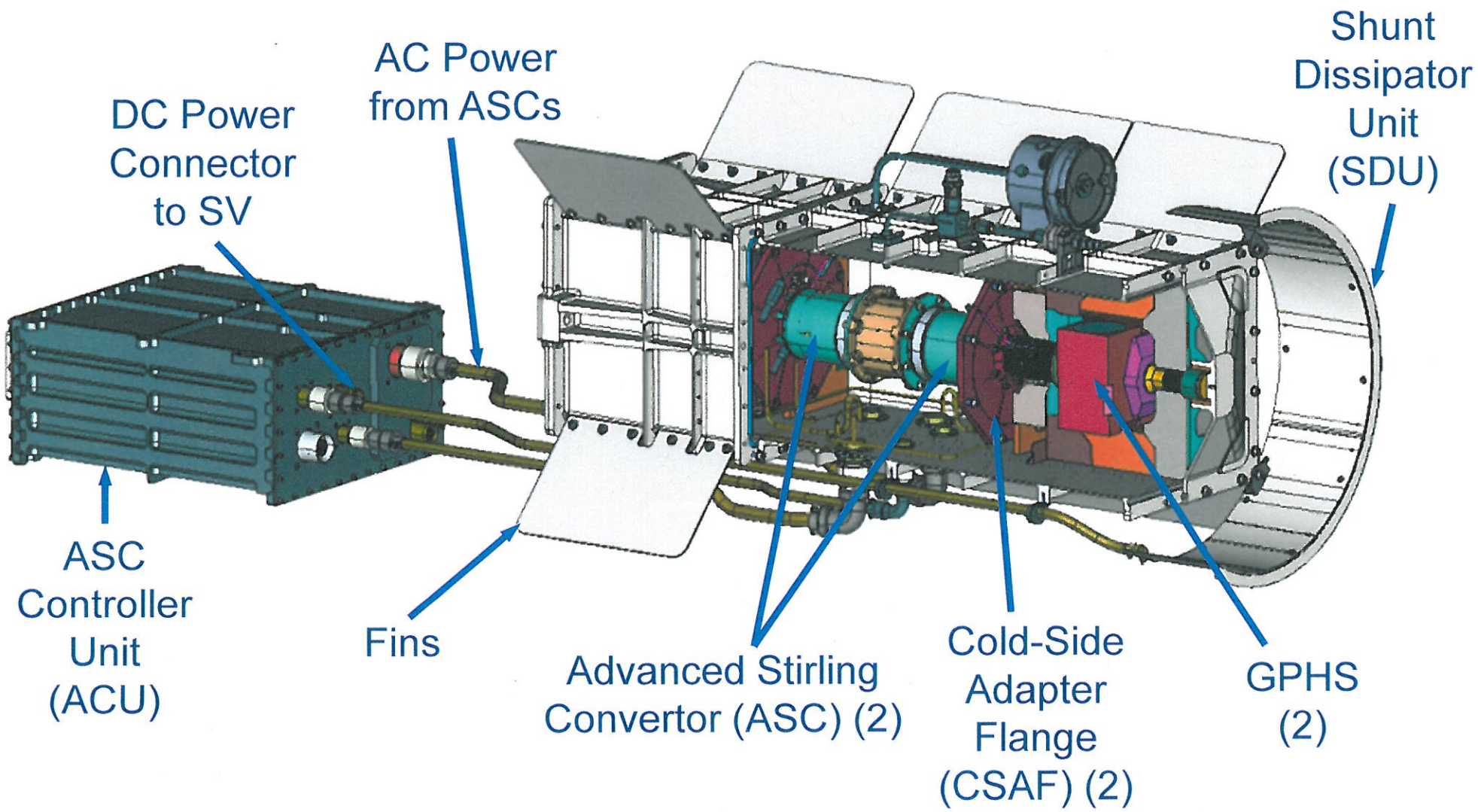
Advanced Stirling Radioisotope Generator: Teamwork and System Reliability

Chris Steffen, Jr.

1-May-2013

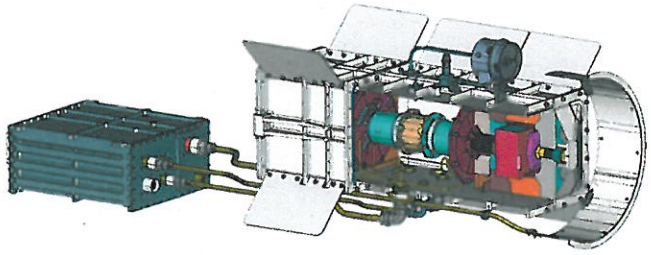

NASA
DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA ·
Radioisotope Missions
46 RTGs were used safely in 27 missions since 1961
10 Earth orbit missions (Transit, Nimbus, LES)
8 planetary missions(Pioneer, Voyager, Galileo, Ulysses, Cassini, New Horizons)
6 on lunar surface missions (Apollo ALSEP)
3 on Mars surface missions (Viking 1 & 2, MSL Curiosity)
300 RHUs were used safely in 10 missions since 1969
6 planetary missions(Pioneer 10 & 11, Voyager 1 & 2, Galileo, Cassini)
1 on lunar surface missions (Apollo 11)
3 on Mars surface missions (Pathfinder, MER A & B)
1971
1981
1991
2001
New Horizons (2006)
Pluto
Voyager 2 (1977)
Neptune
Uranus
Ulysses (1990)
Voyager 1 (1977)
Saturn
Cassini (1997)
Apollo 11 (1969)
Apollo/ALSEP (5) (1969-1972)
Moon
Jupiter
Pioneer 11 (1973)
Transit 4A (1961)
LES 9 (1976)
Mars
Galileo (1989)
Pioneer 10 (1972)
Transit 4B (1961)
LES 8 (1976)
Viking 1& 2 (1975)
Mars Pathfinder (1996)
MER Rovers A & B (2003)
MSL Curiosity (2011)
Transit 5BN-1 (1963)
Transit 5BN-2 (1963)
Nimbus III (1969)
Transit Triad-01-1X (1972)
IAPG April 2013
Distances & Planets Are Not To Scale

Advanced Stirling Radioisotope Generator (ASRG)

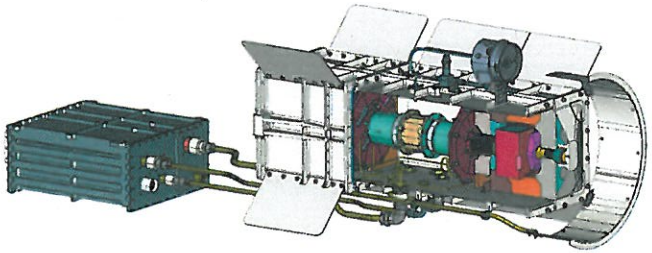


ASRG Project Key Deliverables

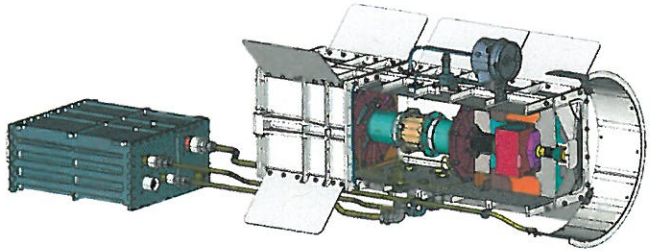
Qualification Test Unit
Fueled & Tested **2016**



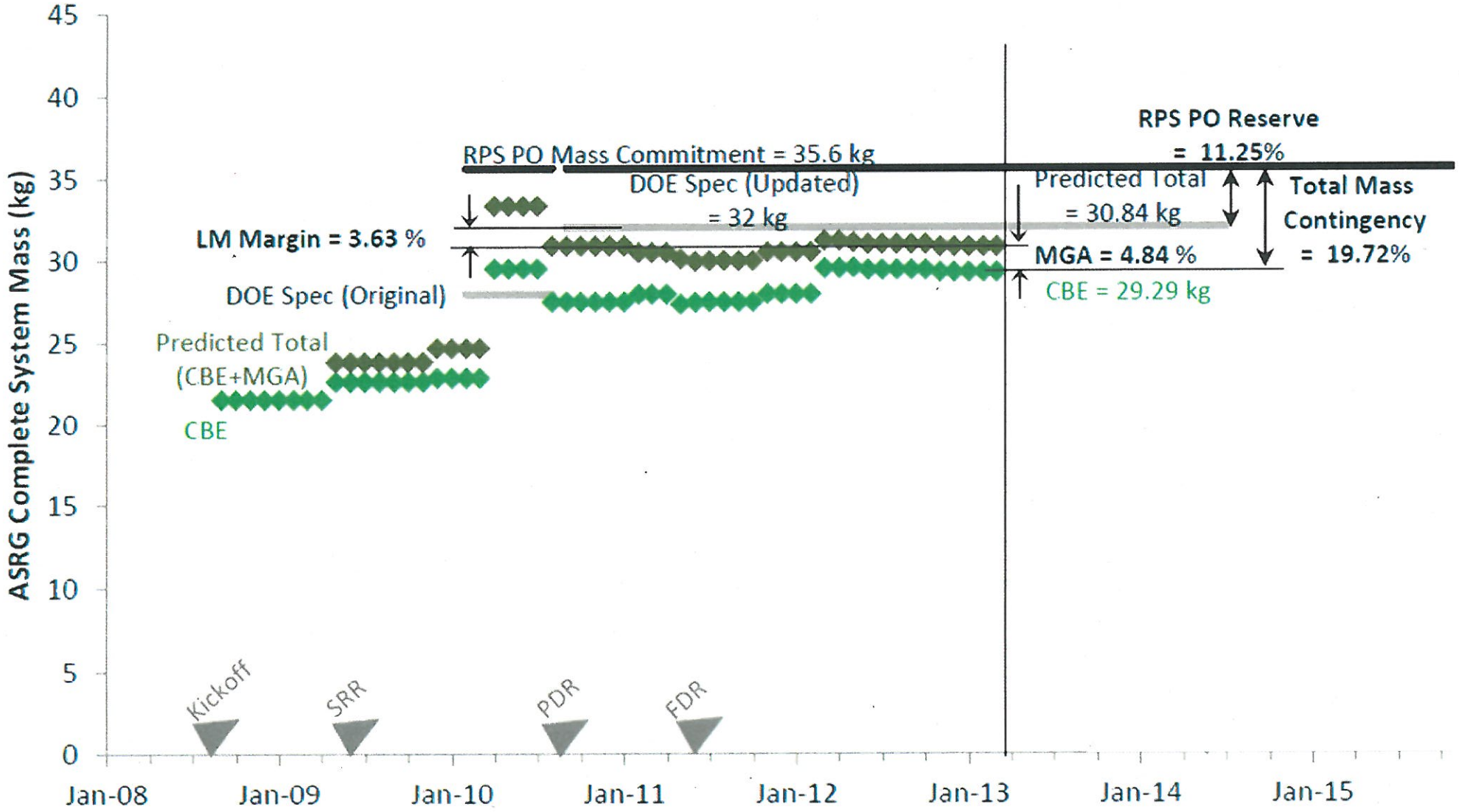
Flight #1 Unit
shipped for Fueling
& Testing **2016**



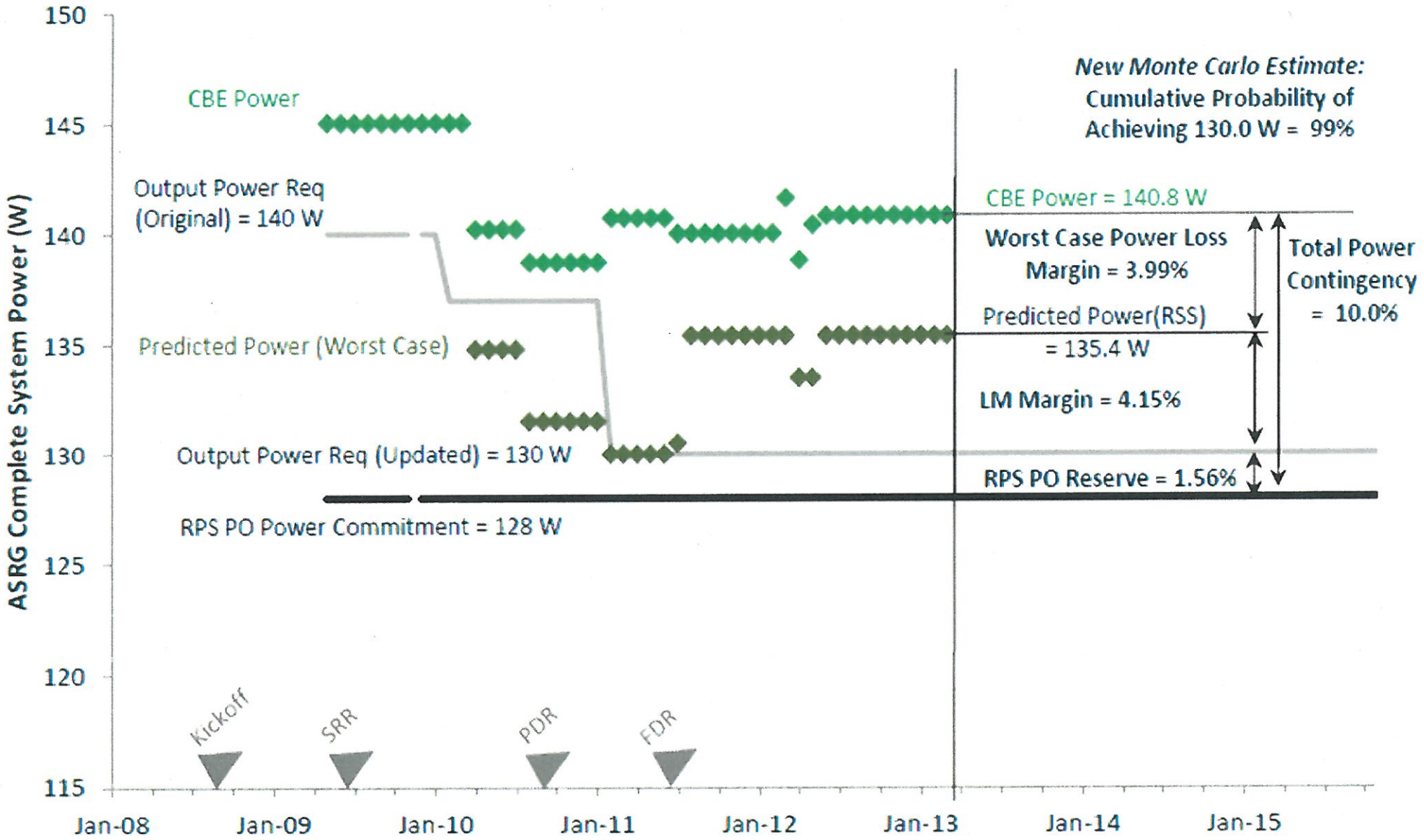
Flight #2 Unit
shipped for Fueling
& Testing **2017**



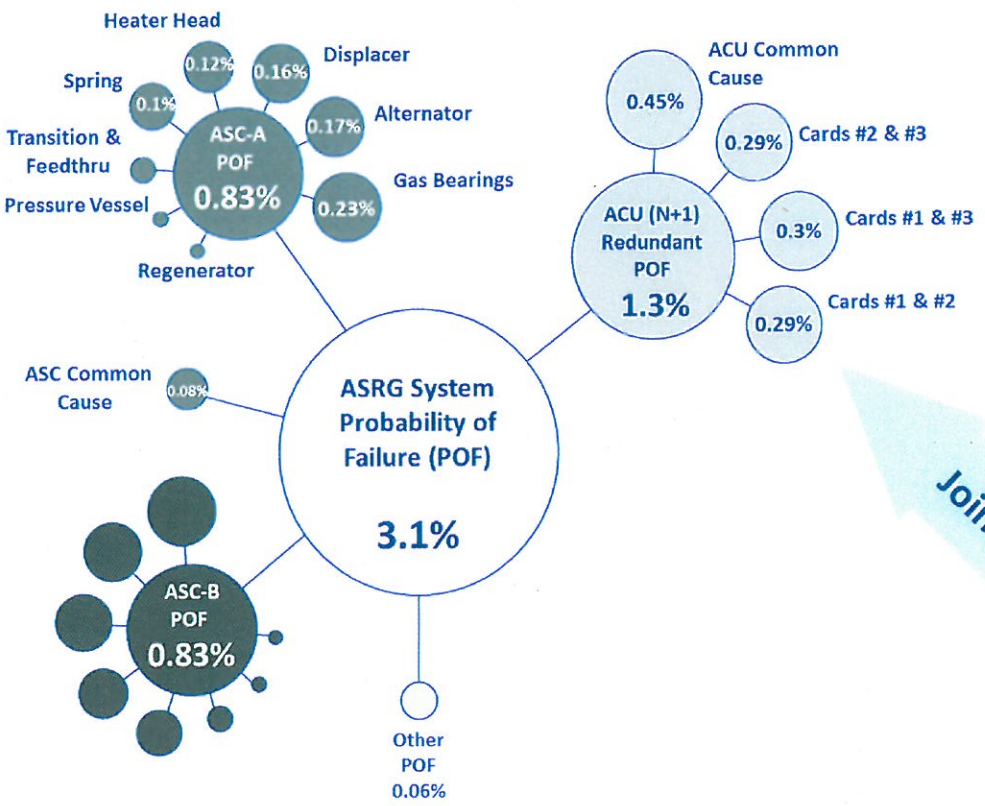
ASRG Mass Metric – March 2013



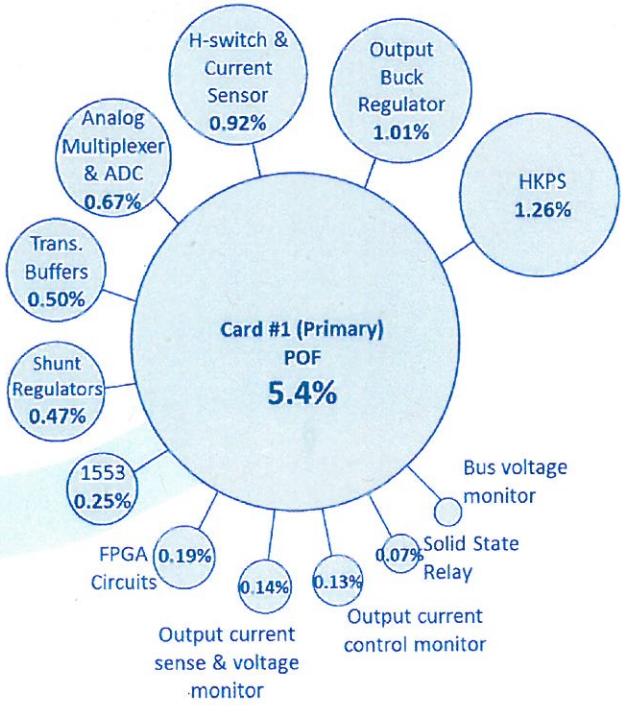
ASRG Power Metric – March 2013



ASRG Reliability Metric – March 2013



Joint Probability



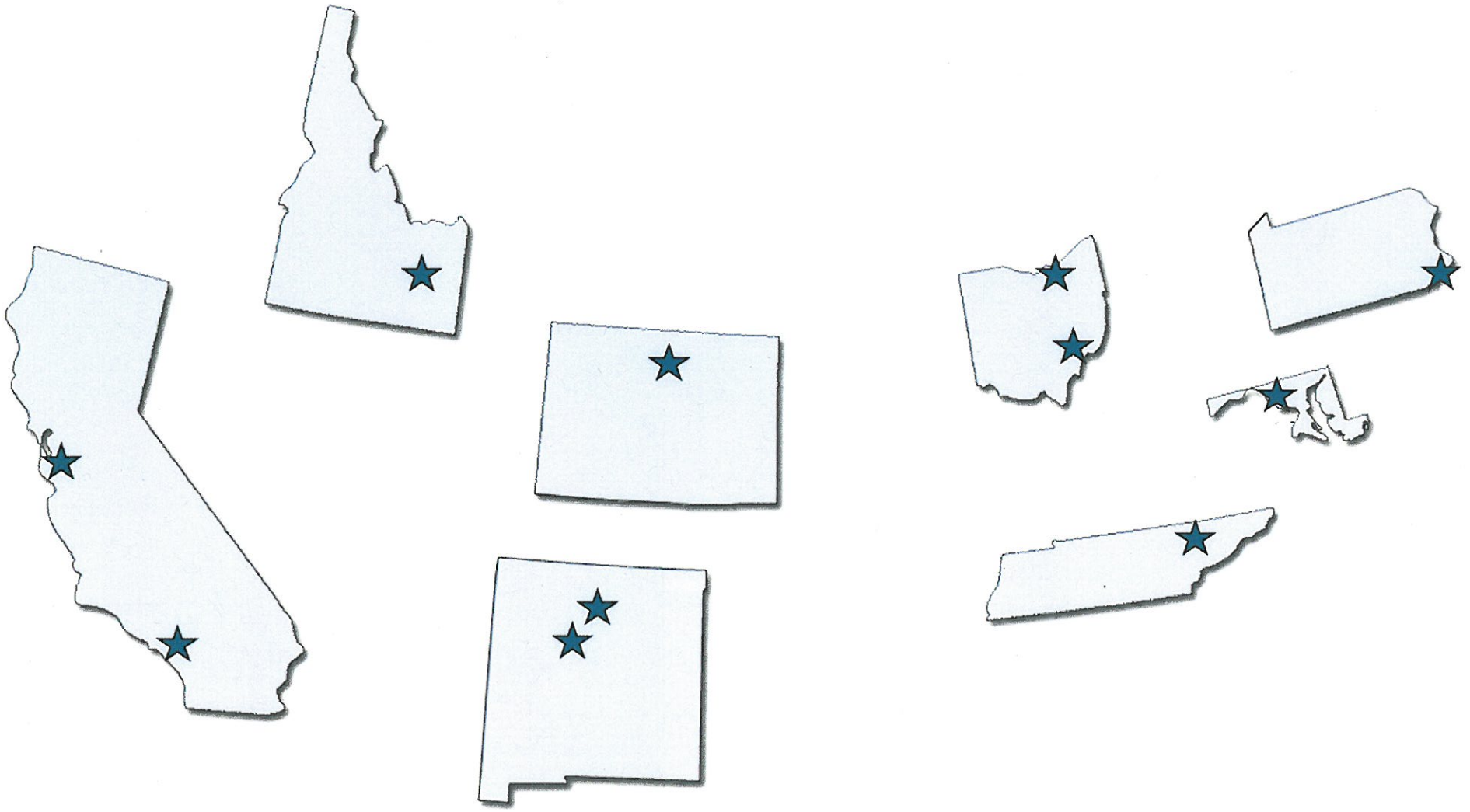
ASRG System Probability of Success (Delivered power for 17 years) 96.9%

Card #2 POF 5.3%

Card #3 (Alternate) POF 5.4%

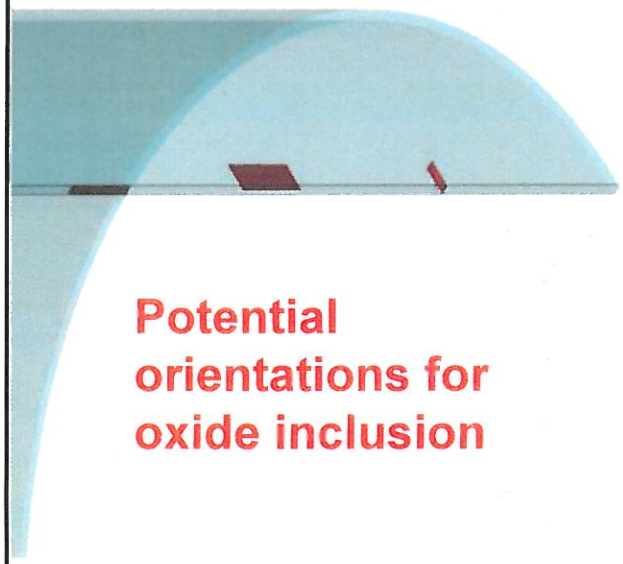
Questions about this graphic, Chris Steffen *(steffen@nasa.gov)*

Travel is good for project communication

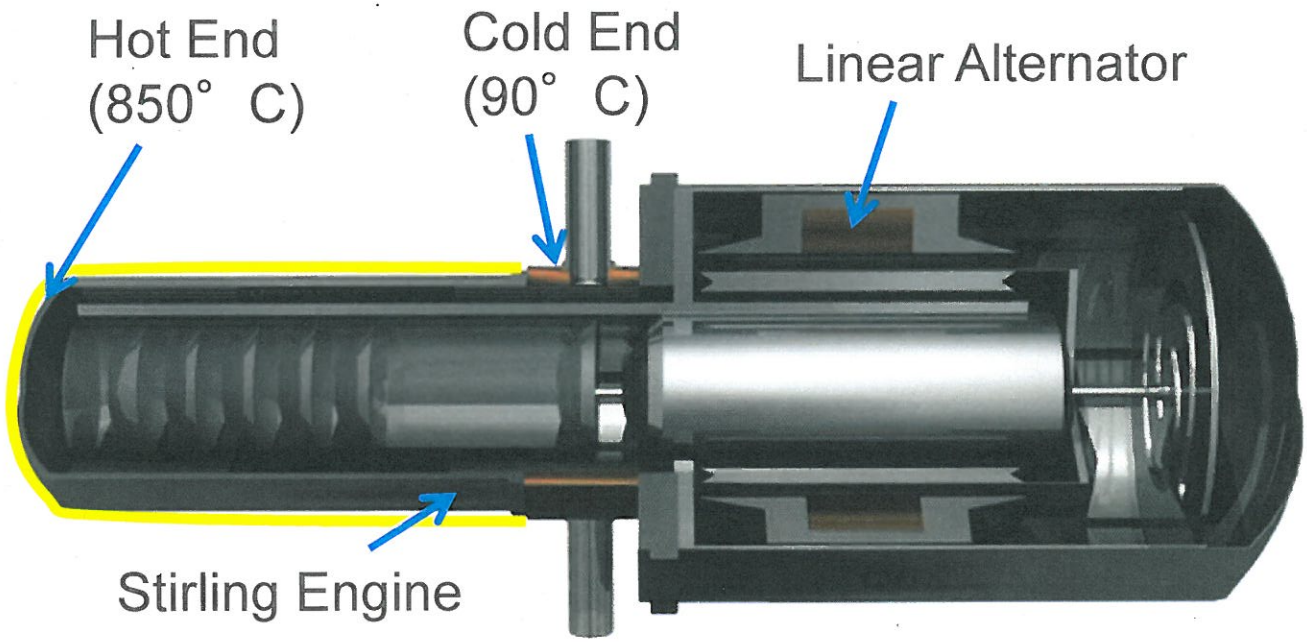


Reliability challenge: heater head casting

- Thin-walled metallic ***Heater Head*** component (outlined in yellow)
- Ni-based super alloy ***Heater Head*** machined from casting
- Casting is known for potential ***oxide inclusions*** (ceramic flakes)
- Micro-focused Computed Tomography (CT) key to "seeing" these flaws
- Component yield was developing as an issue; parts could meet criteria
- NASA Engineering Safety Center: "criteria needs test-verified basis"

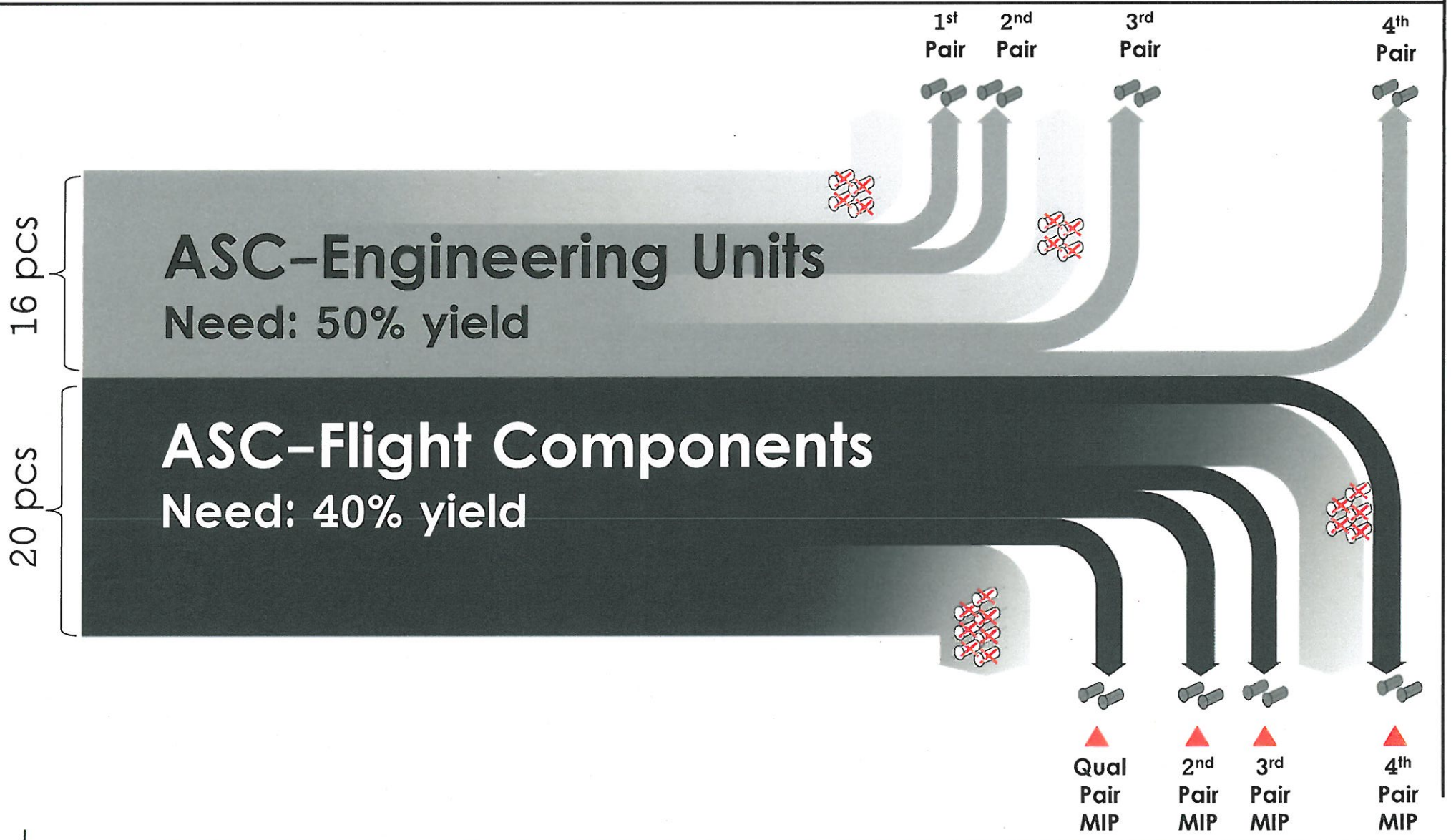


Potential orientations for oxide inclusion

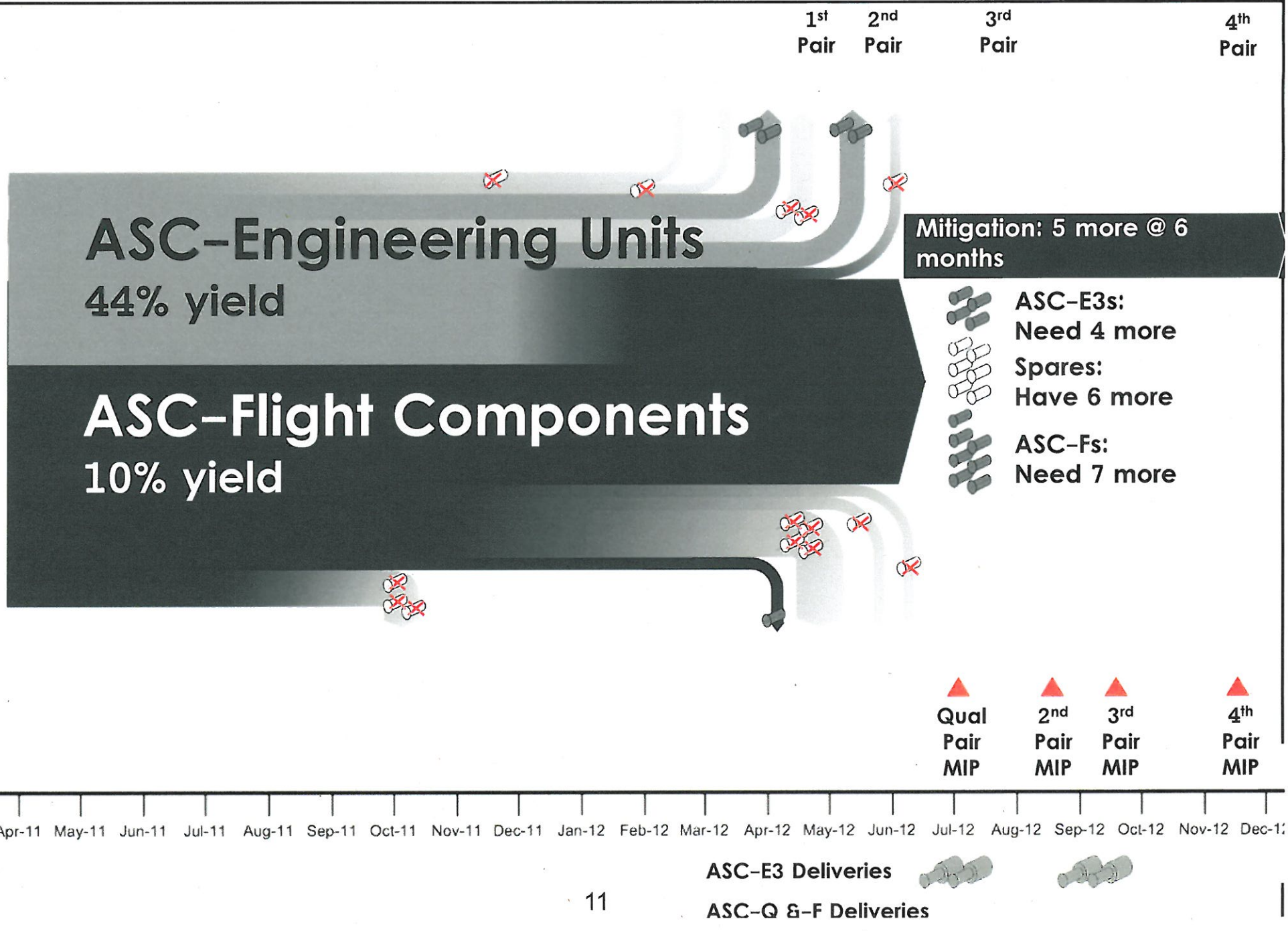


Advanced Stirling Convertor

Plan: Heater Head development



Reality: Heater Head development



Reliability challenge: heater head casting

Technical Risk: Oxide Inclusions present a risk to meeting fatigue life requirement (68 years)

Schedule Consequence: Insufficient component yield threatens critical path schedule with 3 months

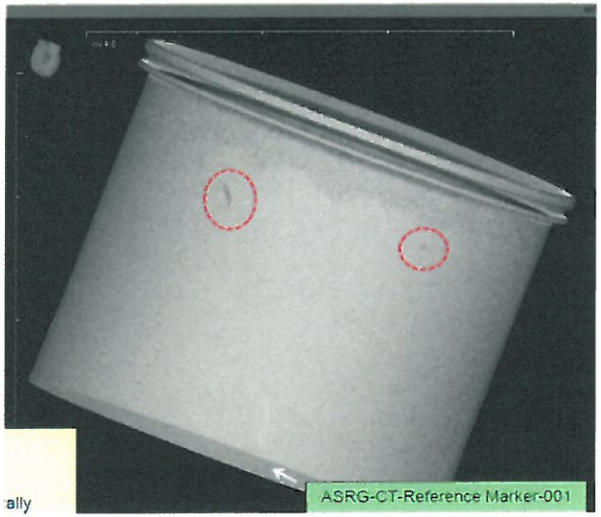
Approach: Assemble investigation team and resolve in 3 months

1. Verification: Material coupon testing → batch specific matl props
2. Verification: Fracture mechanics & selection criteria → test-verified properties
3. Validation: Component stress testing → design specific reliability data

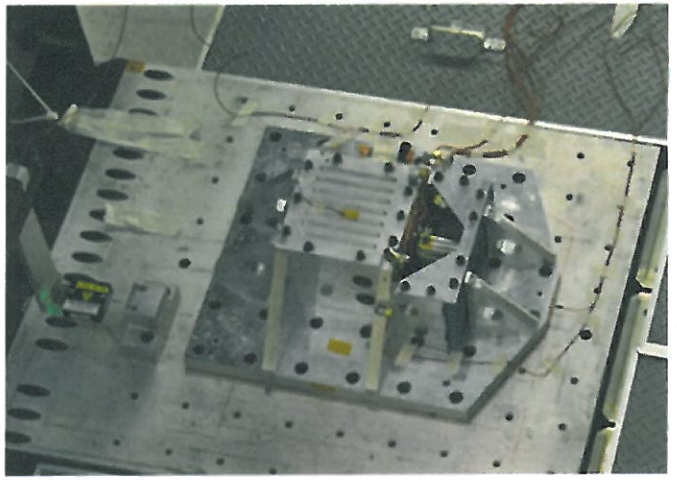
Goal: Resulting in test verified, design specific acceptance criteria for 4x design life on fatigue, validated with component testing

Skills and Assets Required

FEM Analysis

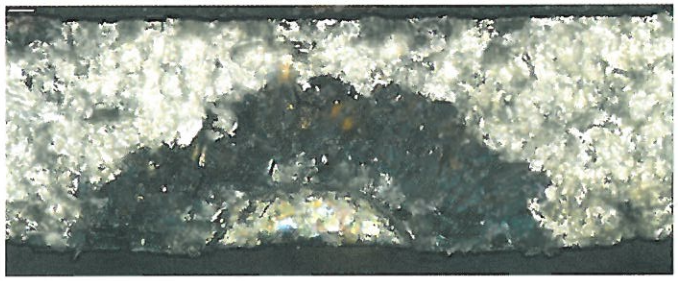


Micro-focused CT scanning

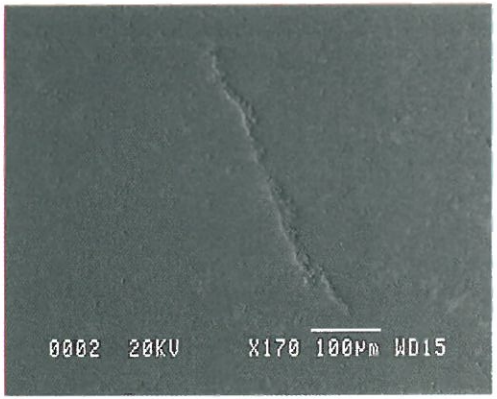


Structural Dynamics Testing & cumulative damage analysis

Rapid design & manufacturing

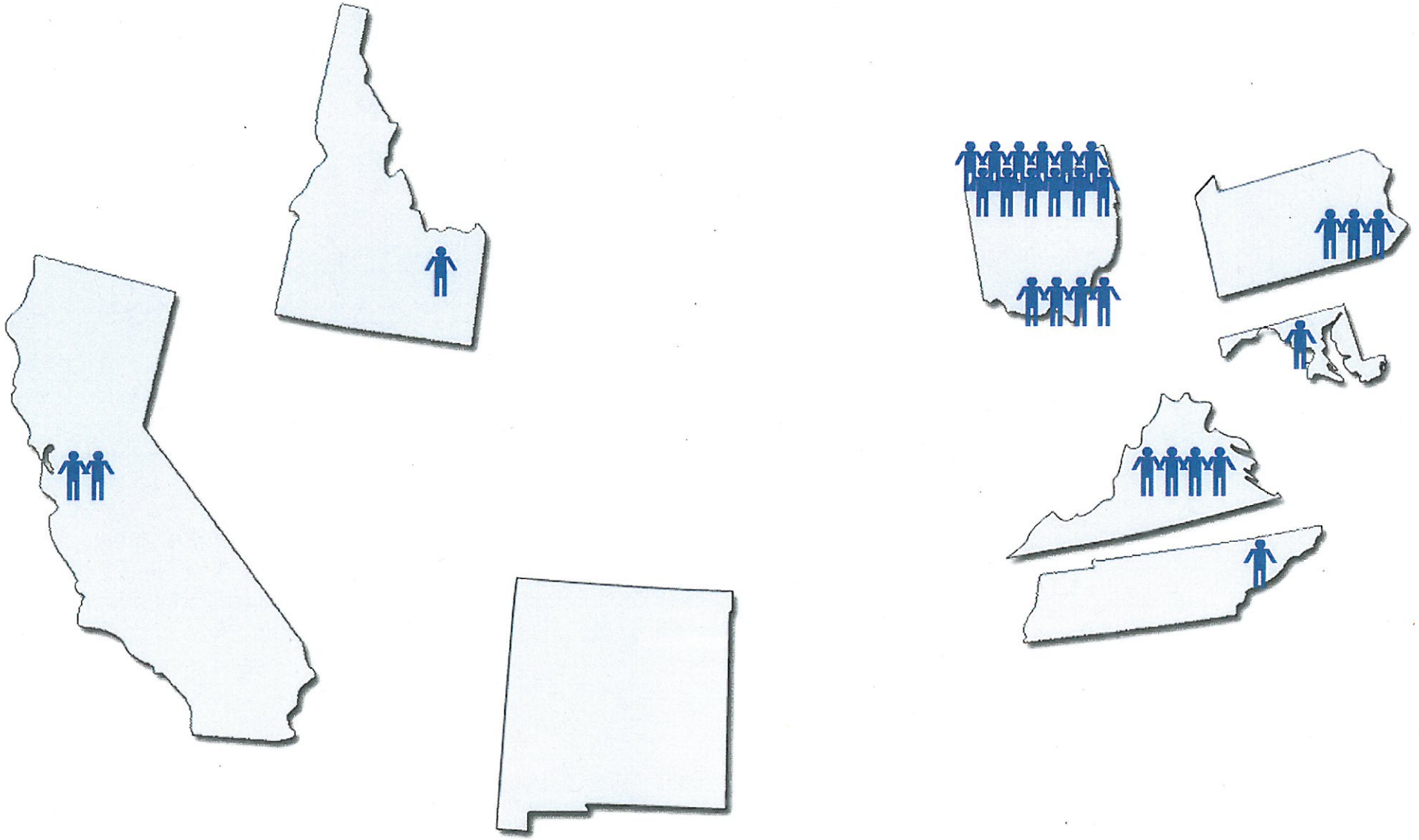


Material Properties testing & Fracture Mechanics analysis



SEM Imagery

Investigation Team, core members



Key Results

1. ***Comprehensive approach:***
   - Sixteen* separate fatigue crack growth specimen tests
   - Design trade study on "critical-flaw-size vs wall thickness"
   - Refined (tighter!) acceptance criteria, supported by test-verified materials properties
   - Eight qualification level vibe stress tests on five different components
2. ***NESC concurrence:***
   - results conclusions
   - residual risk for the ASRG project
3. ***Timely closure:***
   - preserved system reliability and margin for fatigue life
   - Preserved project schedule despite tighter acceptance criteria

Only possible with a badge-less team working pulling together

Thanks to the investigation team

- Greg McNelis – LM (co-lead)
- Dennis Petrakis – LM
- Glen Davis – Sunpower
- Kyle Wilson – Sunpower
- Lou Qualls – ORNL
- Louis Ghosn – NASA GRC
- Wayne Wong – NASA GRC
- Kate McGinnis – NASA GRC
- Jeff Schreiber – Consultant, formerly GRC
- Brad Kirkwood, INL
- Jack Chan - LM
- Scott Benson, GRC -- Project Management Rep.
- Randy Bowman – GRC
- Ramesh Kalluri – GRC
- Dave Krause - GRC
- Jack Telesman –GRC
- Chuong Ha – LM
- Ron McNally – LM
- Gary Wood – Sunpower
- Aaron Thomas – Sunpower
- Kim Otten – GRC
- Sal Oriti – GRC
- Zach Williams – GRC

<u>Consultants (NESC):</u>

Dawn Emerson, Bob Piascik, Bill Prosser, Raju Ivatury, Dave Dawicke