LA-UR-17-22663
Approved for public release; distribution is unlimited.

Title: Source Physics Experiment Phase II Dry Alluvium Geology (DAG) Experiments Design Reviews

Author(s): Dickson, Peter
Seitz, Gerald John
Deines, Kyle J.
Gentzlinger, Robert C.
Mesick, Nathaniel Jordan Paul
Peebles, Garrett William
Saeger, Veronica Irene

Intended for: Design Reviews held at LANL

Issued: 2017-04-03

Source Physics Experiment Phase II

Dry Alluvium Geology (DAG) Experiments Design Reviews

Los Alamos National Laboratory
SPE Team

Peter Dickson, M-6
Jerry Seitz, Q-6
Kyle Deines, ES-EPD
Robert Gentzlinger, A-3
Nathan Mesick, W-11
Garrett Peebles, W-2: W76
Veronica Saeger, W-11

February 22 and 23, 2017

Dry Alluvium Geology (DAG)
HE Initiator Final Design Review

HE Source Design Requirements Summary

- Explosive yield (TNT equivalence) ranging from 1,000 kg to 50,000 kg;
- Well-characterized detonation parameters;
- Well-characterized yield;
- Explosive must be safe to handle (insensitive) and stable enough to remain in place for extended periods;
- Approximately (as far as possible within hole geometry constraints) spherically equivalent (isotropic) detonation;
- Robust initiation system;
- Reasonable cost.

Explosive Selection

- **Unsensitized nitromethane was chosen for several reasons:**
  - Readily available in large quantities (industrial solvent);
  - Inexpensive (~ $2 – $5 / lb);
  - Transported as a flammable liquid;
  - Handled using COTS equipment;
  - Shock-insensitive unless chemically sensitized;
  - Indefinitely stable;
  - Well-characterized JWL parameters;

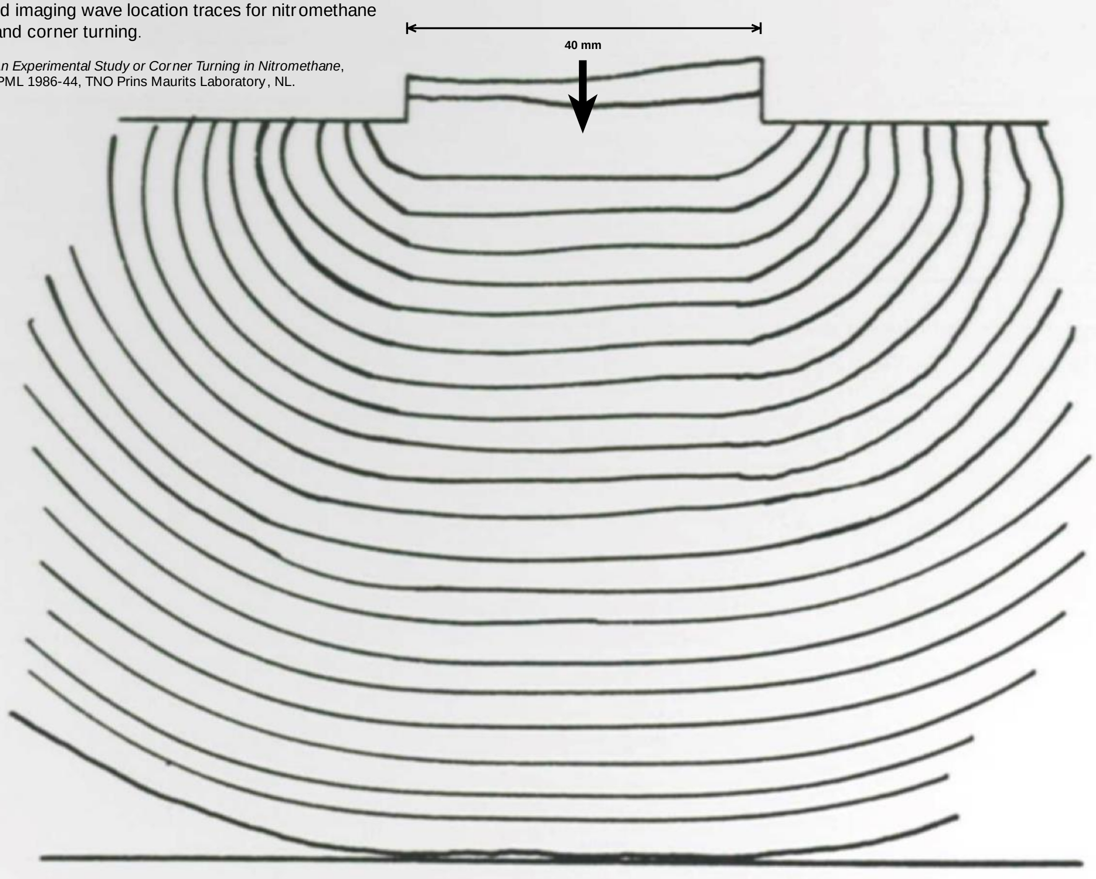
Properties of nitromethane

Chemical formula	CH_3NO_2
Molecular mass	61.0
Appearance	Colorless oily liquid
Melting point	-29 ˚C
Boiling point	101 ˚C
Density (nominal)	1.13 g cm^{-3}
Viscosity (25 ˚C)	0.61 cP
Vapor pressure	3.2 kPa (20 ˚C), 14 kPa (50 ˚C)
Flash point	35 ˚C
Oxygen balance	-39%
Detonation velocity	6300 m s^{-1}
Shock hugoniot	$U_s = 1.65 + 1.64U_p$
Detonation shock pressure	13 GPa
TNT equivalence	1.13
Failure diameter	44 mm
Shock initiation threshold pressure	~ 8 GPa

Nitromethane corner turning

High-speed imaging wave location traces for nitromethane breakout and corner turning.

Gibb, A.W., *An Experimental Study or Corner Turning in Nitromethane*, TNO Report PML 1986-44, TNO Prins Maurits Laboratory, NL.

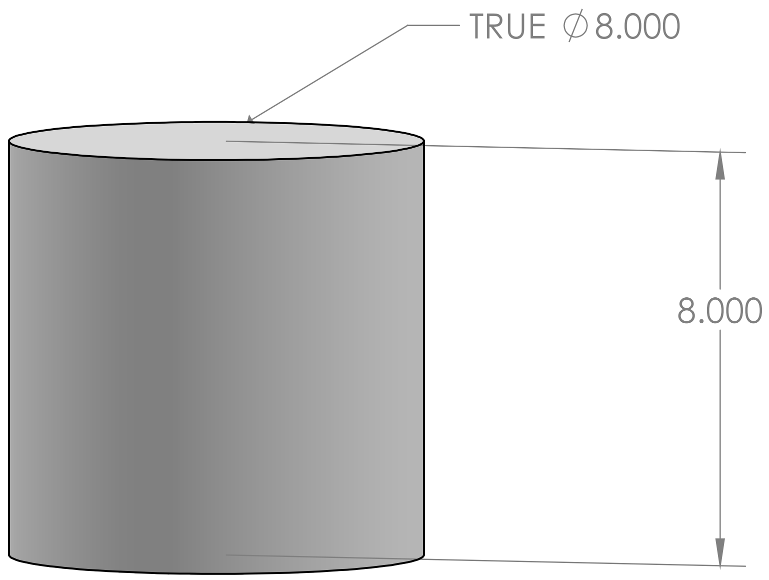


Test Geometries

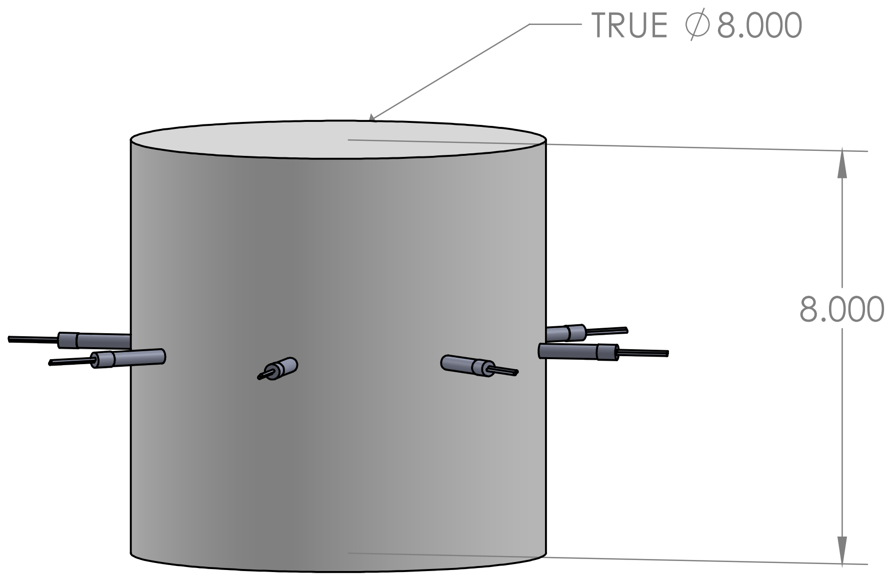
TNT equivalent (metric tons)	1	10	50
Diameter	39.7"	85.5"	86"
Length	39.7"	85.5"	422"
L/D ratio	1	1	4.91

- **The 1,000 kg and 10,000 kg shots can have an L/D of ~ 1.**
- **The 50,000 kg shot L/D will be nearly 5, but that is unavoidable in an 8 ft diameter hole.**

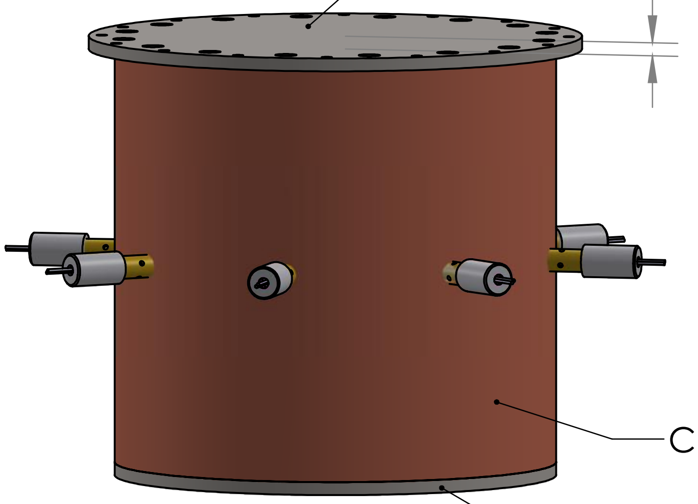
Explosive Charge: 8 in x 8 in cylinder PBX 9501 (~26.6lbs)



Detonators: 8 of RP-83 equatorially distributed on mid-plane

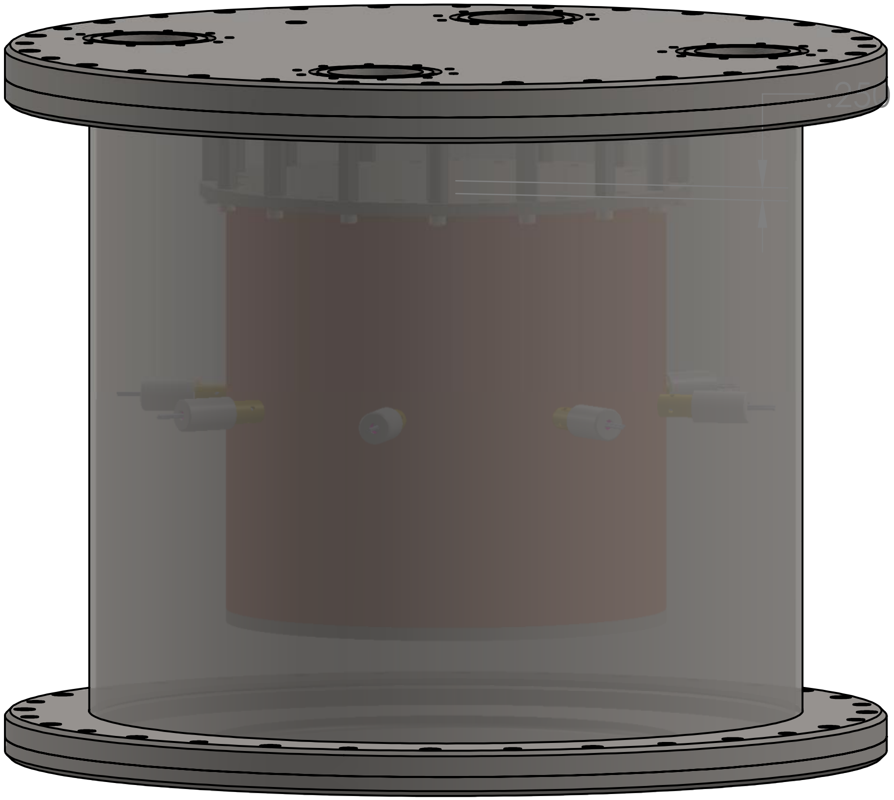


Inner cylinder: ¼ in metal (copper & 304 stainless steel)



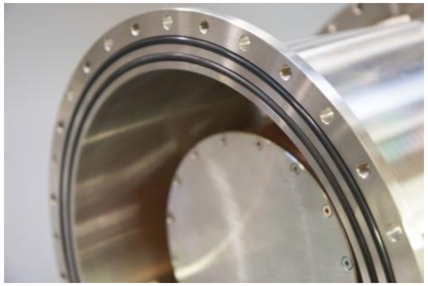
Outer cylinder

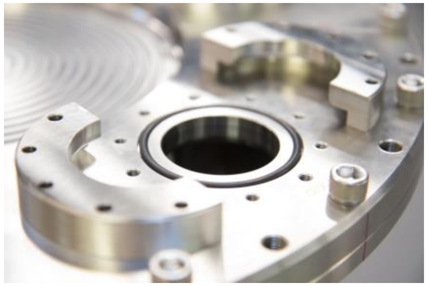
- All 304 stainless (Nitromethane-proof)
- 2.5in air gap between inner and outer cylinders
- 1/8in thick where flyer plates impact
- Overall height 13.75in, overall diameter 17in.

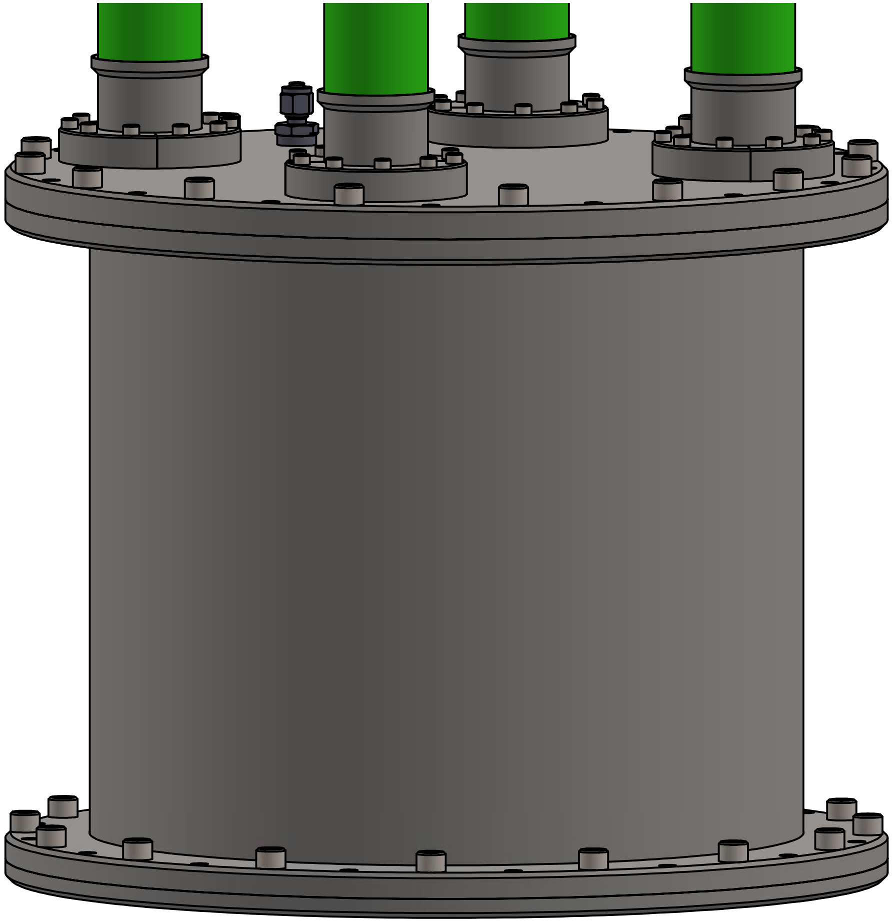


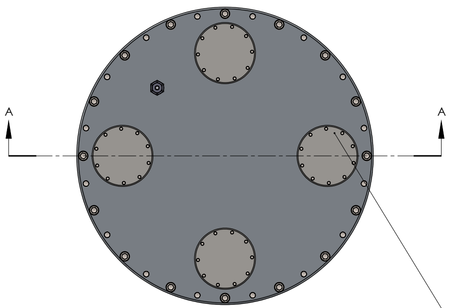
Design details

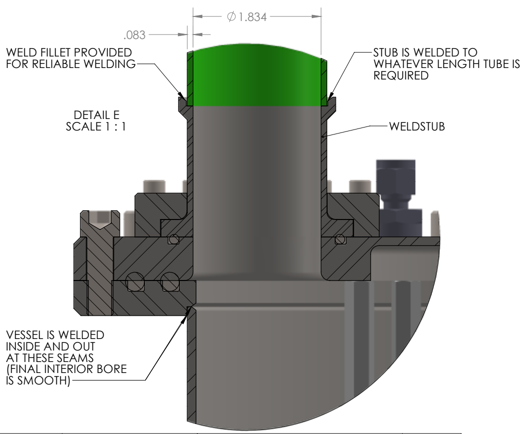
- EPDM o-rings for sealing
- Access fitting allows leak-check to be performed
- Detonators maintained against explosive with springs
- Detonator cables exit through two of the hollow support tubes

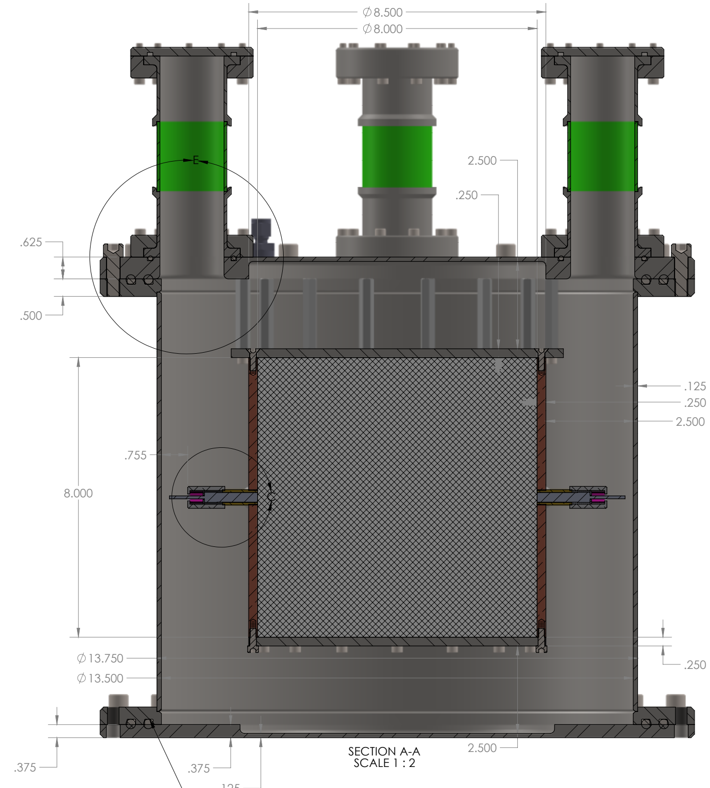




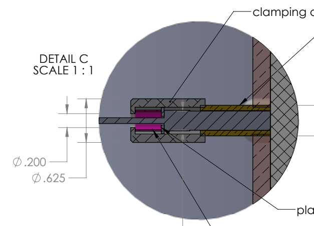








f	PART NUMBER	DESCRIPTION	QTY.
1	MainCharge_V2		1
2	socket countersunk head cap screw_ai		16
3	HX-SHCS 0.19-32x1x1-N		144
4	RP-83detonator		8
5	SS-400-1-OR		1
6	AS568 - 013		9
7	Internal_Cylinder_V3		1
8	Internal_Base_V3		1
9	Internal_Lid_V3		1
10	93620A179		16
11	Outer_Cylinder_V3b		1
12	Outer_Cylinder_V3a		2
13	Outer_Base_V3		1
14	Outer_Lid_V3		1
15	DetonatorSleeve_V3		8
16	DetonatorRetainingCap_V3		8
17	TubeHoldDown_V3		16
18	TubingWeldStub_V1		8
19	Tube_V1		4
20	SealingBlank_V1		4
21	SpringMock		8
22	SpringWasher		8



This entire assembly shown will weigh ~150lbs. (incl. explosive, but not incl. the weld stubs and tubing)
Internal cylinder is copper; detonator mounting parts are brass and aluminum; all other metal (including fasteners) is 304 stainless for compatibility with nitromethane

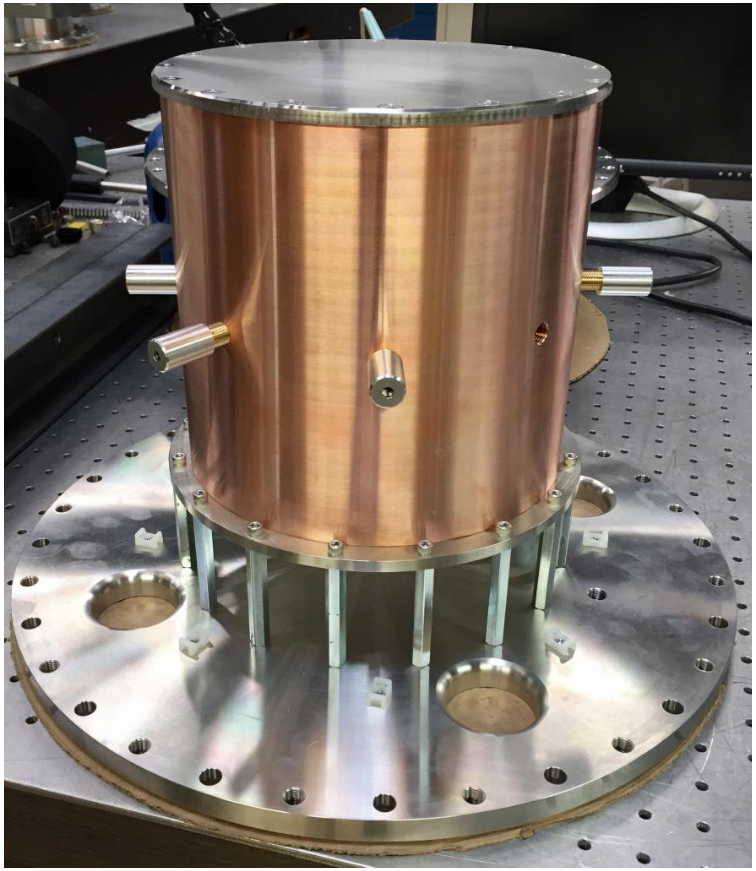
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
.x ±.030
.xx ±.020
.xxx ±.005
.xxxx ±.0005
ANGULAR: ±30'
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
UNCLASSIFIED

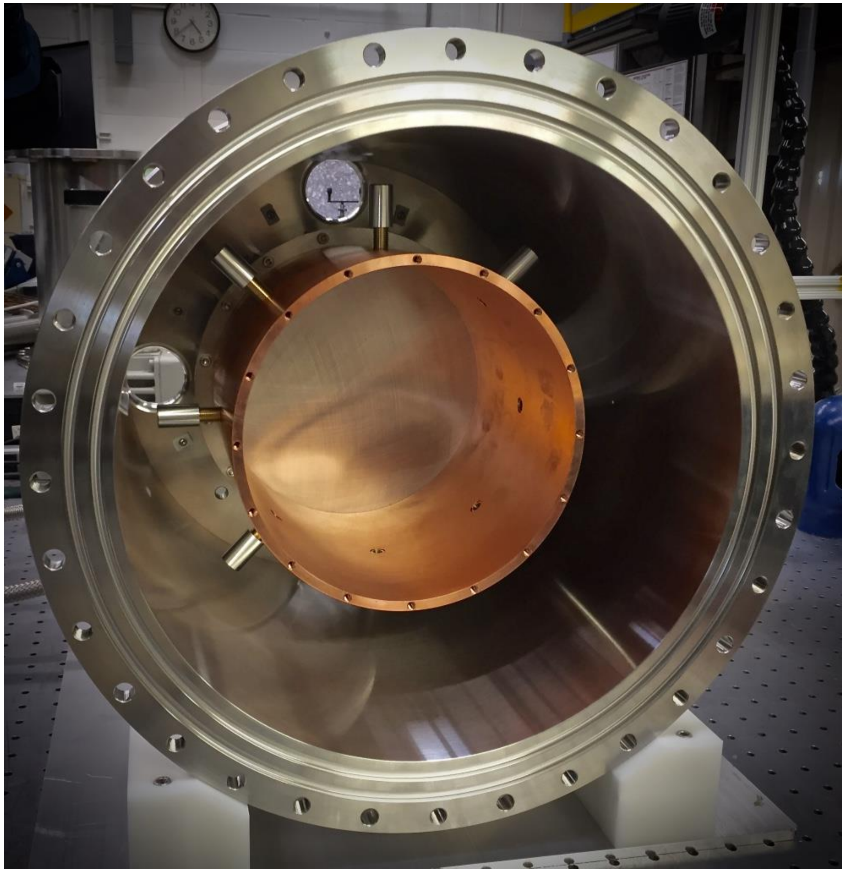
	NAME	DATE
DRAWN	Matt Holmes	7/12/16
CHECKED		
CUSTOMER		

COMMENTS:

Los Alamos NATIONAL LABORATORY — LANL WX-6
TITLE: SPE_Source_Assy_V3
SIZE C — DWG. NO. SPE_Source_Assy_V3 — REV
SCALE: 1:8 — WEIGHT: — SHEET 1 OF 2

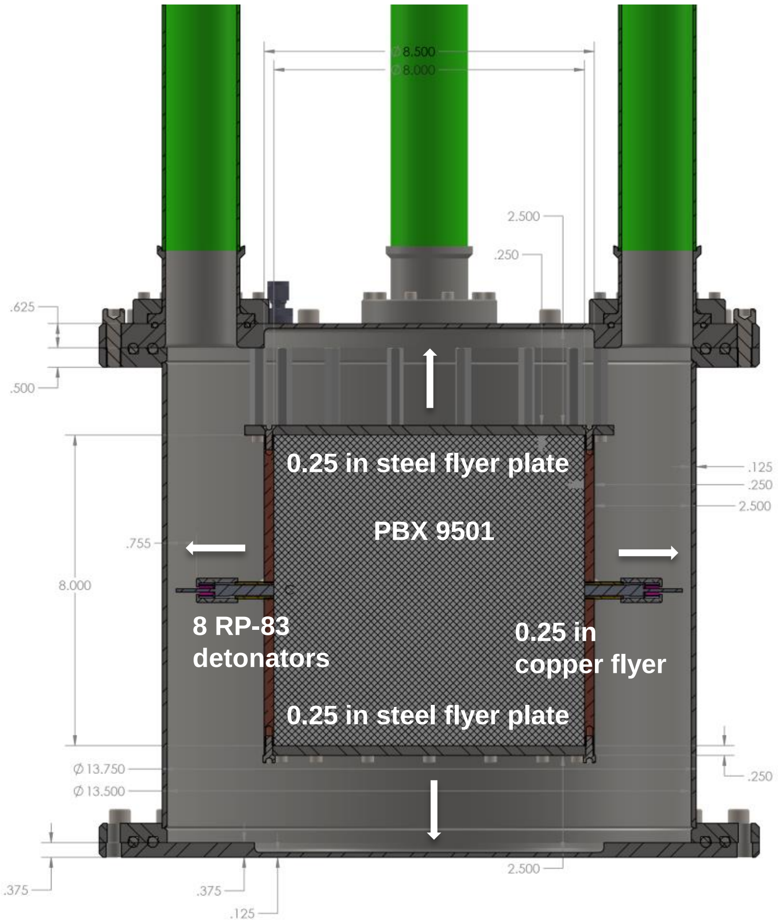
Initiation Canister





Initiator Concept

- Explosively driven flyer plates fired both axially and radially in the center of the nitromethane container;
- 2 sets of 4 RP-83 detonators interleaved at 45˚ locations around the charge equator on separate firesets for redundancy;
- Approximately 13 GPa, 2 μs shock into the nitromethane.
- Unlike direct HE drive, this design is very tolerance-tolerant.



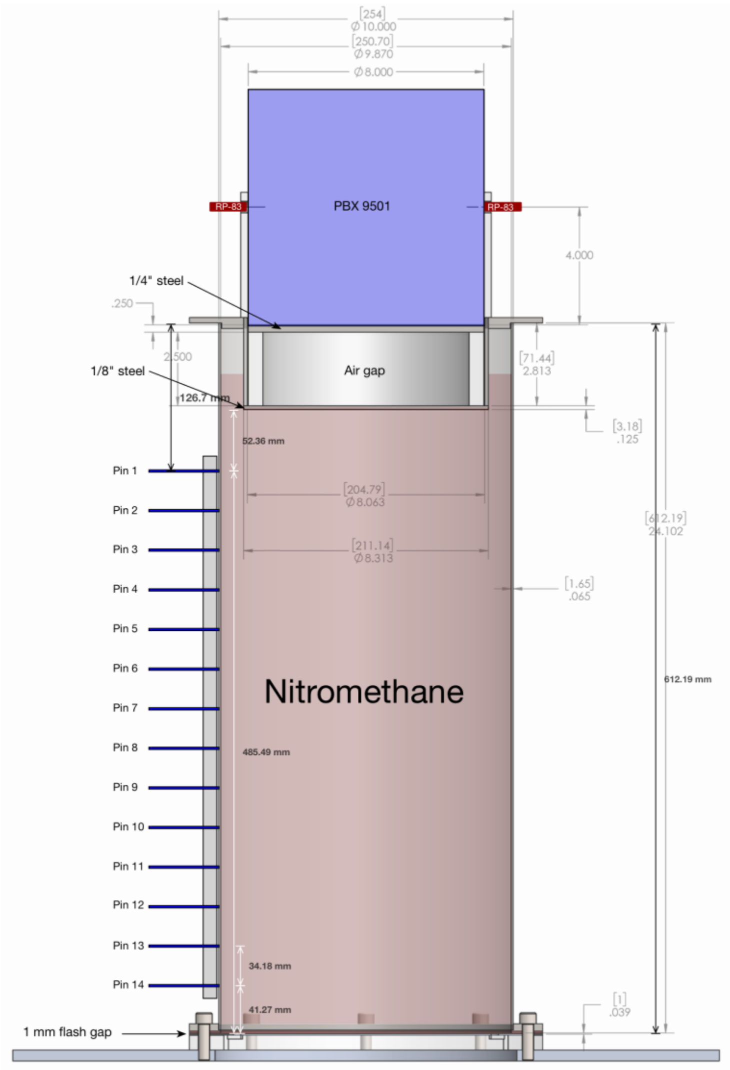
Experimental test series

- **Basic initiation tests**
  - Establish that unsensitized nitromethane is promptly detonated by the proposed initiation method with adequate corner turning
  - Measure detonation velocities and curvature
  - Confirm initiation margins

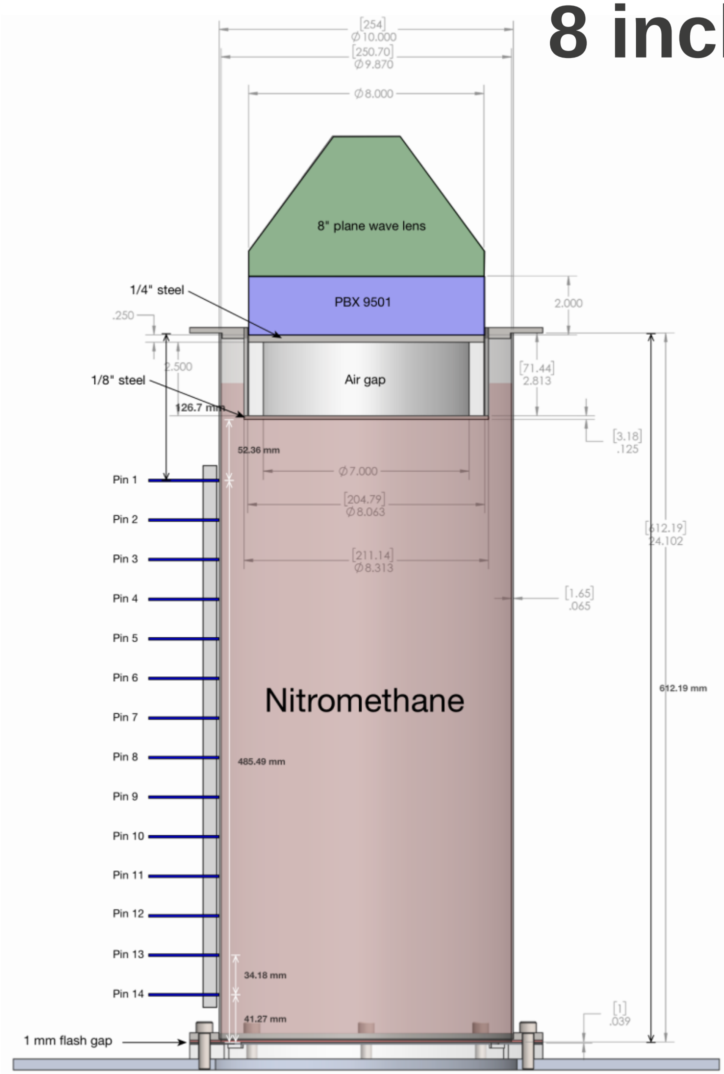
- **Initiation design tests**
  - Use PDV to confirm flyers and outer canister jump-off velocities are in line with predictions
  - Test full initiation design in nitromethane to ensure full and prompt detonation.

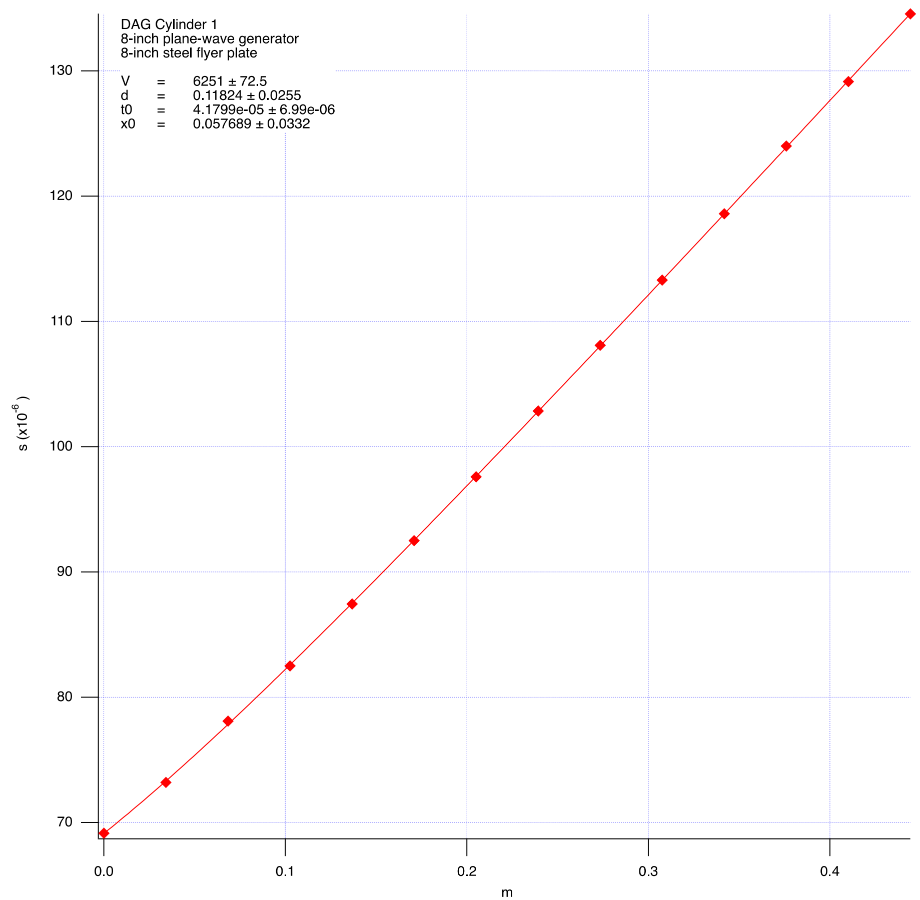
Cylinder tests

- **10-inch-diameter x 24-inch steel tube;**
- **14 pins to measure phase velocity at the wall;**
- **Streak flash gap in the base to measure curvature.**

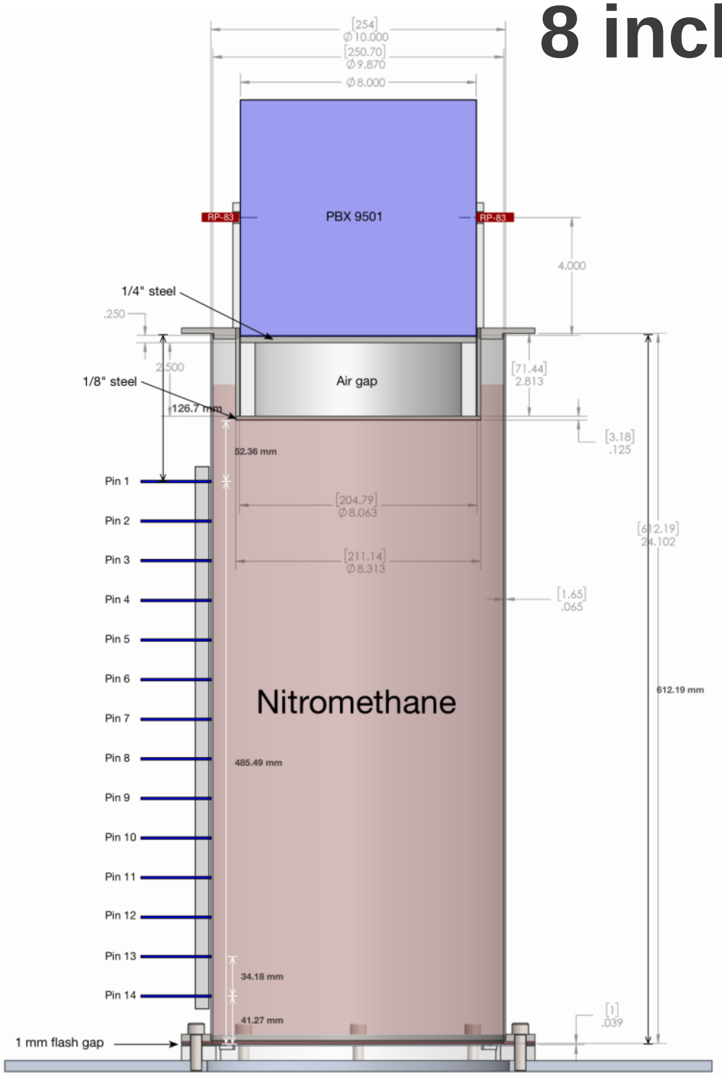


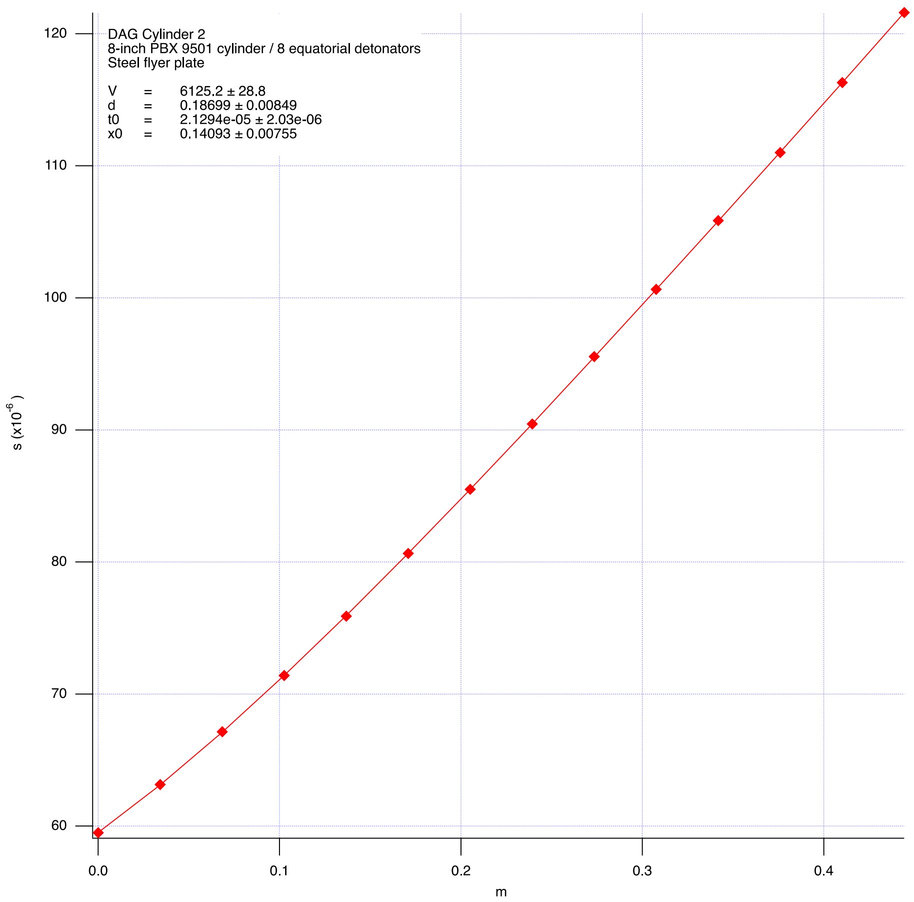
8 inch plane wave / steel flyer



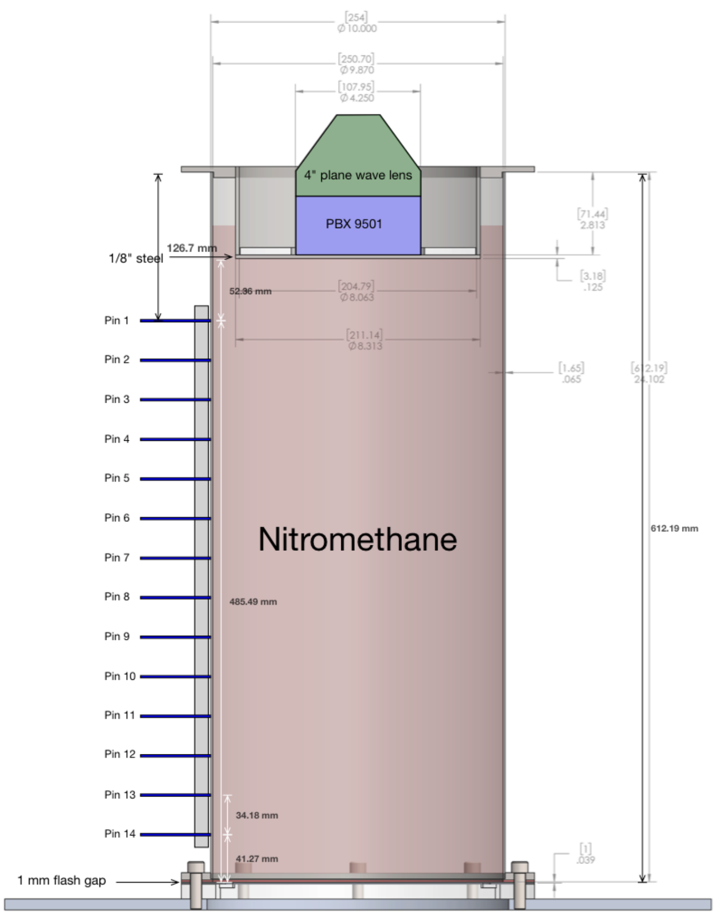


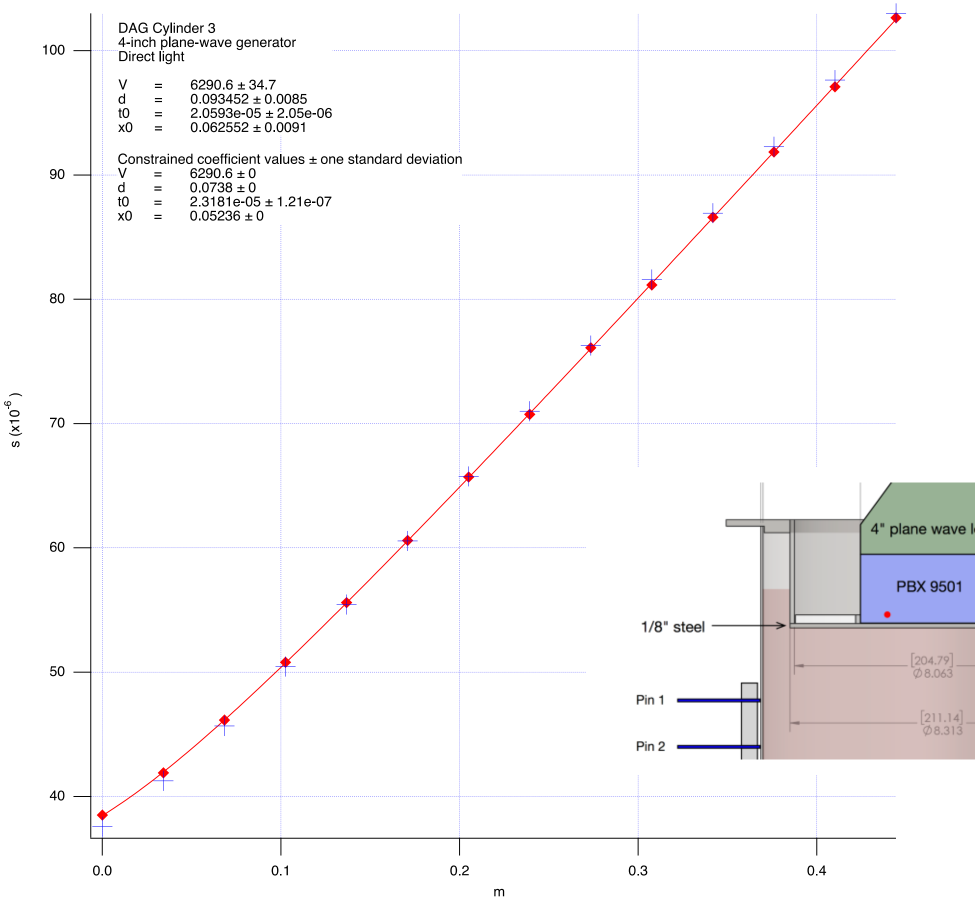
8 inch cylinder / 8 pt / steel flyer



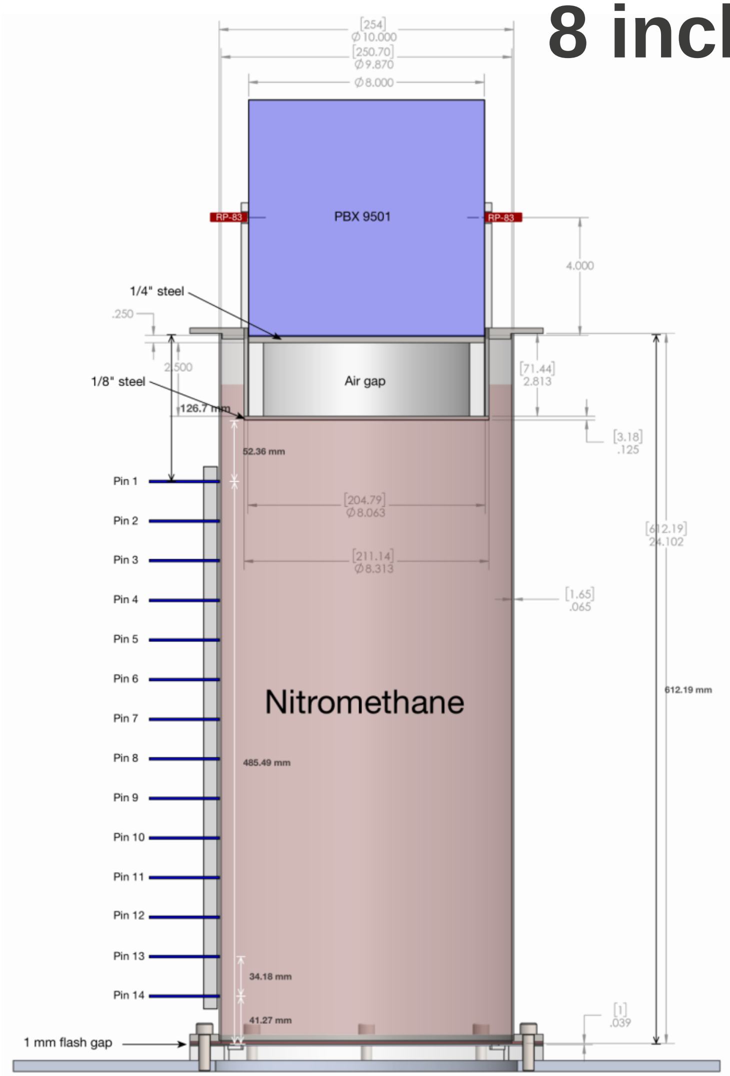


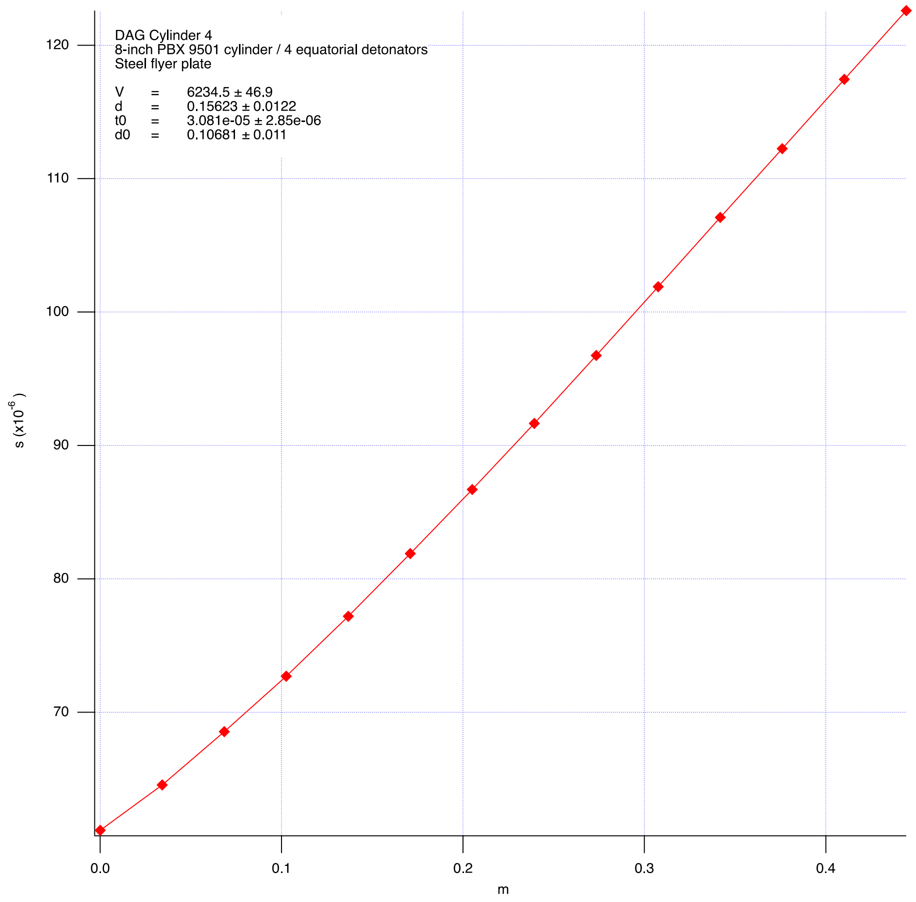
Direct explosive initiation



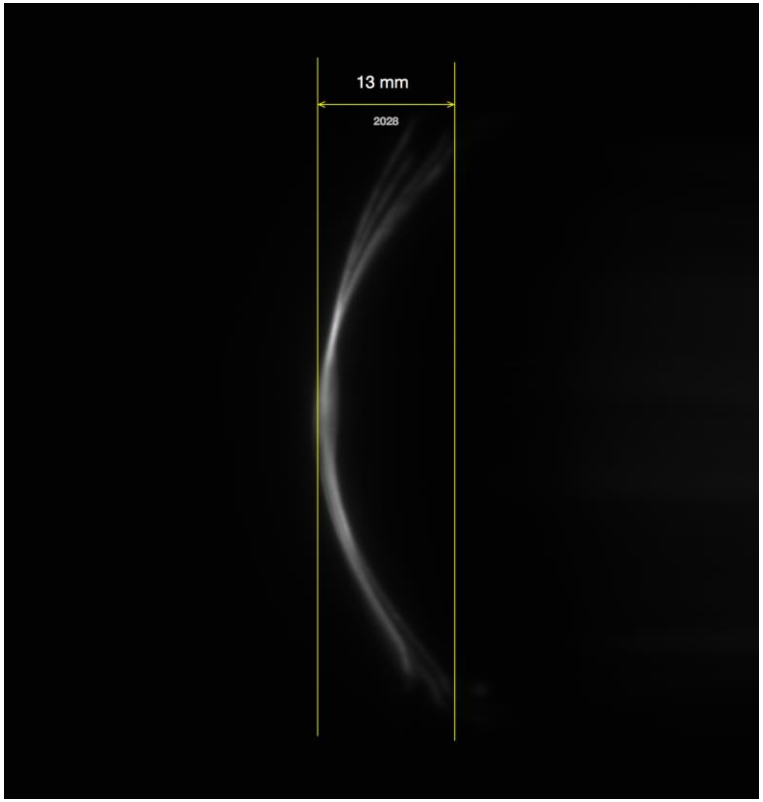


8 inch cylinder / 4 pt / steel flyer

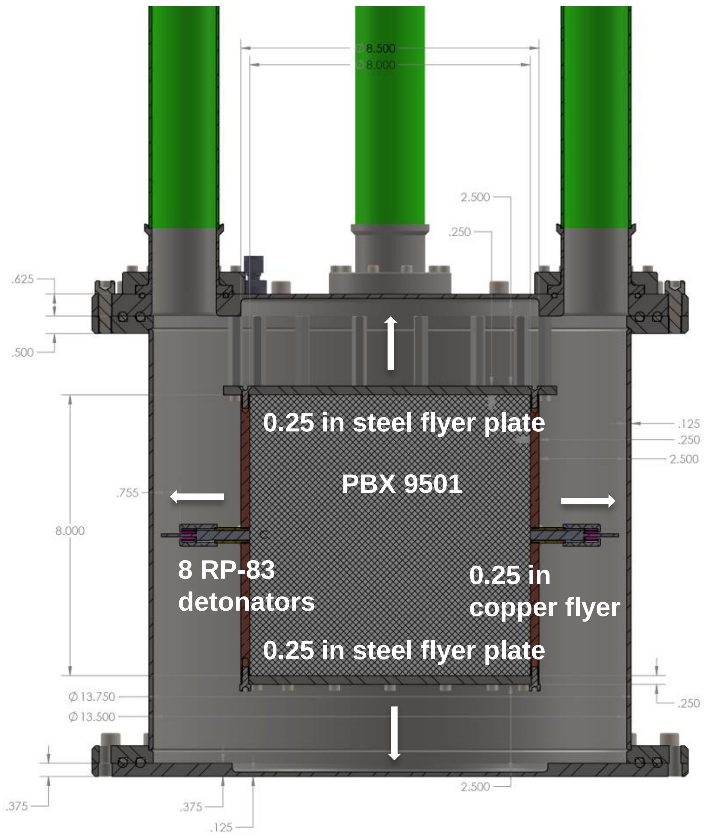


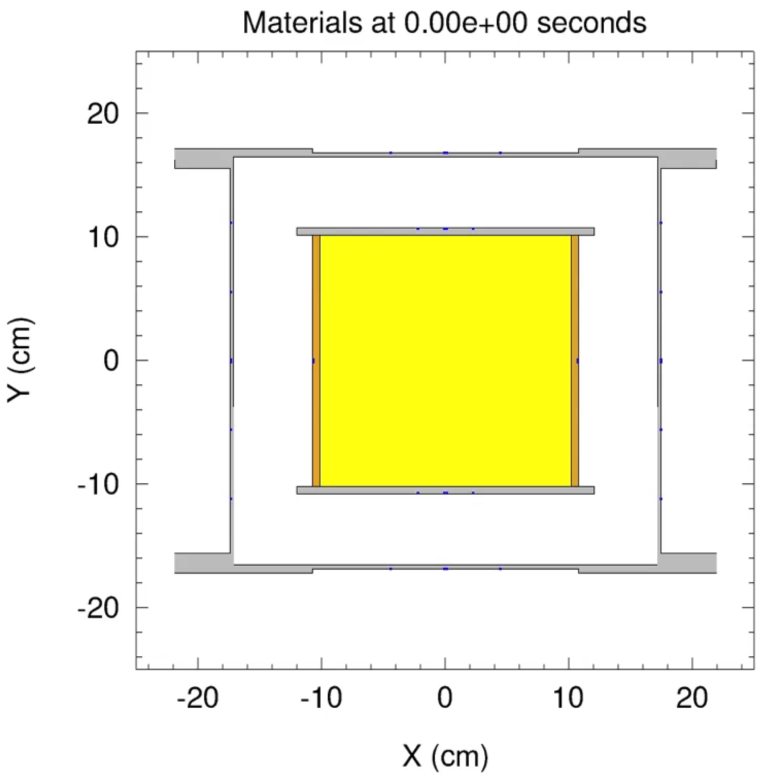


Streak data



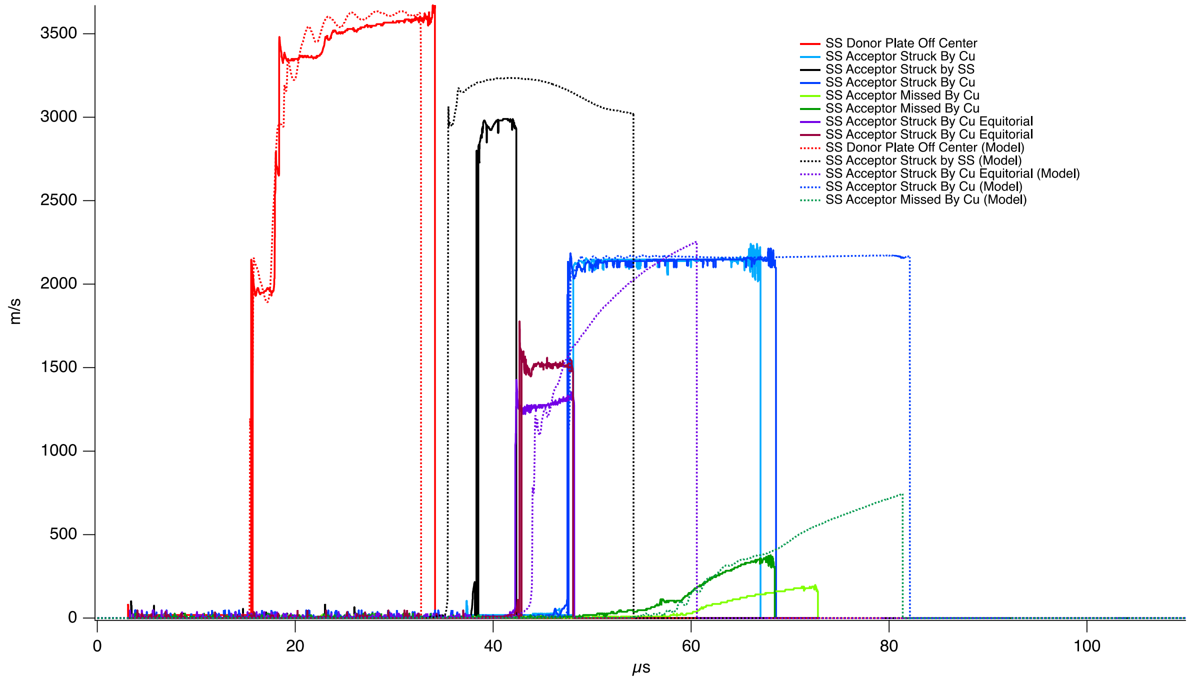
Initiator PDV test



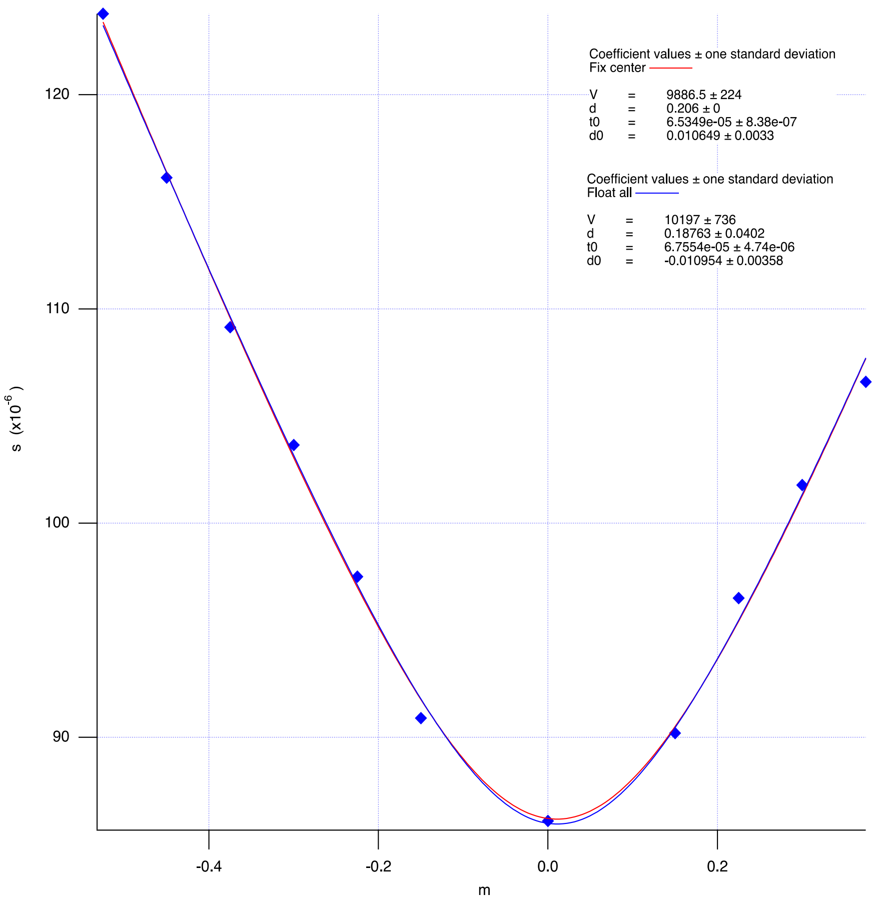


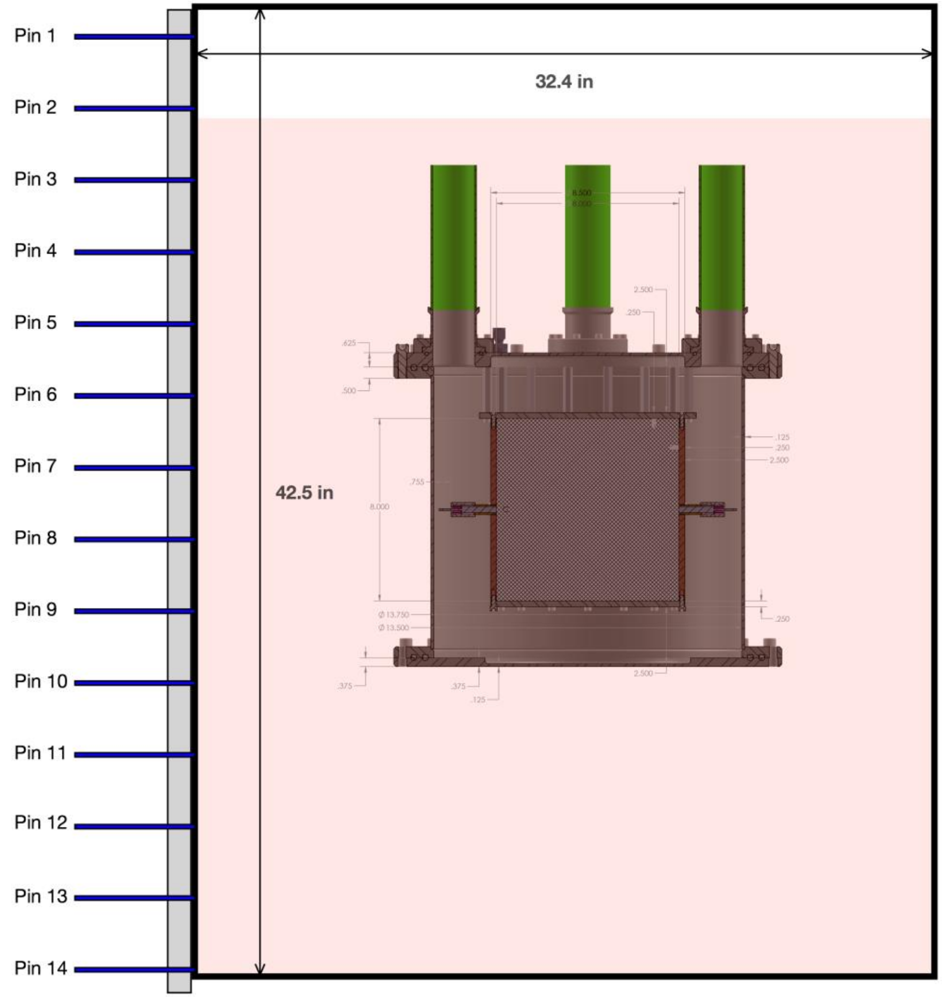
PDV experimental data vs. model

- Good timing and velocity agreement in most locations.
- Predicted pressures should be approximately correct.



DAG Initiator test





National Nuclear Security Administration · Nevada National Security Site · Los Alamos National Laboratory EST. 1943 · National Security Technologies LLC Vision • Service • Partnership · Lawrence Livermore National Laboratory · Sandia National Laboratories · Nevada

Recommendations

- Nitromethane initiation tests confirm that it detonates promptly as expected, even under the lowest shock input tested, and that corner turning is as reported in the literature.
- Characterization of the proposed initiation system shows that it performs as designed, with a significant margin for prompt initiation.
- Testing the proposed initiation system with approximately 1000 lbs of nitromethane resulted in full detonation with no indication of dead zones.

Dry Alluvium Geology (DAG) Experiments Timing & Firing Preliminary Design Review (PDR)

Topics

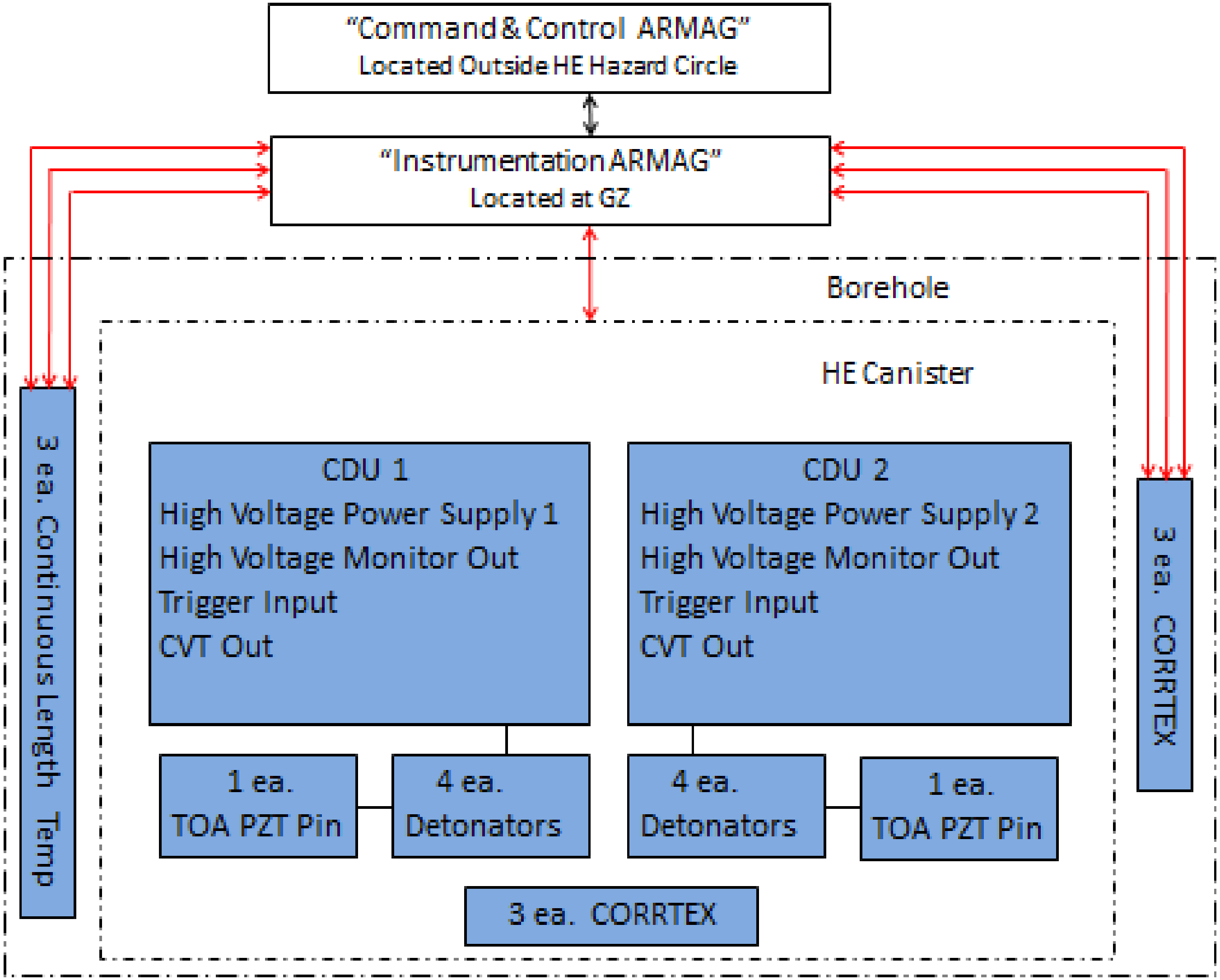
- **High Level Review - "as proposed" vs current**
- **Timing & Firing System (T&F)**
- **Firesets/Detonators****
- **Fireset/Detonator Diagnostics**
- **Surface/Subsurface Cabling**
- **Other Diagnostics: CORRTEX, grout temperature, NM level/leak**

**Detonator specification/selection dictated by explosives train, as such covered by M-6

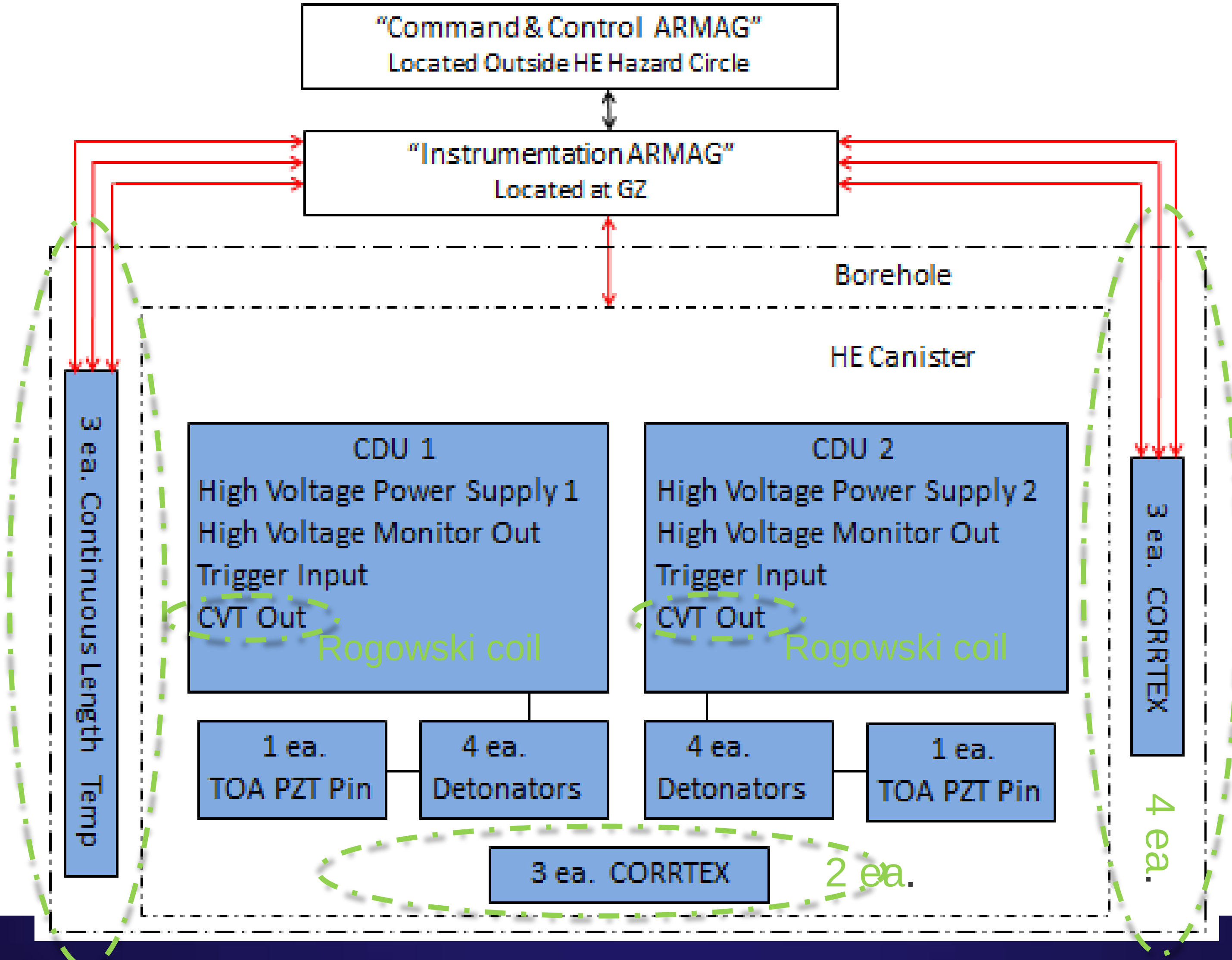
Topics

- ***High Level Review - "as proposed" vs current***
- Timing & Firing System (T&F)
- Firesets (CDU)
- Fireset/Detonator Diagnostics
- Surface/Subsurface Cabling
- Other Diagnostics: CORRTEX, grout temperature, NM level/leak

Topic: High Level Review - "as proposed" vs current

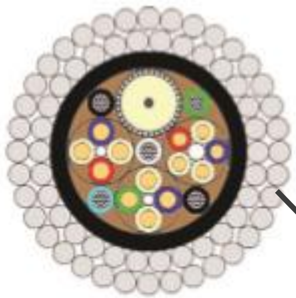


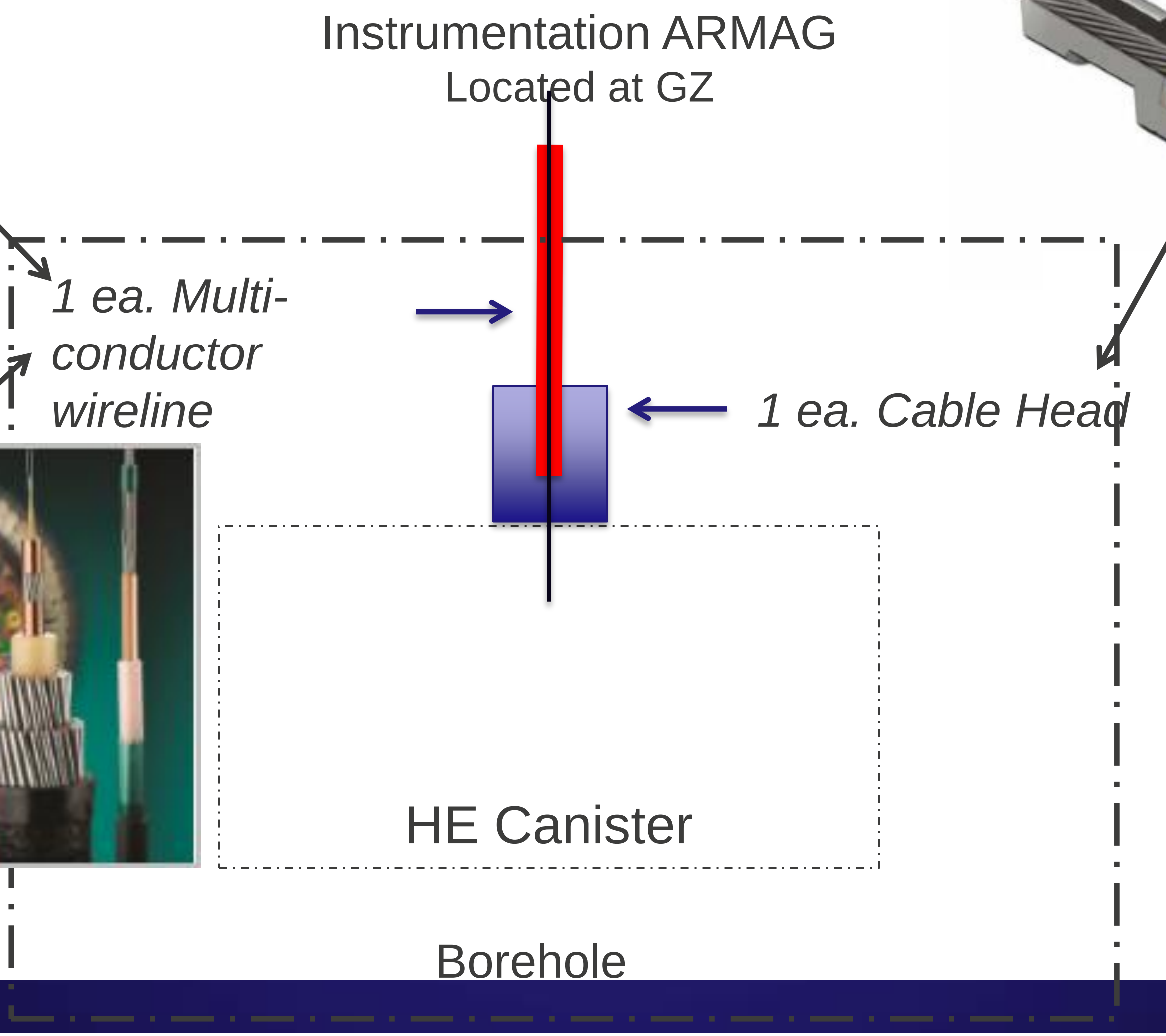
Topic: High Level Review - "as proposed" vs current



Topic: High Level Review - "as proposed" vs current

Technical Approach: Cabling - Utilize Oil & Gas Technology

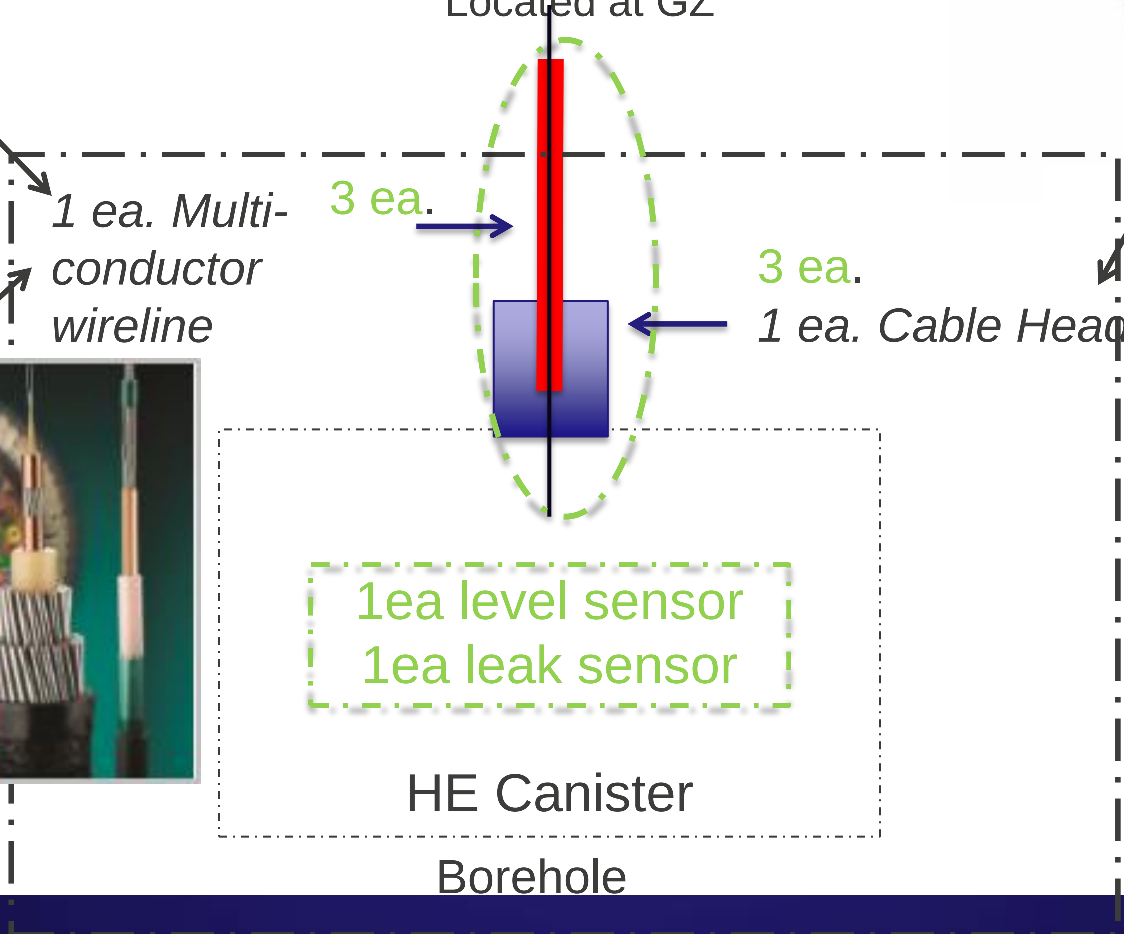




This approach avoids the need for gas block cable and tolerates high temperatures and other stemming issues

Topic: High Level Review - "as proposed" vs current

Technical Approach: Cabling - Utilize Oil & Gas Technology



This approach avoids the need for gas block cable and tolerates high temperatures and other stemming issues

Topics

- High Level Review - "as proposed" vs current
- ***Timing & Firing System (T&F)***
- Firesets (CDU)
- Fireset/Detonator Diagnostics
- Surface/Subsurface Cabling
- Other Diagnostics: CORRTEX, temperature, NM level/leak

Topic: Timing and Firing System (T&F)

BLUF (Bottom Line Up Front)

1) LANL HE oversight safety committee has reviewed and approved the DAG/Kappa West T&F system
2) The T&F system was used to execute "frag shot" at Kappa West - February 2017
3) We will continue to make improvements to the T&F system

- ✓ ***DAG T&F baseline design was based on an existing system in use at LANL***
- ✓ ***Kappa West provided an "early start" venue for fielding the DAG T&F system at the NNSS***

Topic: Timing and Firing System (T&F)

Command and Control ARMAG

Used by both DAG and Kappa West

Topic: Timing and Firing System (T&F)

Command and Control ARMAG

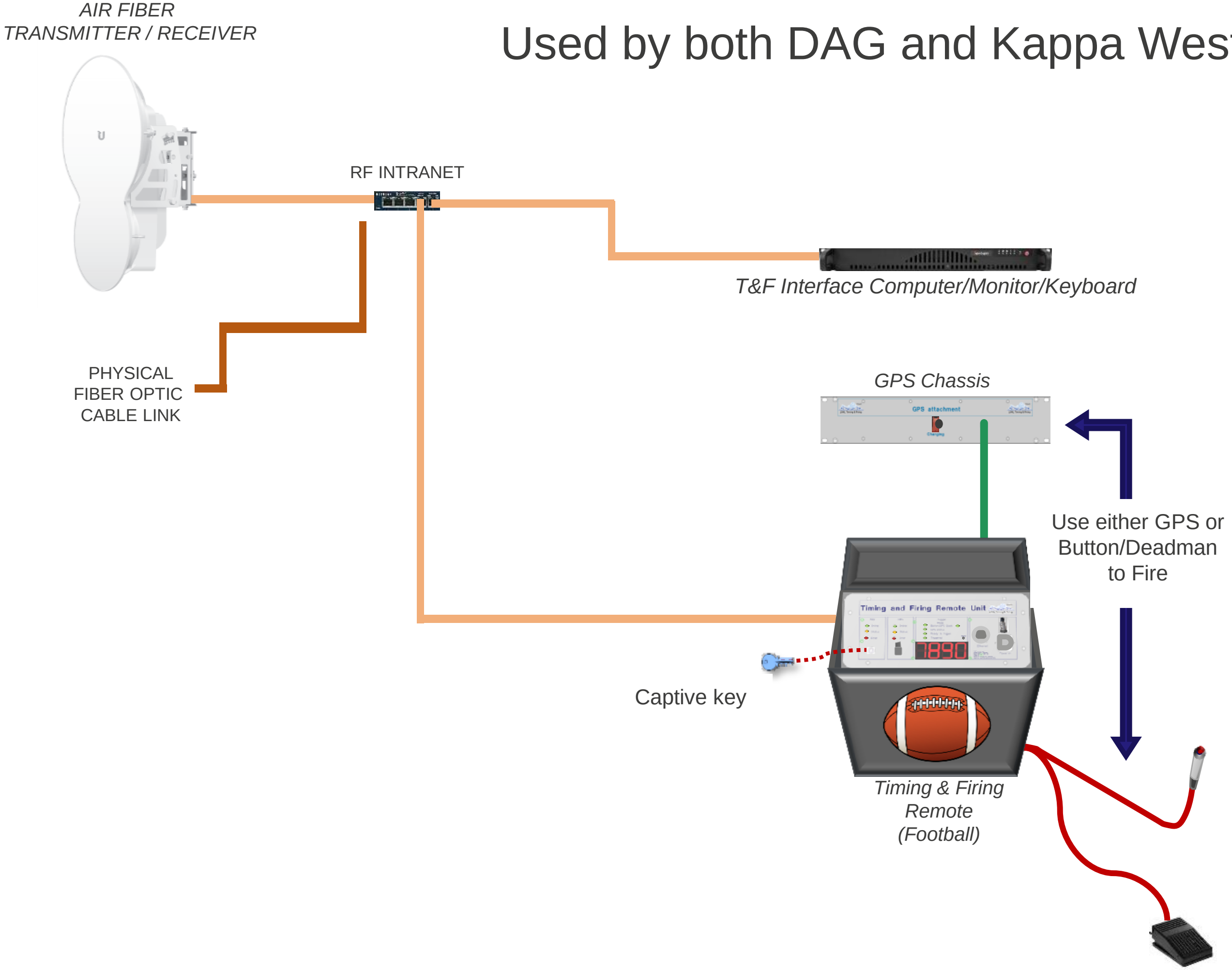
Used by both DAG and Kappa West

X-RAY | Timing and Firing | Timing and Firing | HS Camera 1 & 2 | HS Camera 3 & 4 | Communications

Topic: Timing and Firing System (T&F)

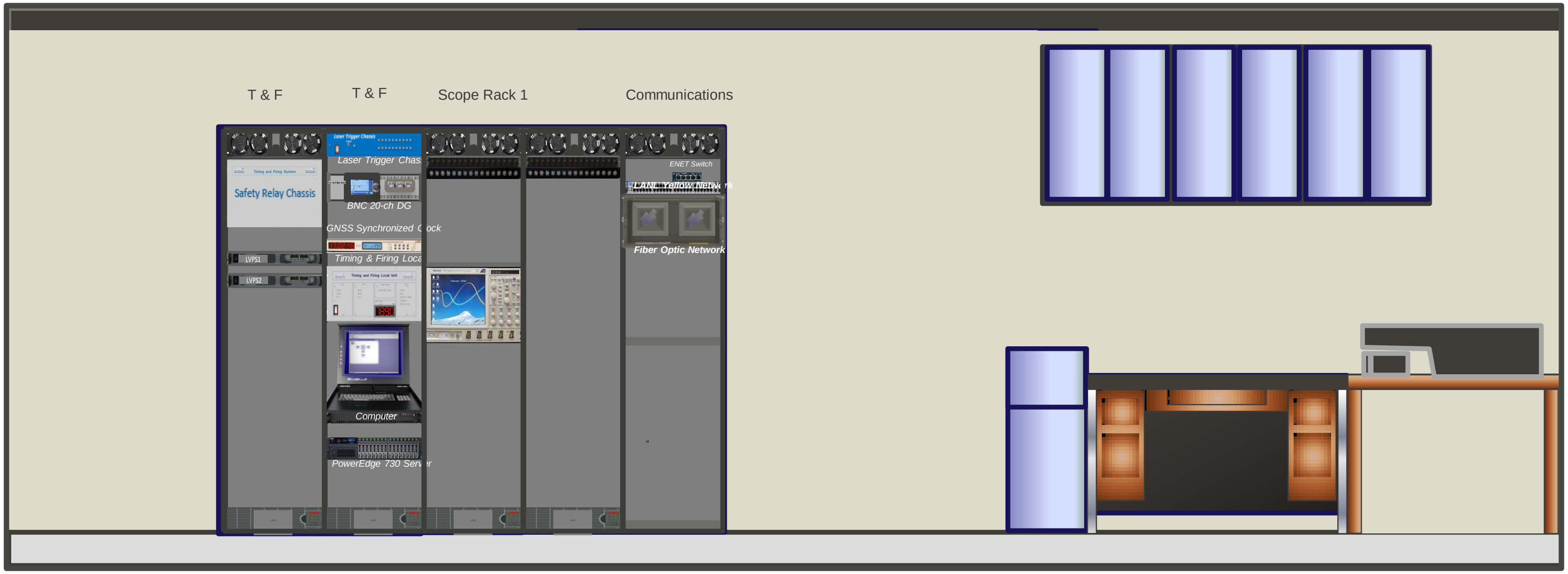
Command and Control ARMAG

Used by both DAG and Kappa West



Topic: Timing and Firing System (T&F)

DAG Instrumentation ARMAG

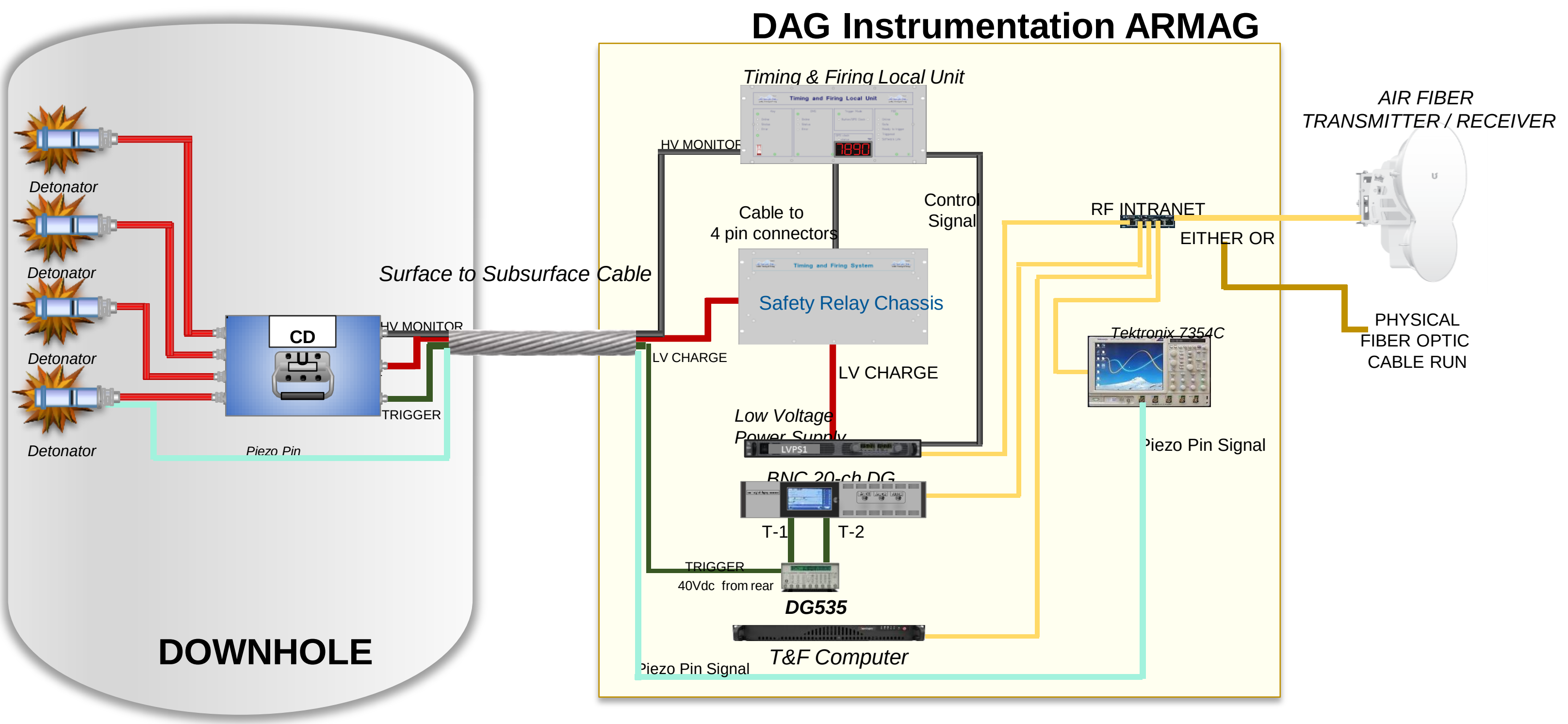


Topic: Timing and Firing System (T&F)

Kappa West Instrumentation ARMAG

Topic: Timing and Firing System (T&F)

Topic: Timing and Firing System (T&F)

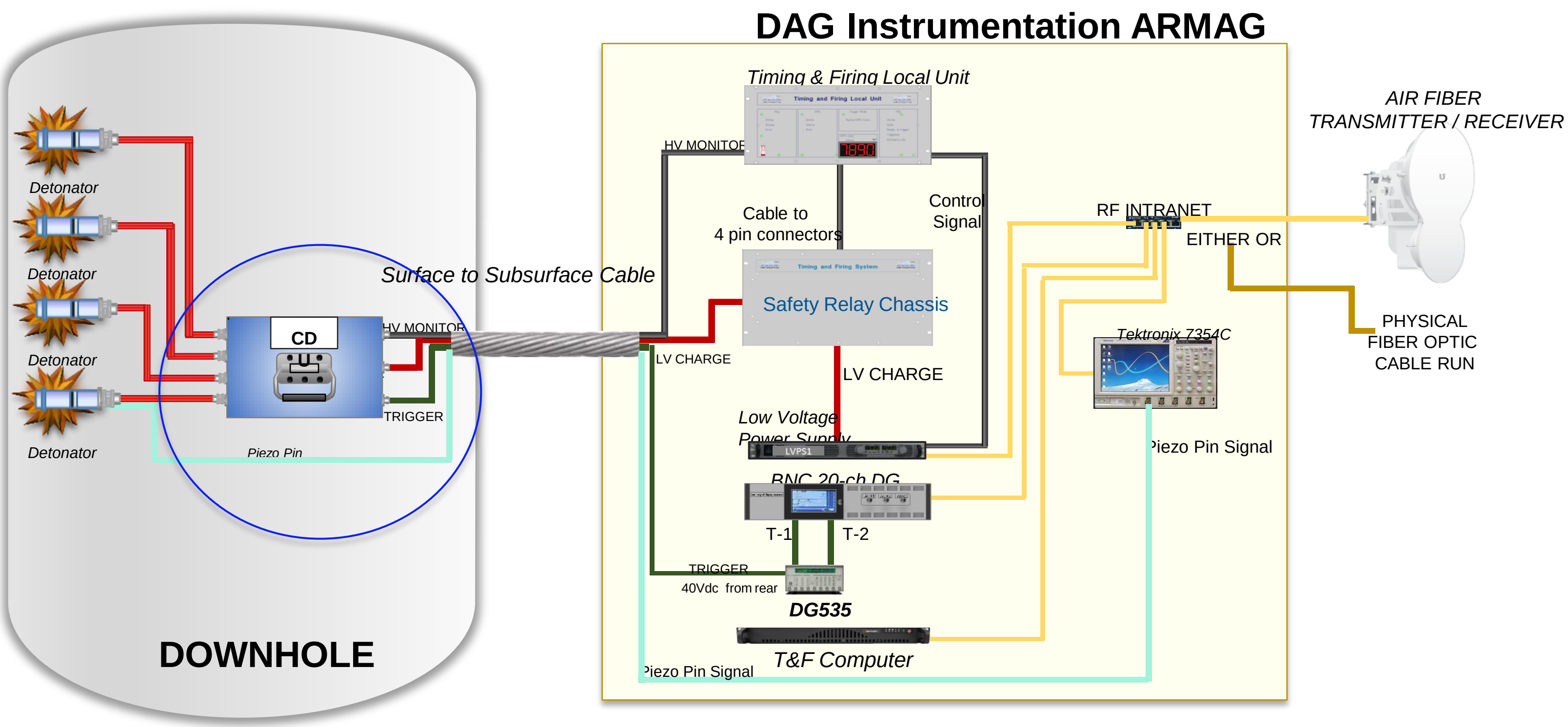


National Nuclear Security Administration · Nevada National Security Site · Los Alamos National Laboratory EST. 1943 · National Security Technologies LLC Vision • Service • Partnership · Lawrence Livermore National Laboratory · Sandia National Laboratories · Nevada

Topics

- High level review "as proposed" vs current
- Timing & Firing System (T&F)
- ***Firesets (CDU)***
- Fireset/Detonator Diagnostics
- Surface/Subsurface Cabling
- Other Diagnostics: CORRTEX, temperature, NM level/leak

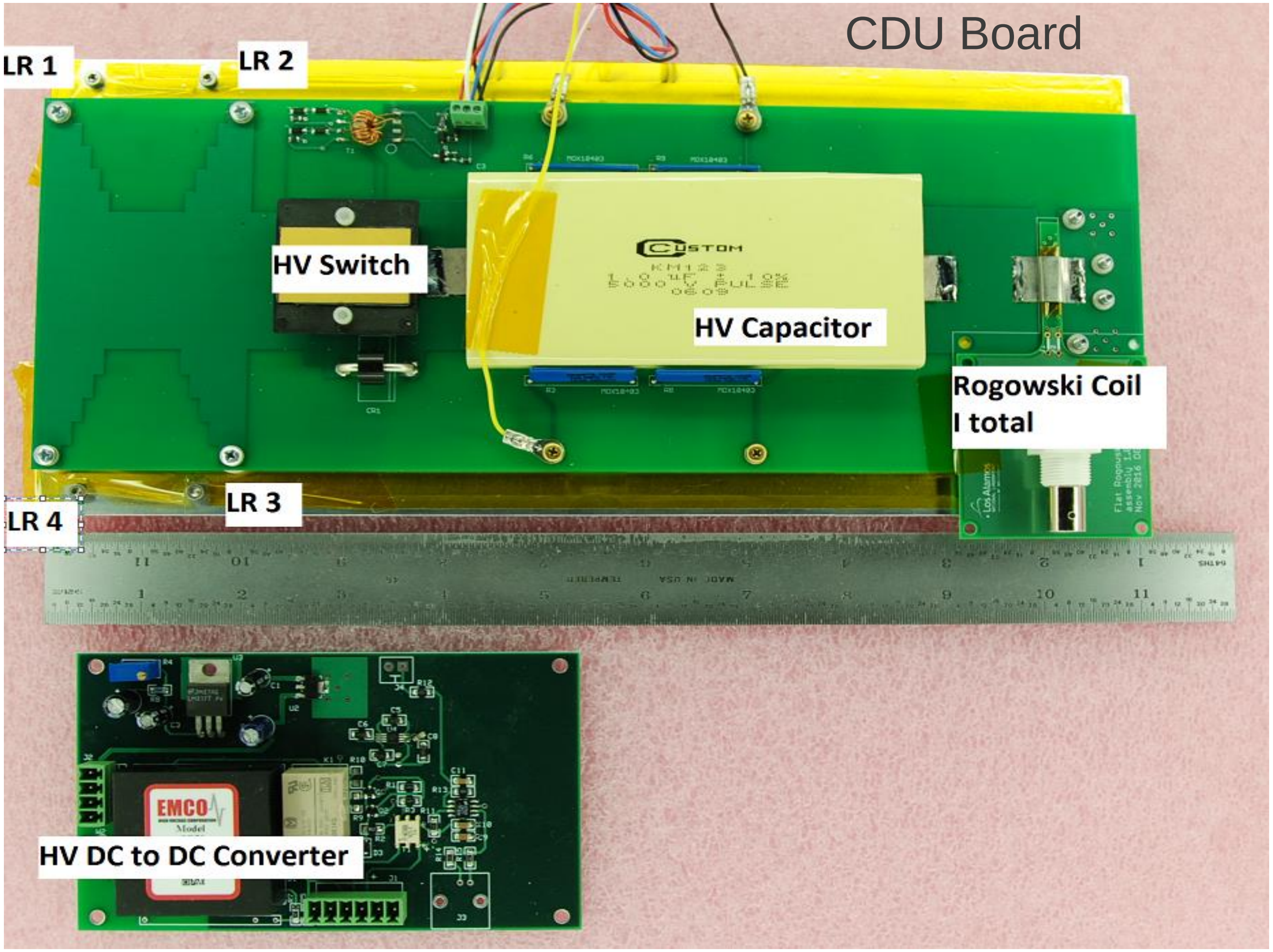
Topic: Firesets (CDU)



Topic: Firesets (CDU)

- Modeling
  - Criteria
    - HV charge: 3500 volts max
    - HV capacitor: 1-2 uf
    - 4 detonators per CDU configured in parallel
    - Firing cables 20 feet long
- Identify worst case environmental operating conditions (NNSS open field testing) and impact with regard to reliability
  - Considered Temperature/swing/cycling, Humidity/Rain, Vibration, Dust/Dirt/Sand
    - Temperature/swing/cycling (0 to150 F/8hours/5 cycles)
    - Rain
    - Dust/dirt/sand
- Identify critical parts
  - HV Capacitor, HV DC to DC converter, HV switch, Detonator Cabling
    - Reviewed past projects to identify baseline parts/manufactures'

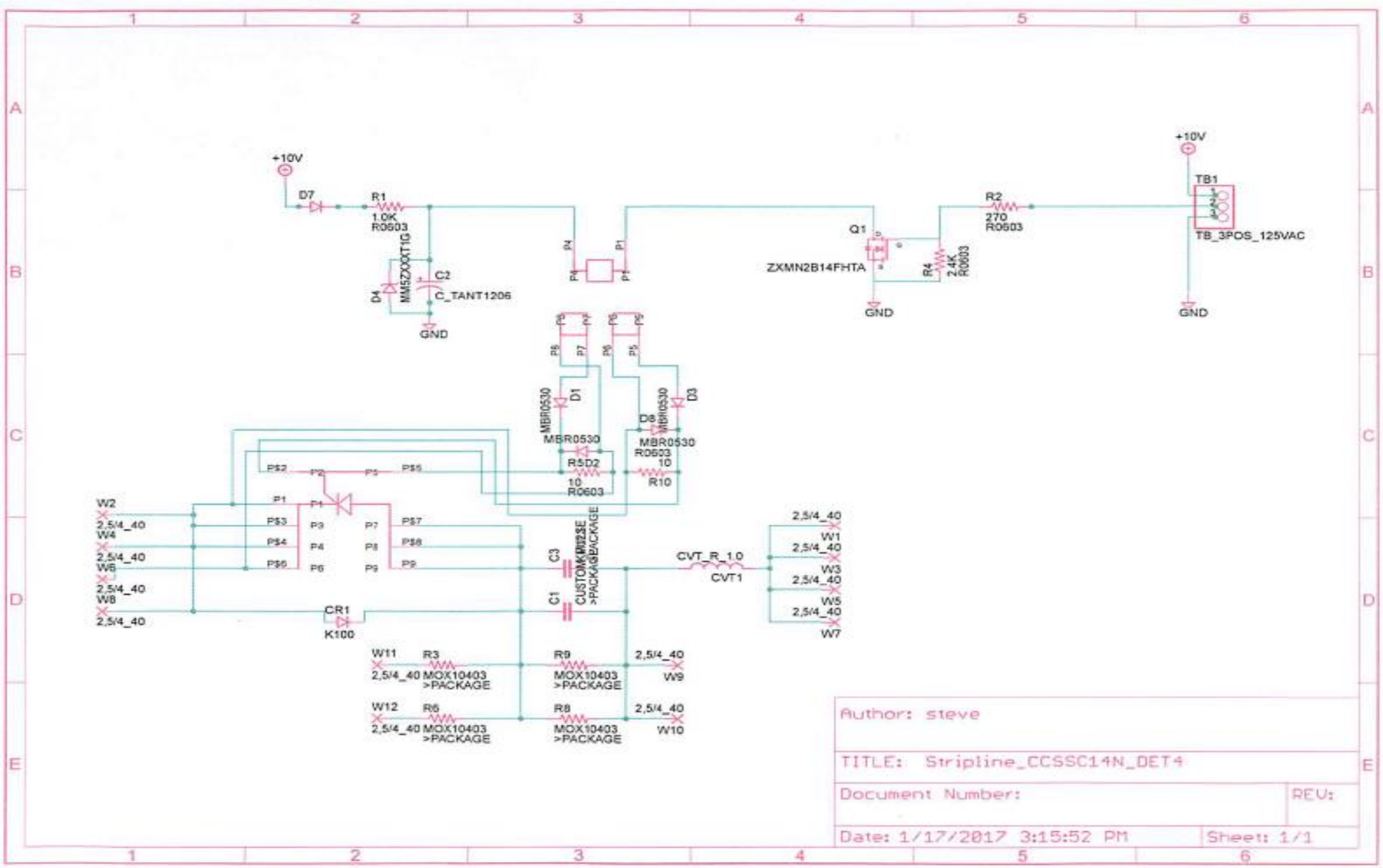
Topic: Firesets (CDU)



HV DC to DC Converter Board

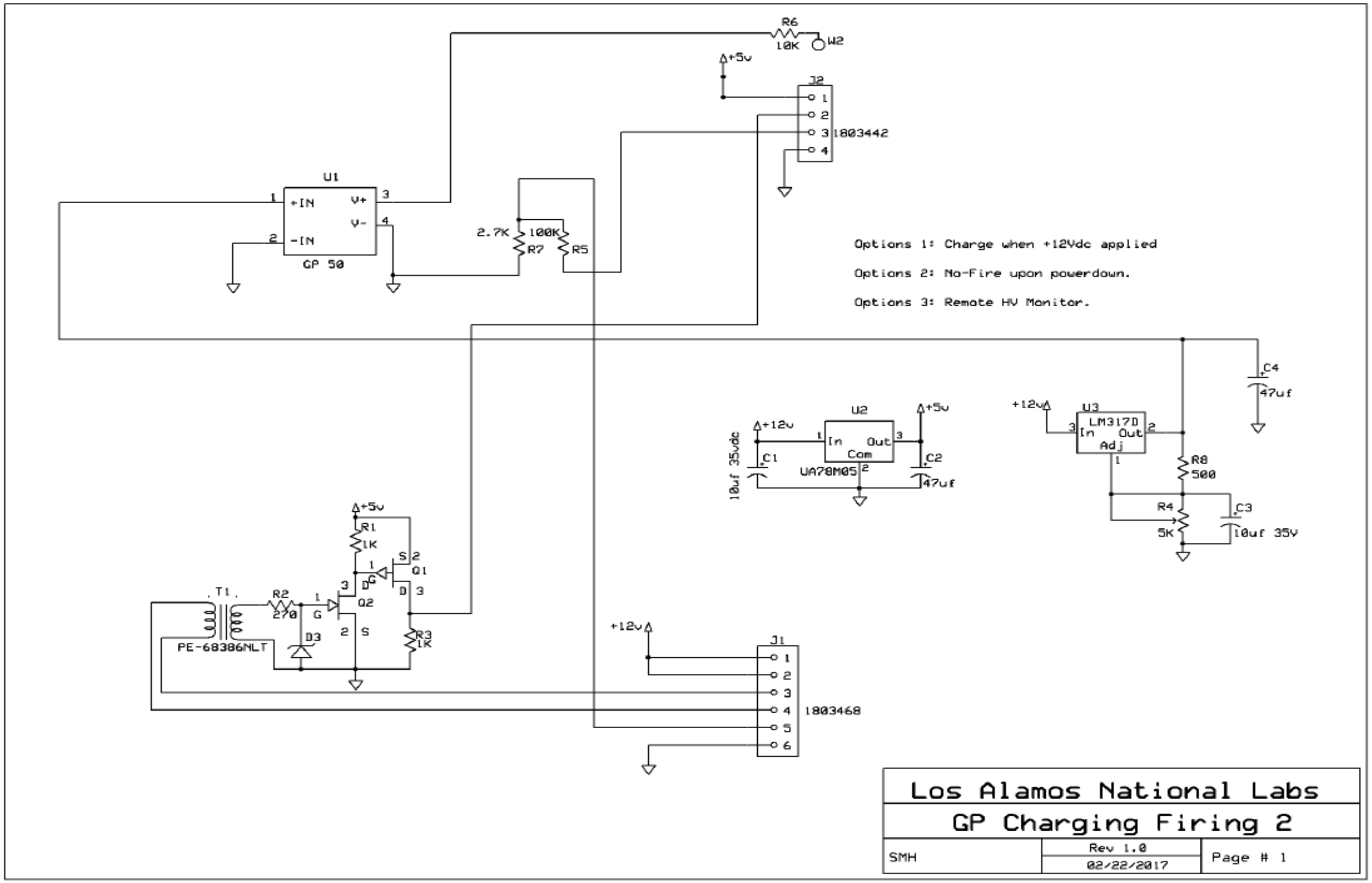
Topic: Firesets (CDU)

CDU Board



Topic: Firesets (CDU)

HV DC to DC Converter Board



Topics

- High level review "as proposed" vs current
- Timing & Firing System (T&F)
- Firesets (CDU)
- ***Fireset/Detonator Diagnostics***
- Surface/Subsurface Cabling
- Other Diagnostics: CORRTEX, temperature, NM level/leak

Topic: Fireset/Detonator Diagnostics

- Rogowski Coil
  - Will be used to facilitate characterization of the CDU/detonator - performance/margin
    - Charge voltage vs Time to Burst &Burst Current
  - Will be installed/integrated into the CDU, but not used subsurface - tentative
- Piezo Pin
  - Will be used to facilitate characterization of the CDU/detonator timing
    - Start of Current to Detonator Breakout (surface)
    - T zero to Detonator Breakout (surface & subsurface)
  - Will be installed and used subsurface
    - Concerns regarding the ability of the Piezo pin to "drive" ~ 1500 feet of coax cable – experiment conducted at Kappa West – demonstrated it will provide the requisite data

Topics

- High level review "as proposed" vs current
- Timing & Firing System (T&F)
- Firesets (CDU)
- Fireset/Detonator Diagnostics
- ***Surface/Subsurface Cabling***
- Other Diagnostics: CORRTEX, temperature, NM level/leak

Topic: Surface/Subsurface Cabling

- Armored multi-conductor cable, not an "exotic product" in the O&G world – used routinely
  - Identified and corresponded with a possible vendor
  - Approximately 12 week delivery for most configurations

Topic: Surface/Subsurface Cabling

- 1ea armored cable containing:
  LVPS, trigger, (inputs; interior of HE Canister)
  HVPS monitor, Piezo Pin, *NM level measurement* (outputs; interior of HE Canister)
- 1ea armored cable containing:
  LVPS, trigger, (inputs; interior of HE Canister)
  HVPS monitor, Piezo Pin, *NM leak detector* (outputs; interior of HE Canister)
- 1ea armored cable containing:
  2 CORRTEX coax cables (interior of HE Canister)
- 2ea armored cable containing:
  2 CORRTEX coax cables (exterior of HE Canister)

Topics

- High level review "as proposed" vs current
- Timing & Firing System (T&F)
- Firesets (CDU)
- Fireset/Detonator Diagnostics
- Surface/Subsurface Cabling
- ***Other Diagnostics:*** CORRTEX, temperature, NM level/leak

Topic: Other Diagnostics

- NM Level Measurement

  Non contact, ultrasonic

  Provides information regarding leak based on liquid level; doesn't provide insight regarding where NM is going

Topic: Other Diagnostics

- NM leak detector
  - Contact, capacitance …TBD
  - Located in the HE package; not in electrical contact with HE

Topic: Other Diagnostics

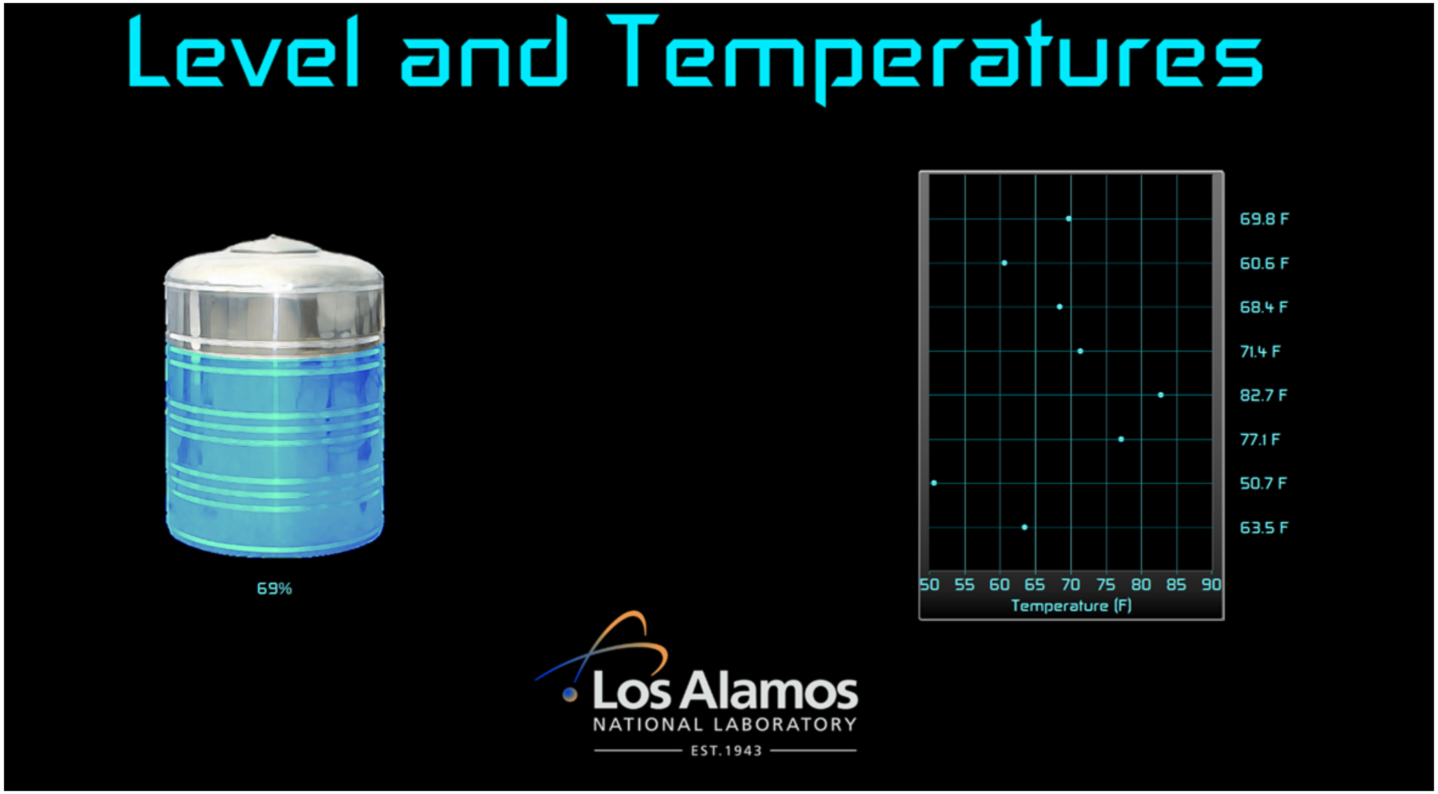
- Grout Temperature

  Type J TC max of 400 F

  Use 1000 feet of TC extension wire; might require 2 runs in parallel to reduce loop resistance to acceptable levels (~ 100ohms)

Topic: Other Diagnostics

- 1 microcontroller periodically reads thermocouples and level
- Data accessible via internal web server (i.e. can be seen by any web browser simultaneously on several computers)

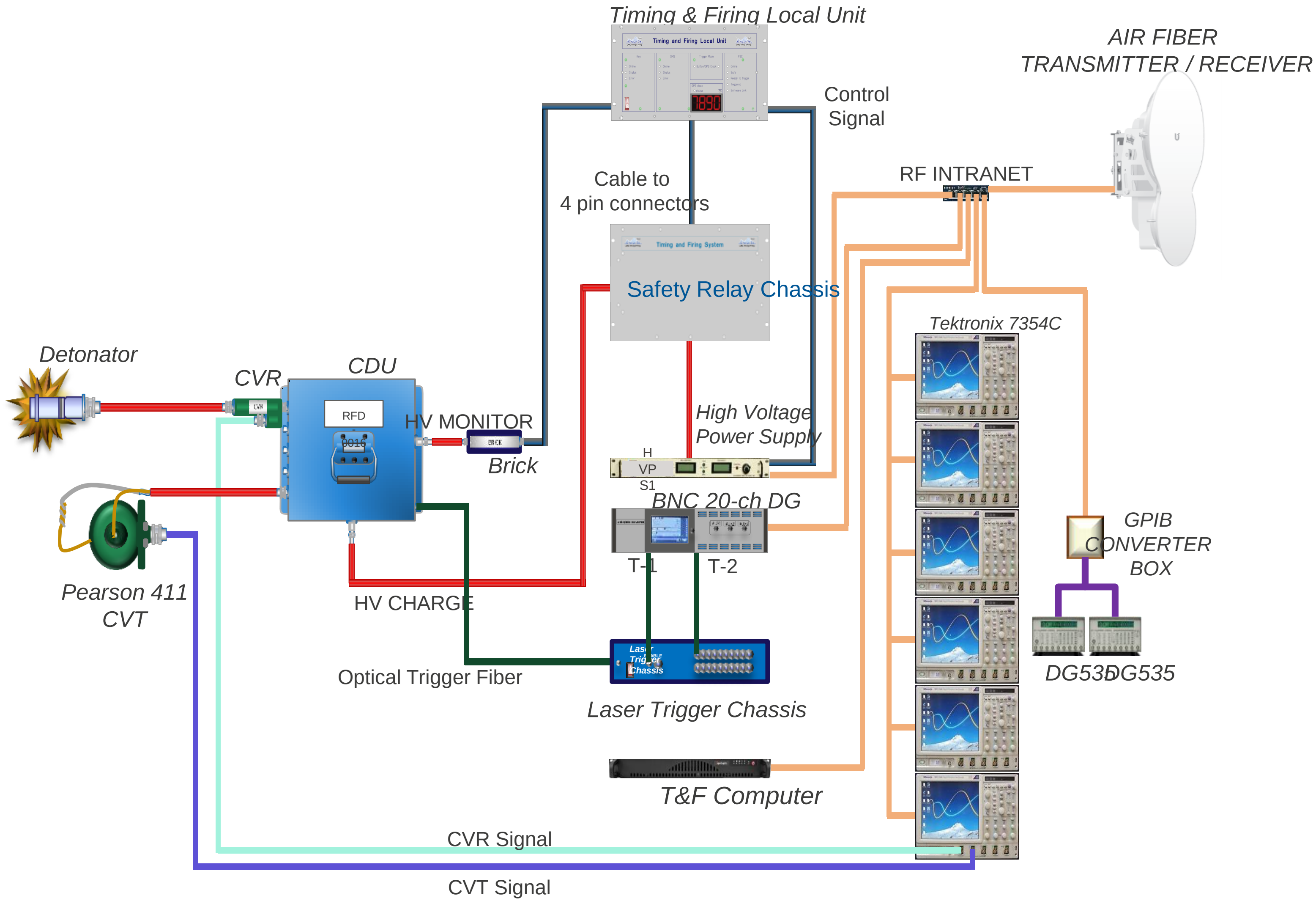


Back Up

Topic: Firesets (CDU)

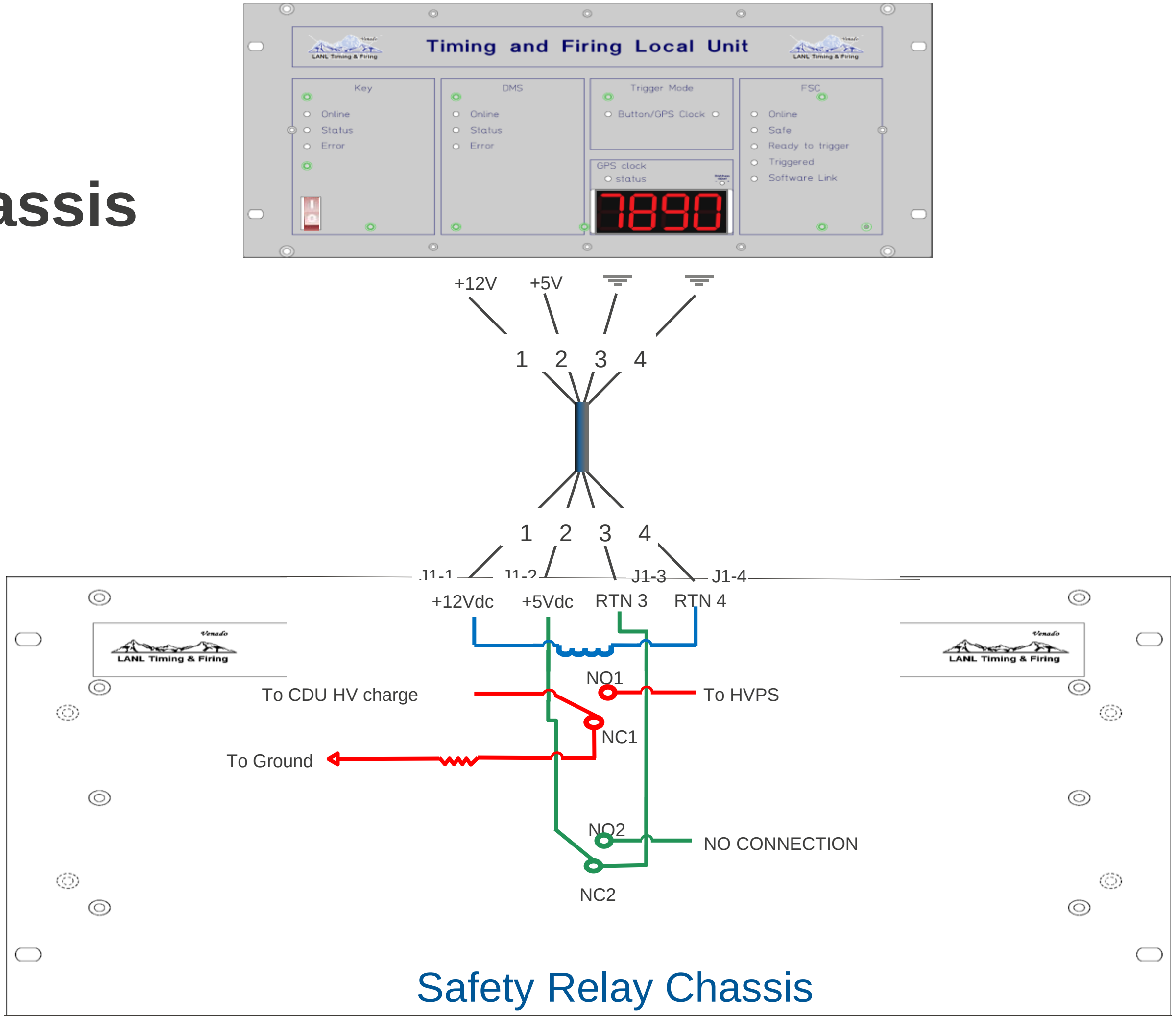
- Investigating 2 different high voltage switches, both are solid state
  - S38 Thyristor Module: Applied Pulse Power Inc.
    - Fielded on a Chevron project
  - CCSSC14N40A10 Single Die: Silicon Power Inc.
    - Used by Q-6 in prototype CDU's

Kappa West Instrumentation ARMAG



Kappa West Instrumentation ARMAG

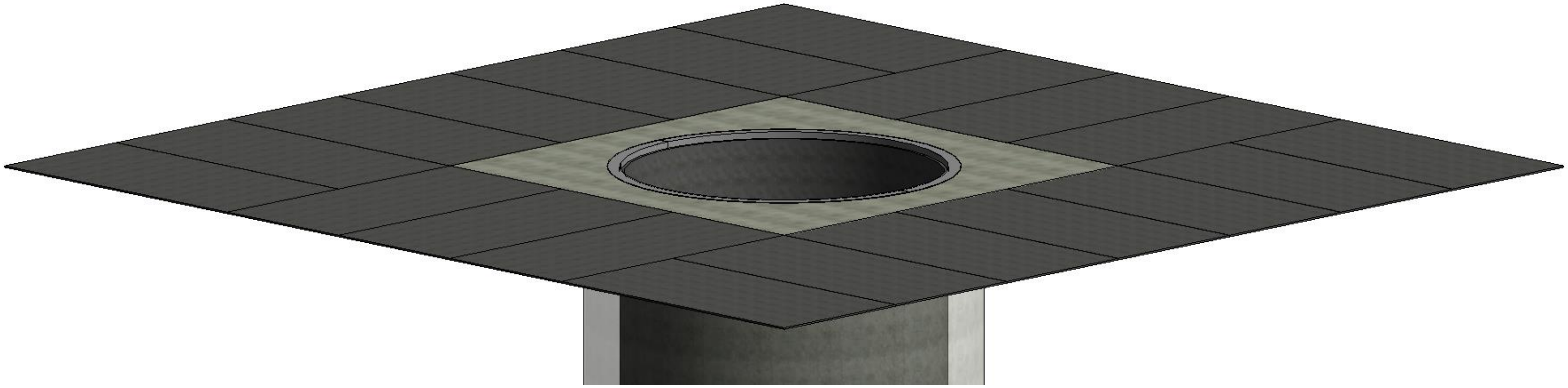
Safety Relay Chassis Function



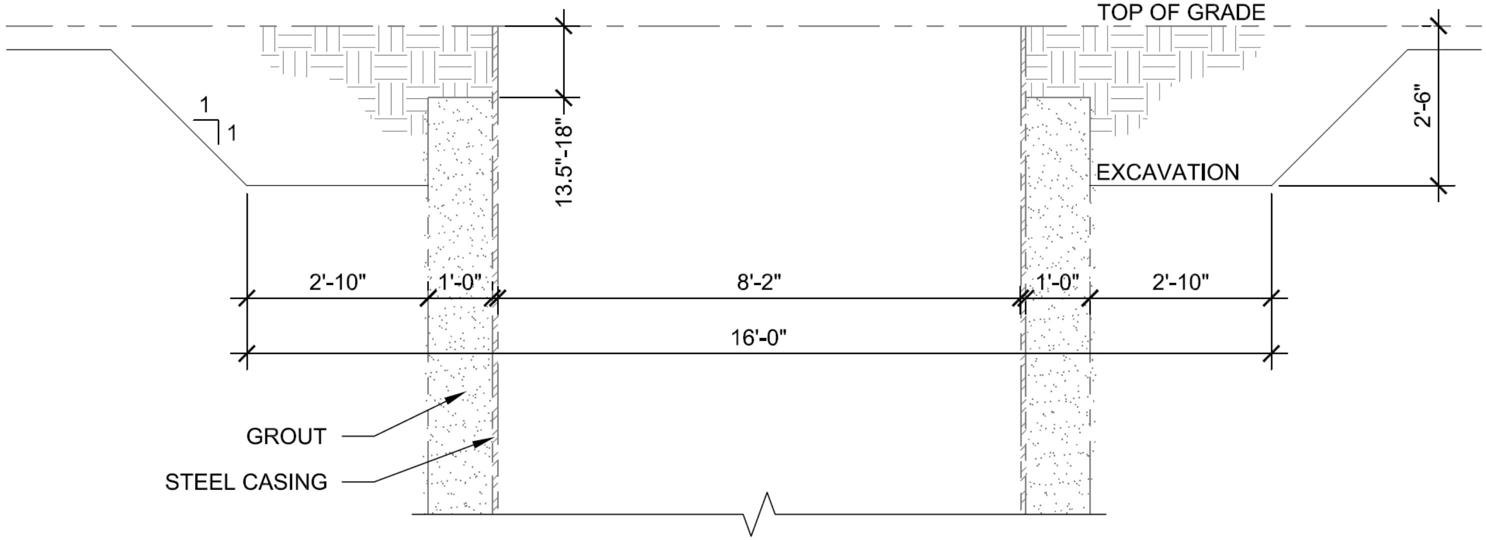
Dry Alluvium Geology (DAG) Platform Preliminary Design Review

Platform Requirements

- **Provide a clean, smooth and safe working surface around U2ez.**
- **Support personnel and equipment activities at the surface including forklift, rigging and stemming equipment.**
- **Support the Tank Support Rings and Landing Beam**
  - Provide a load path from the supported components into the soil below.
  - Prevent stress interaction between the supported components and the existing steel casing and surrounding grout.



EXISTING CONDITIONS

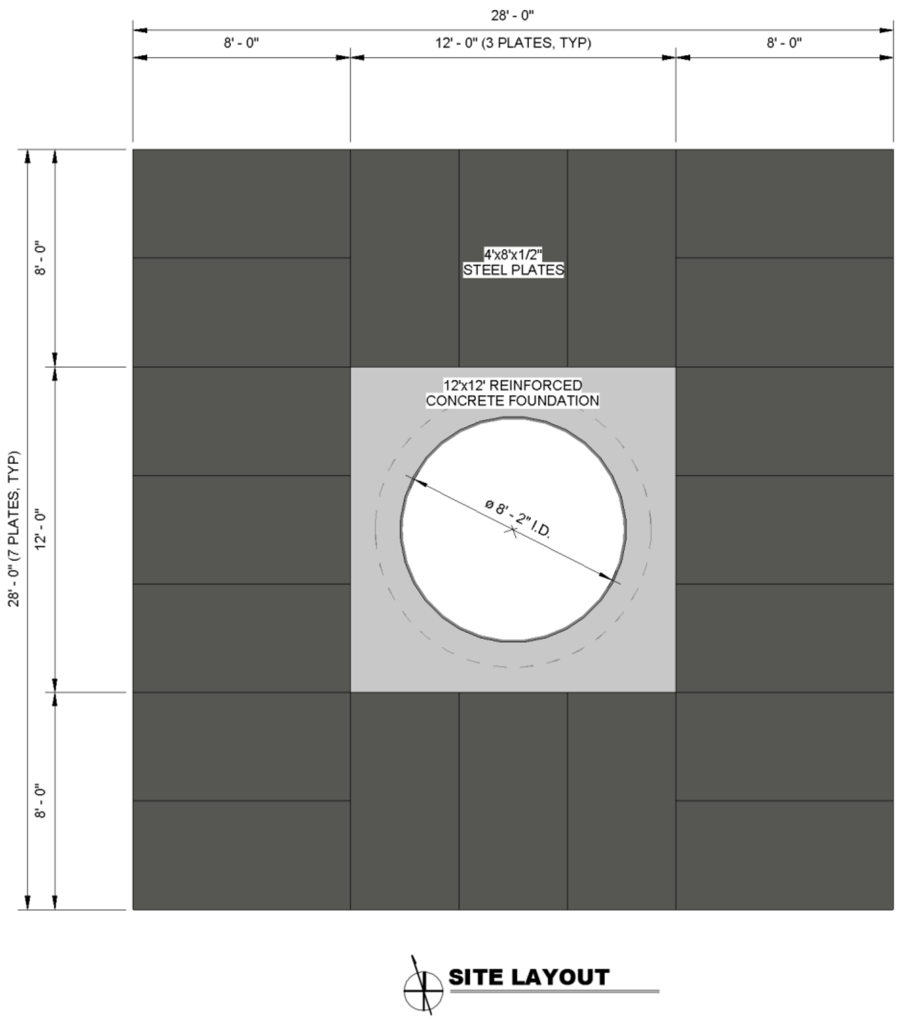


U2ez EXISTING SECTION VIEW

Existing Conditions:

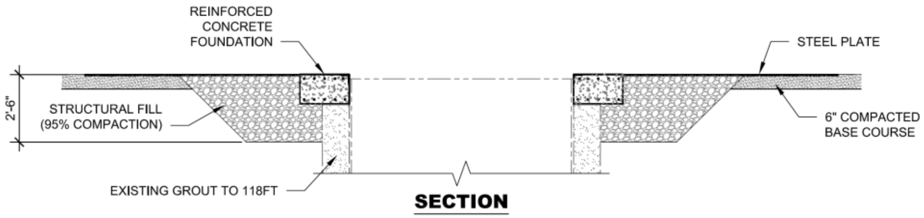
- 98" i.d. steel casing extending 118 ft below grade.
- 12" of grout surrounding the steel casing starting at a depth of 13.5" to 18" below grade and extending the full length of the casing.
- Top soil consisting of mostly native soil and tailings from original hole installation.

PLATFORM DESIGN

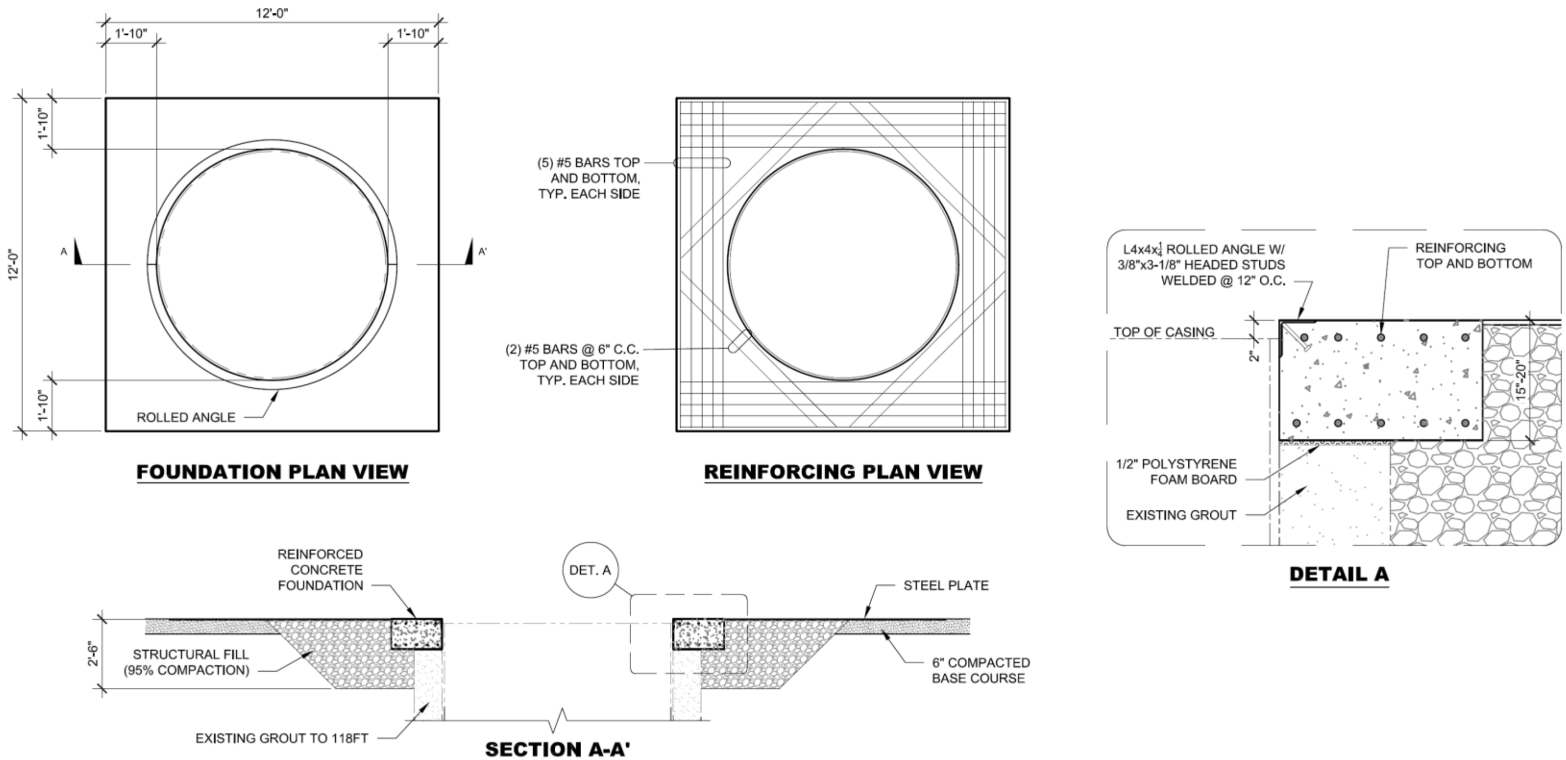


Platform Properties:

- 12' x 12' reinforced concrete foundation to support landing beam, tank support rings, and to provide a clean and smooth working surface.
- 4'x8'x1/2" steel plates surrounding the concrete foundation to support vehicle and personnel traffic.
- Structural fill below concrete.
- 6" compacted base course covering site.



FOUNDATION DESIGN



Foundation Properties:

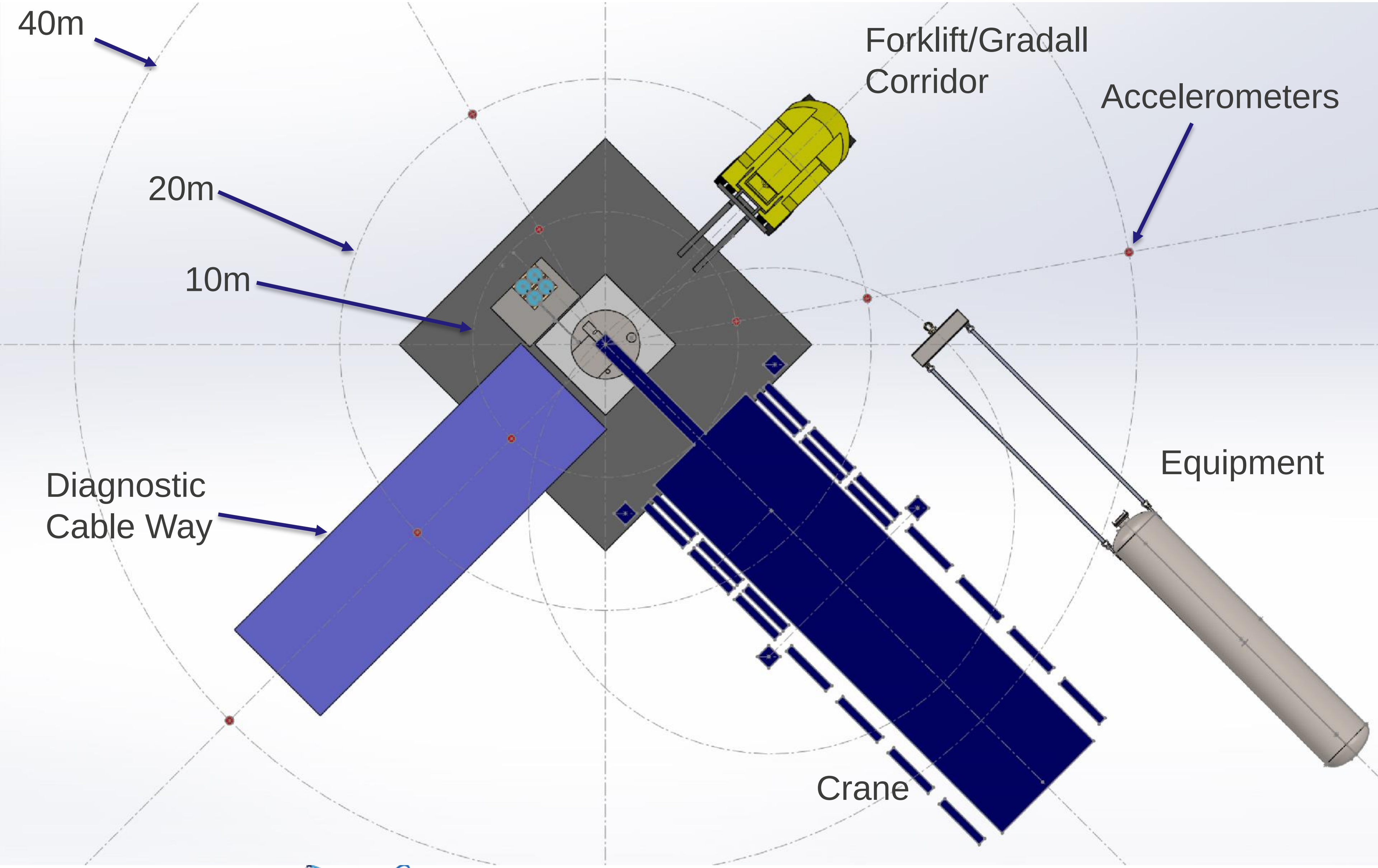
- 12' x 12' x 15" to 20" thick concrete reinforced with (5) #5 bars evenly spaced, top and bottom, around the perimeter. (2) #5 bars spaced at 6" c.c. top and bottom at 45 degrees from perimeter bars.
- ½" thick polystyrene foam board between existing grout and new concrete.
- Rolled L4x4x1/4 steel angle with 3/8X4-1/8 headed studs at 12" o.c. cast-in-place around casing's o.d.

Dry Alluvium Geology (DAG) Tank Preliminary Design Review

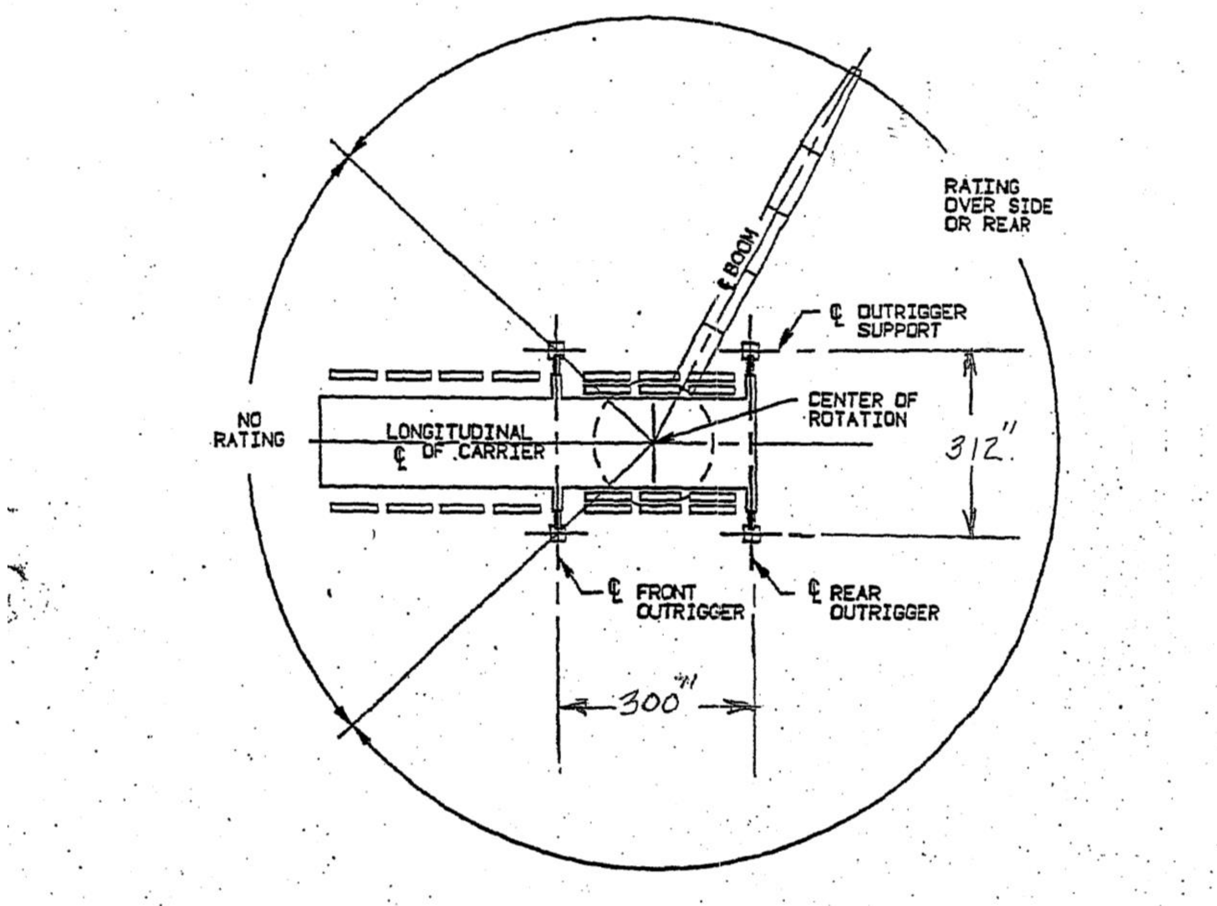
Source Engineering Logistics (Preliminary)

To

Validate Scope & Requirements


40m
20m
10m
Forklift/Gradall
Corridor
Accelerometers
Equipment
Diagnostic
Cable Way
Crane

Old Blue Footprint



Gradall for Forklift Activities

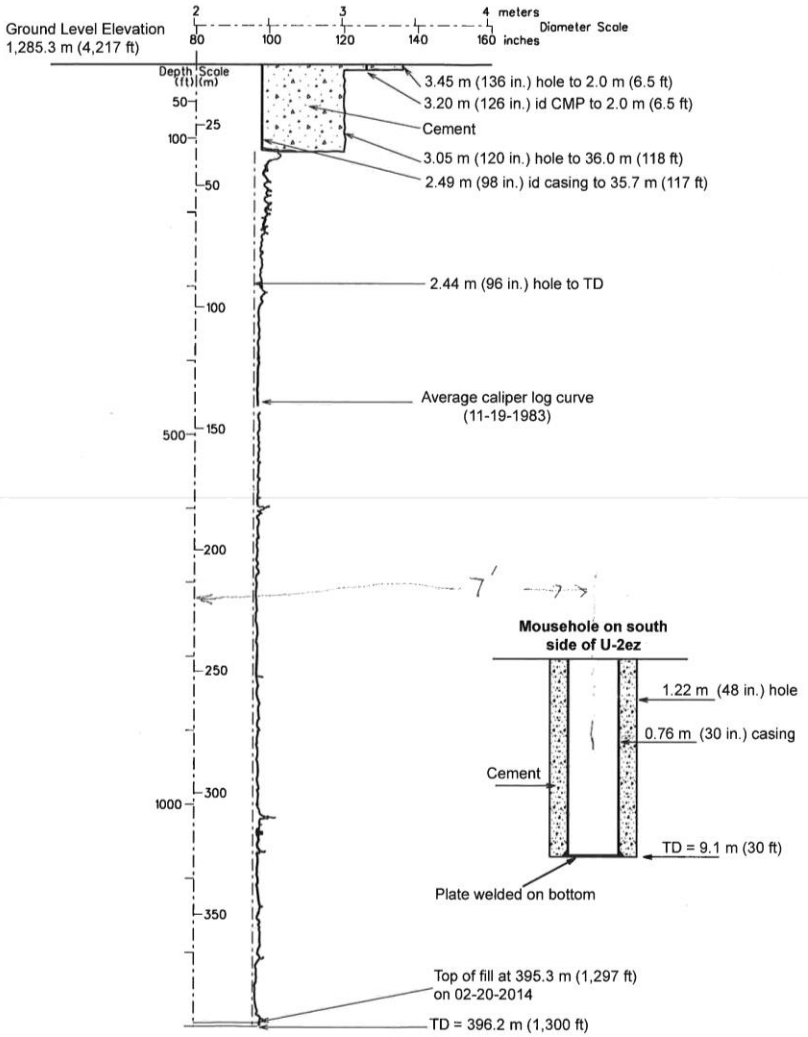
Diagnostic Cable Way:

Needs to be made operational?

Can it be modified to include a ~20' high, small platform to assemble the Initiator Insert Assembly for the large tank?

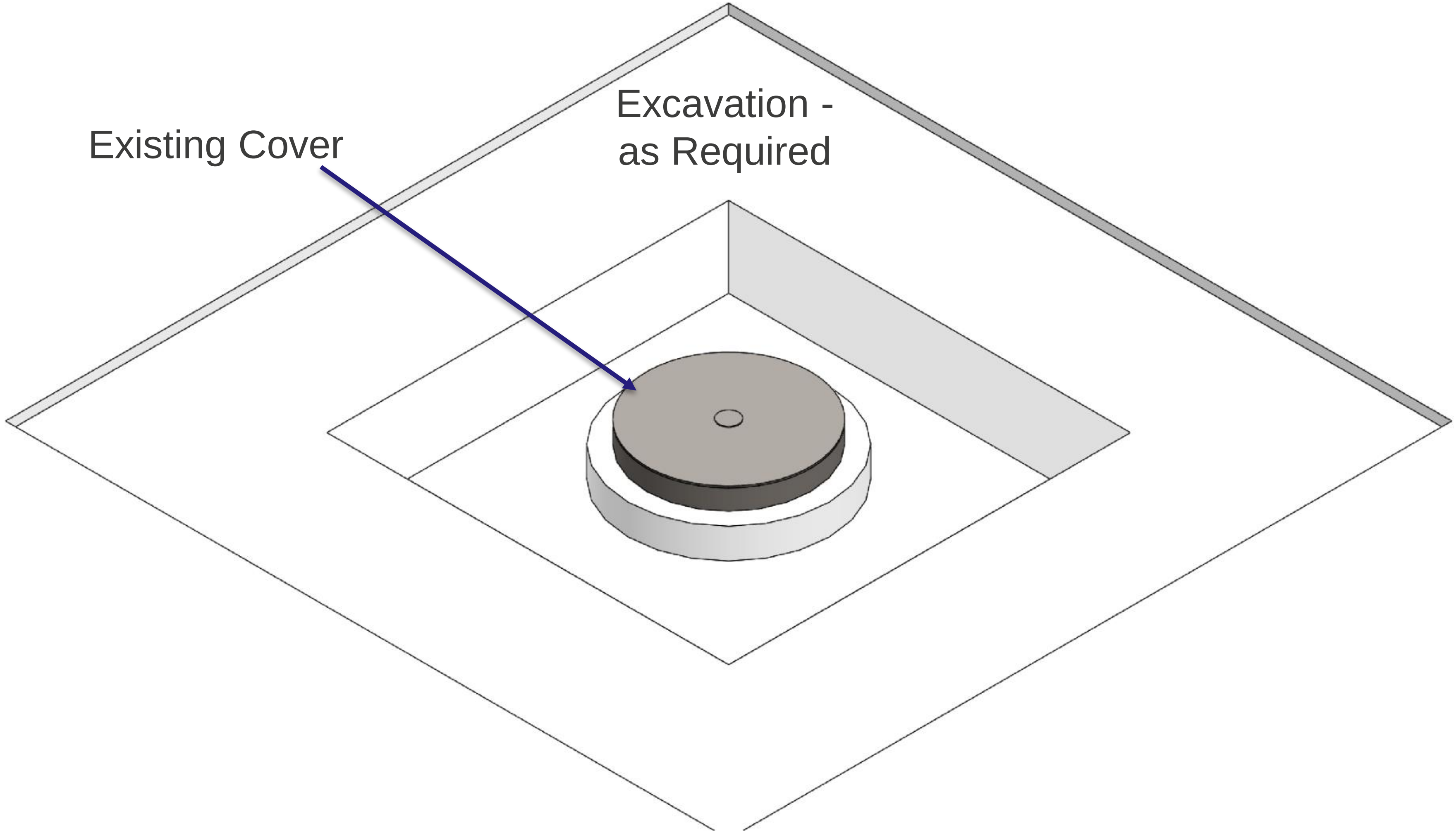
Hole Structure

- Platform is planned to be designed using a removable steel structure supported on engineered compacted fill.
- Concrete piers are being evaluated/considered.

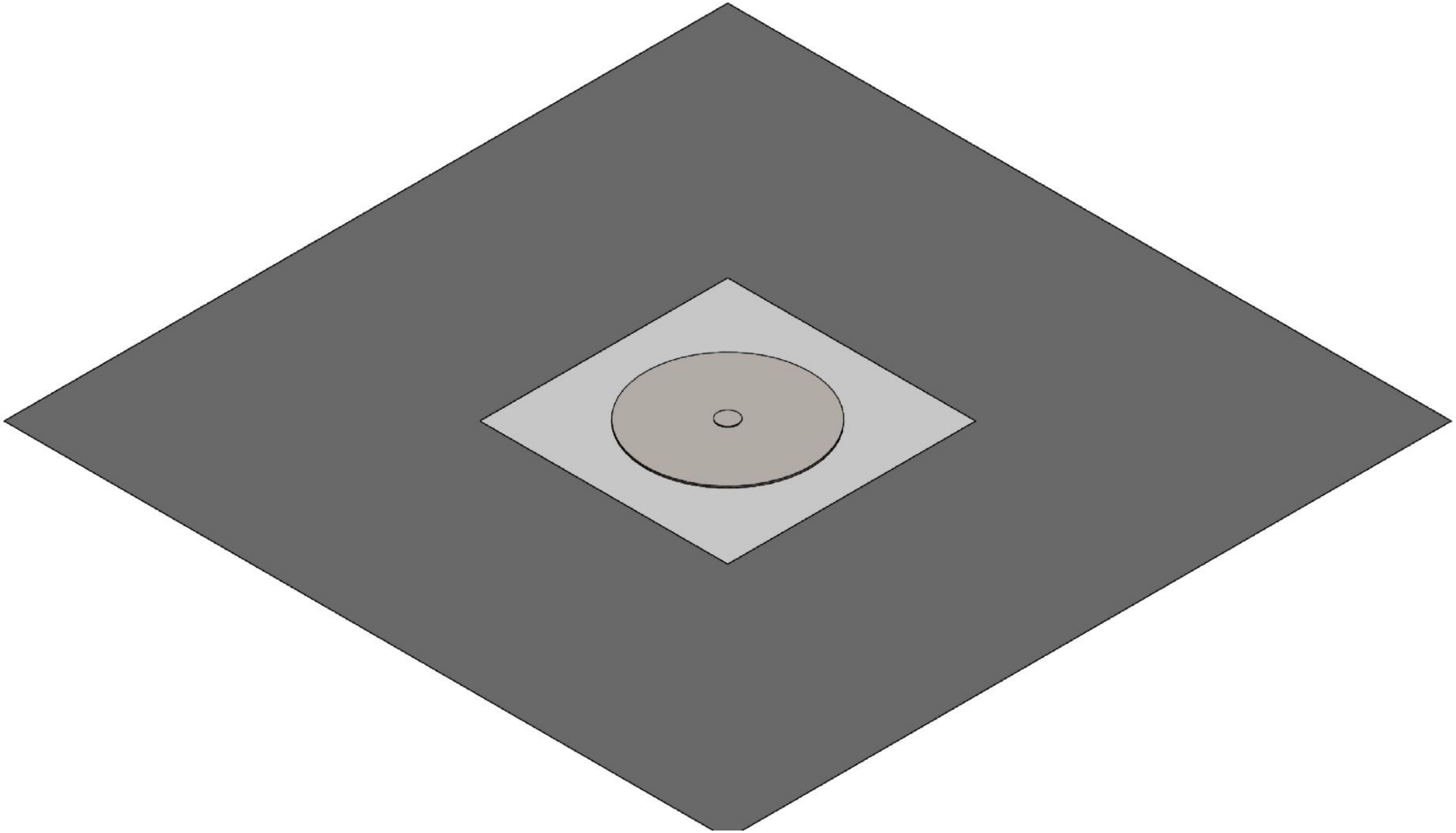


U-2ez Borehole Contruction Diagram with Caliper Log

Hole with Cover

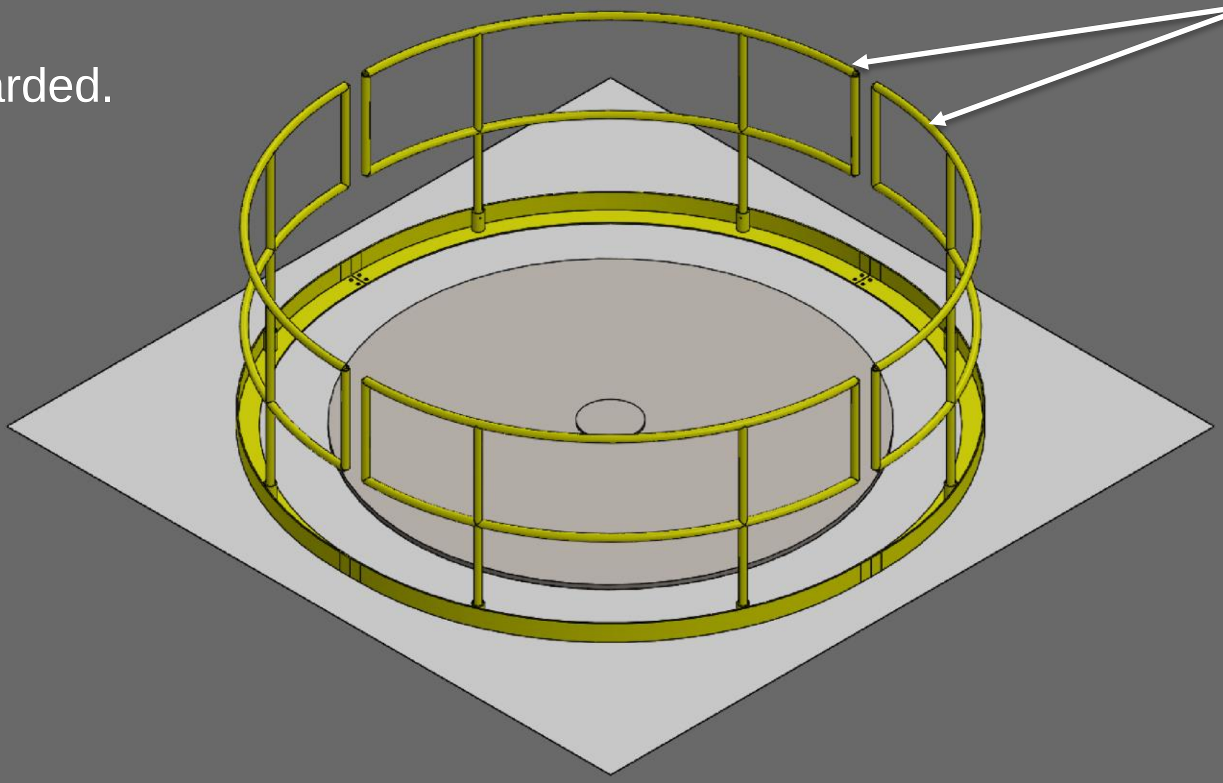


Foundation Installed



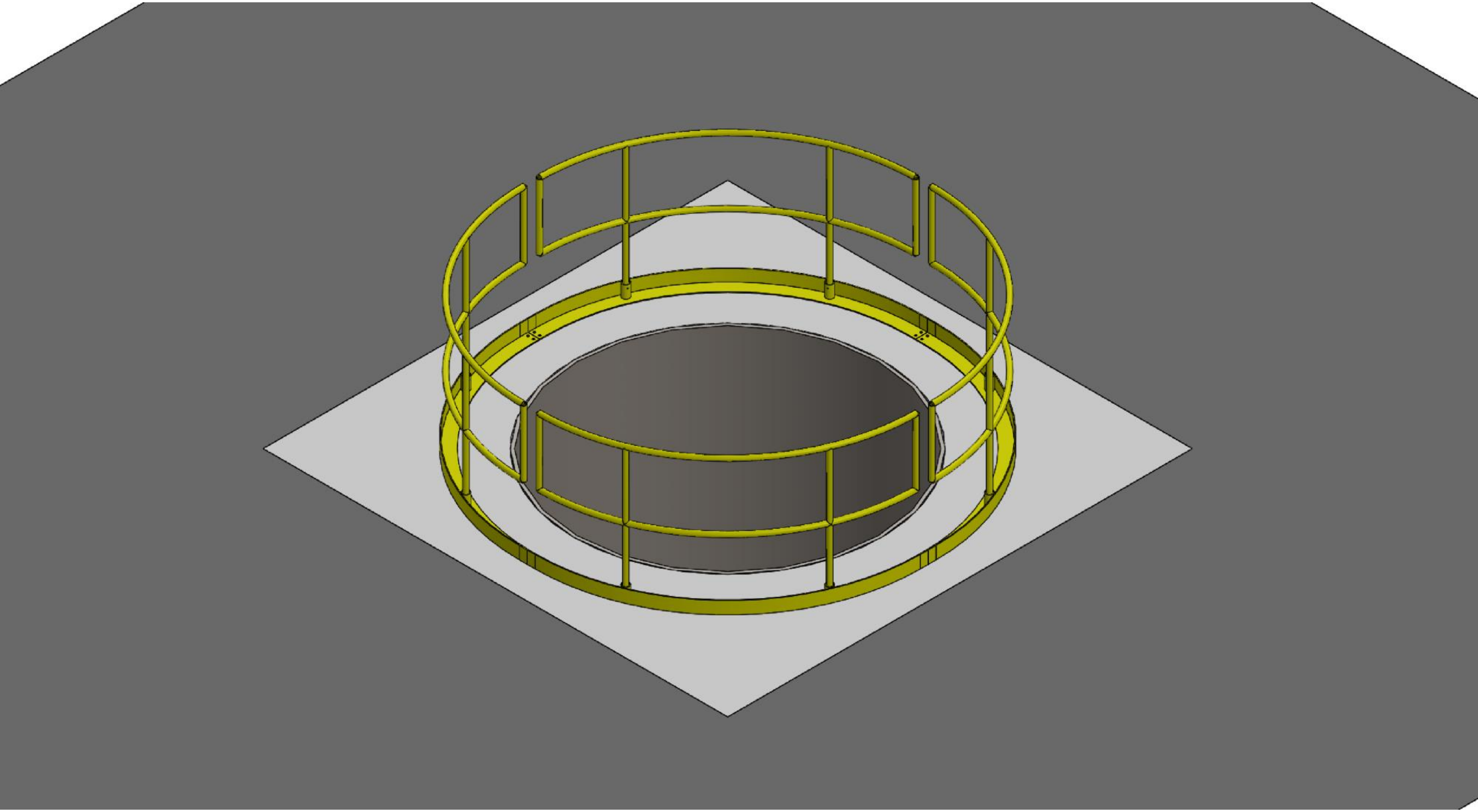
Railing and Toe Plate Installed

The plan is to always have the hole protected/guarded.



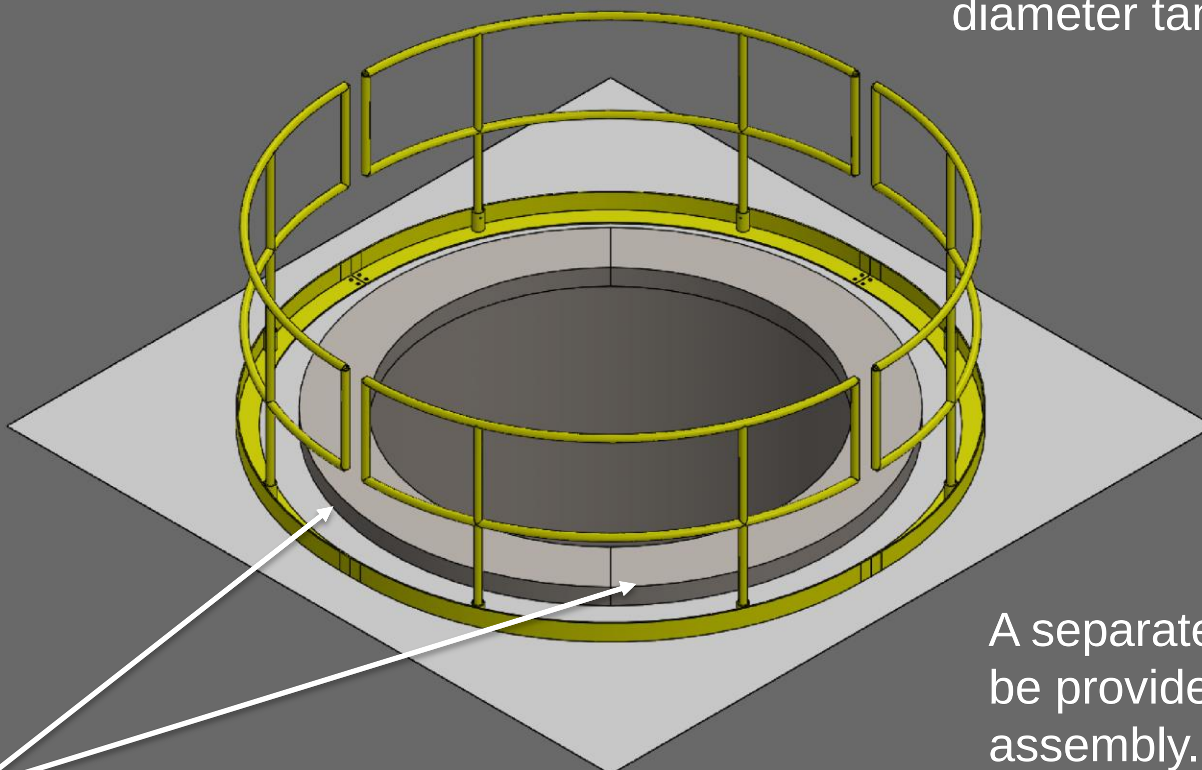
Individual Railings (4)

Removal of Hole Cover



Base Plates Installed

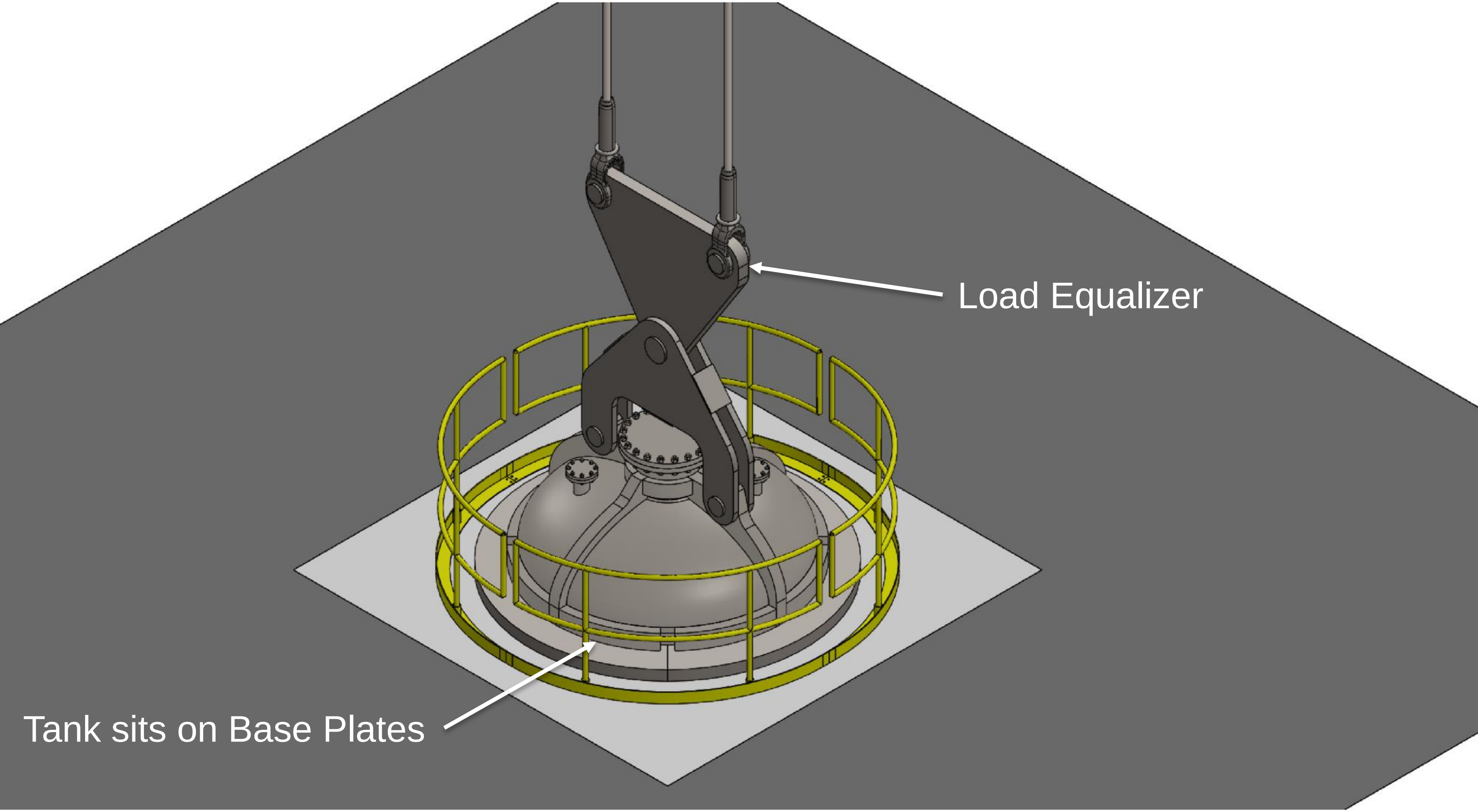
Base plate shown accommodates the large diameter tanks.



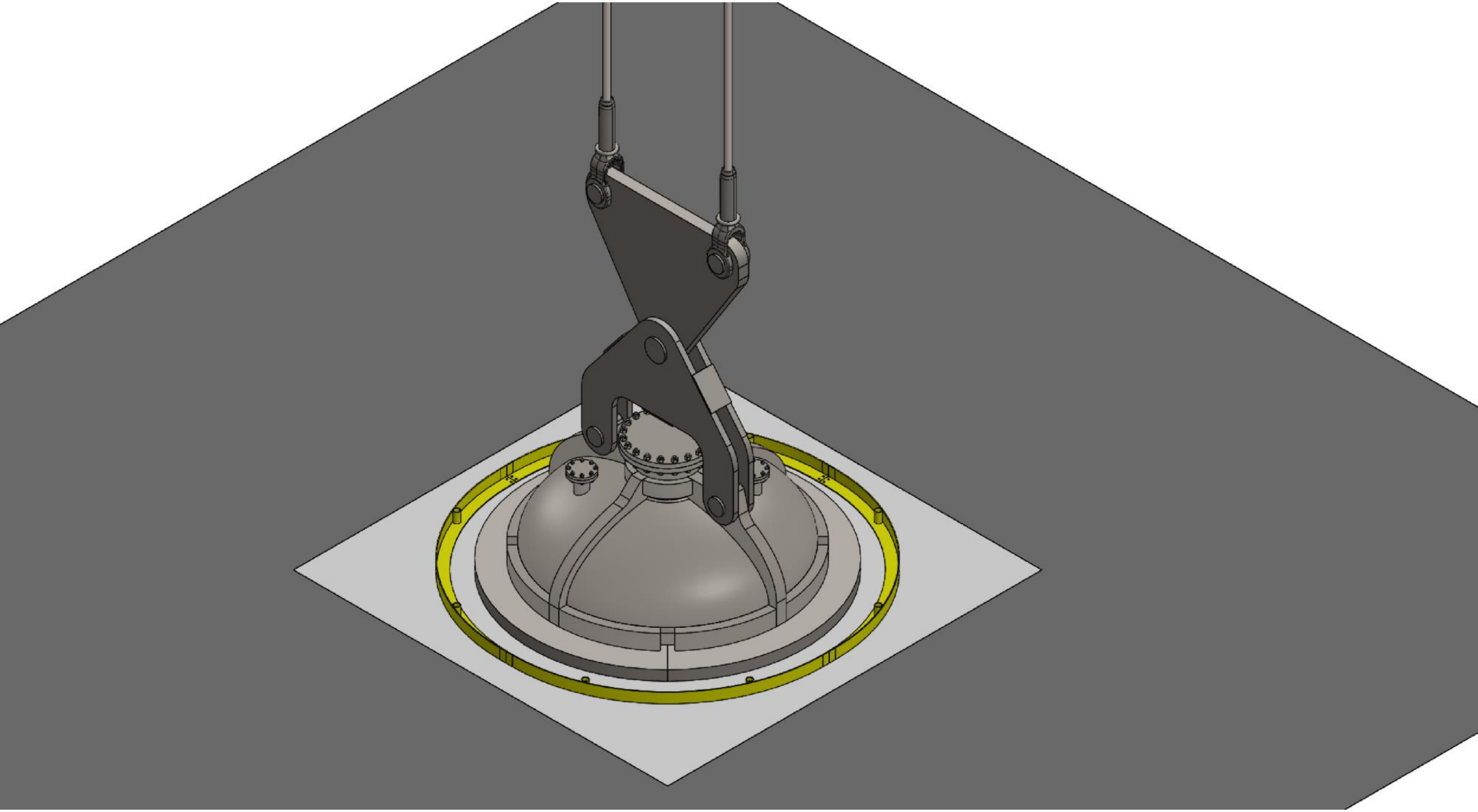
A separate hole cover could be provided with this assembly.

Base Plates
Placed into position

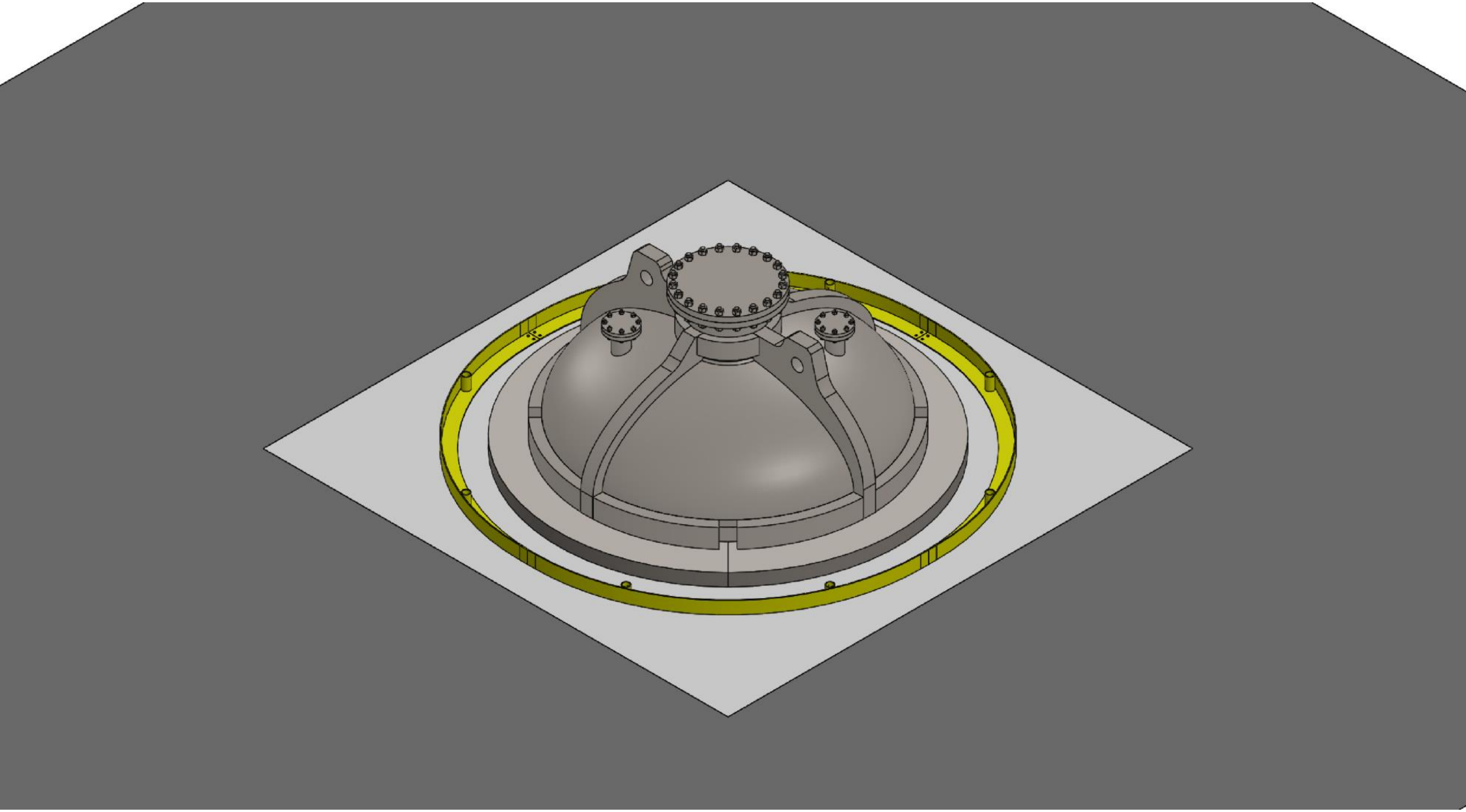
Tank Loaded into Position onto Base Plates



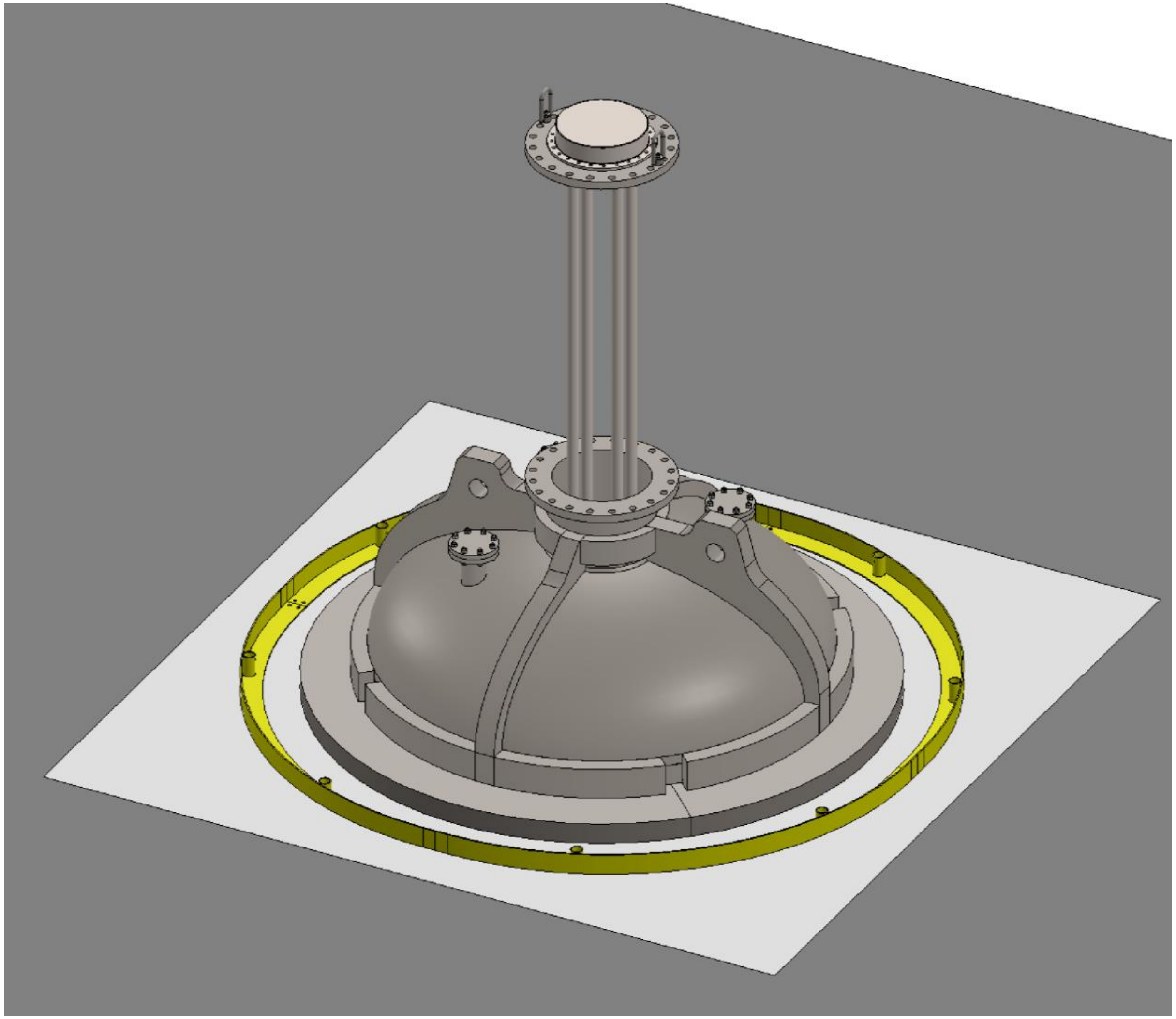
Removal of Railing



Removal of Pendants/Rigging

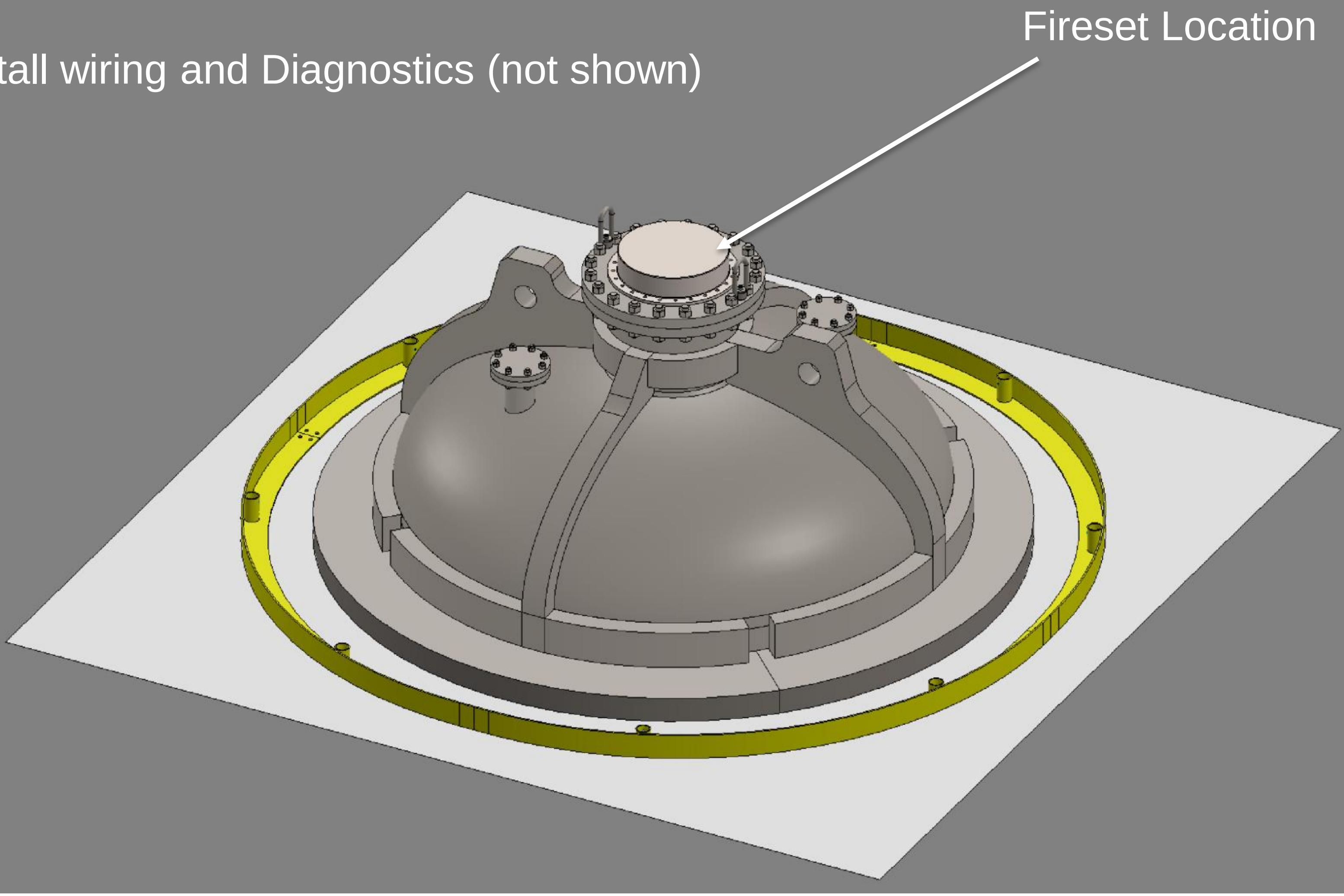


Installation of Initiator



Initiator Installed

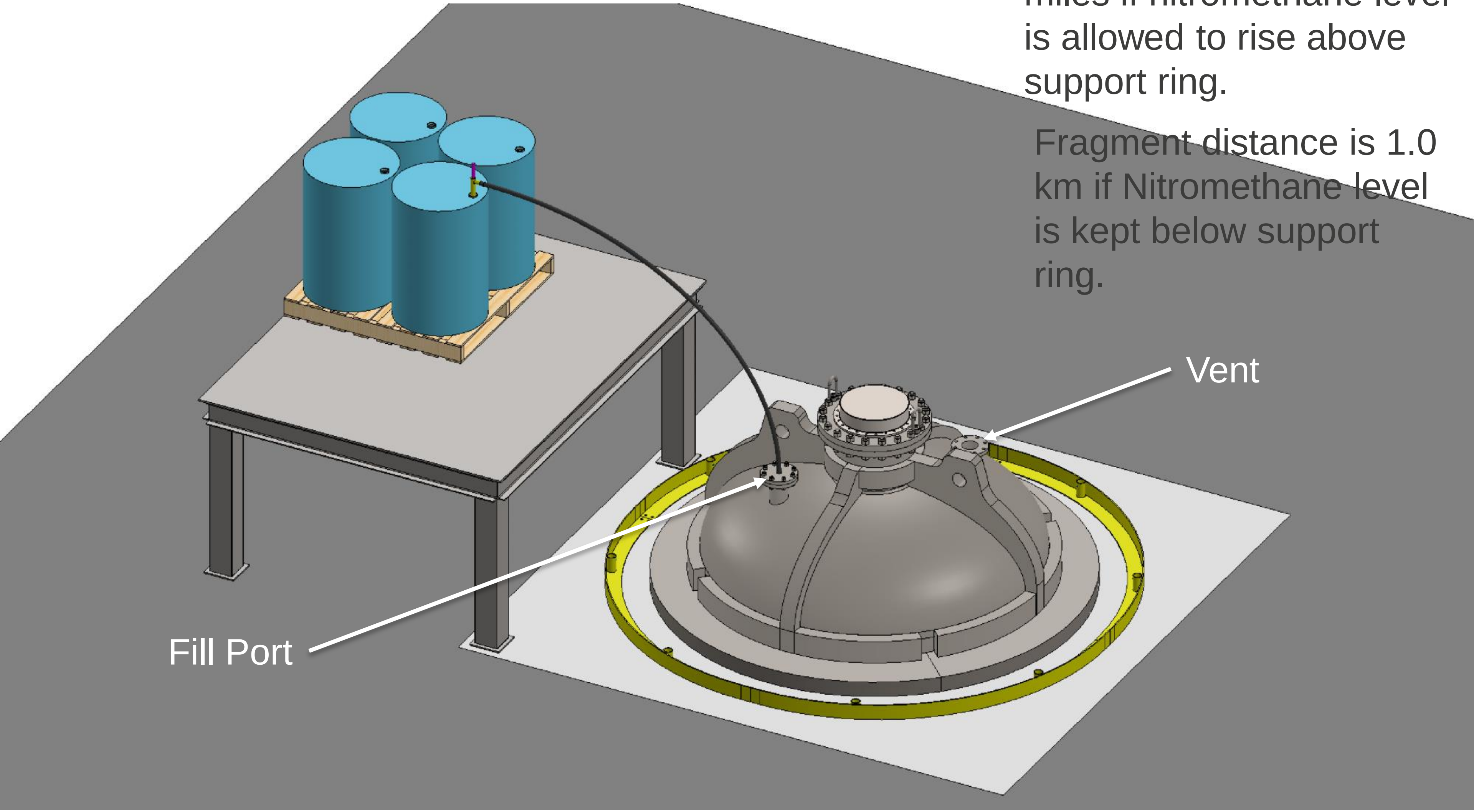
Install wiring and Diagnostics (not shown)



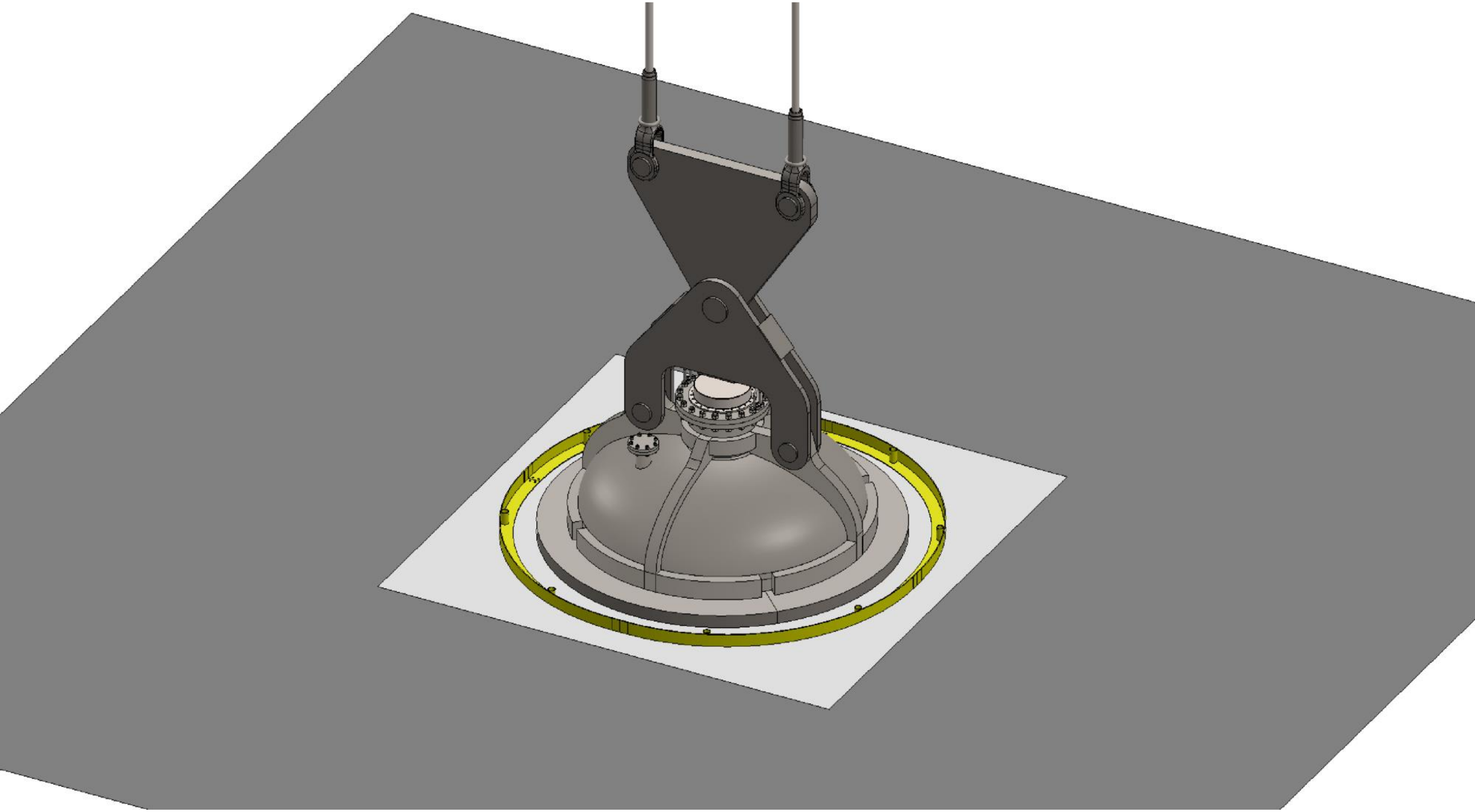
Fill Tank with Nitromethane

Fragment distance 3.5 miles if nitromethane level is allowed to rise above support ring.

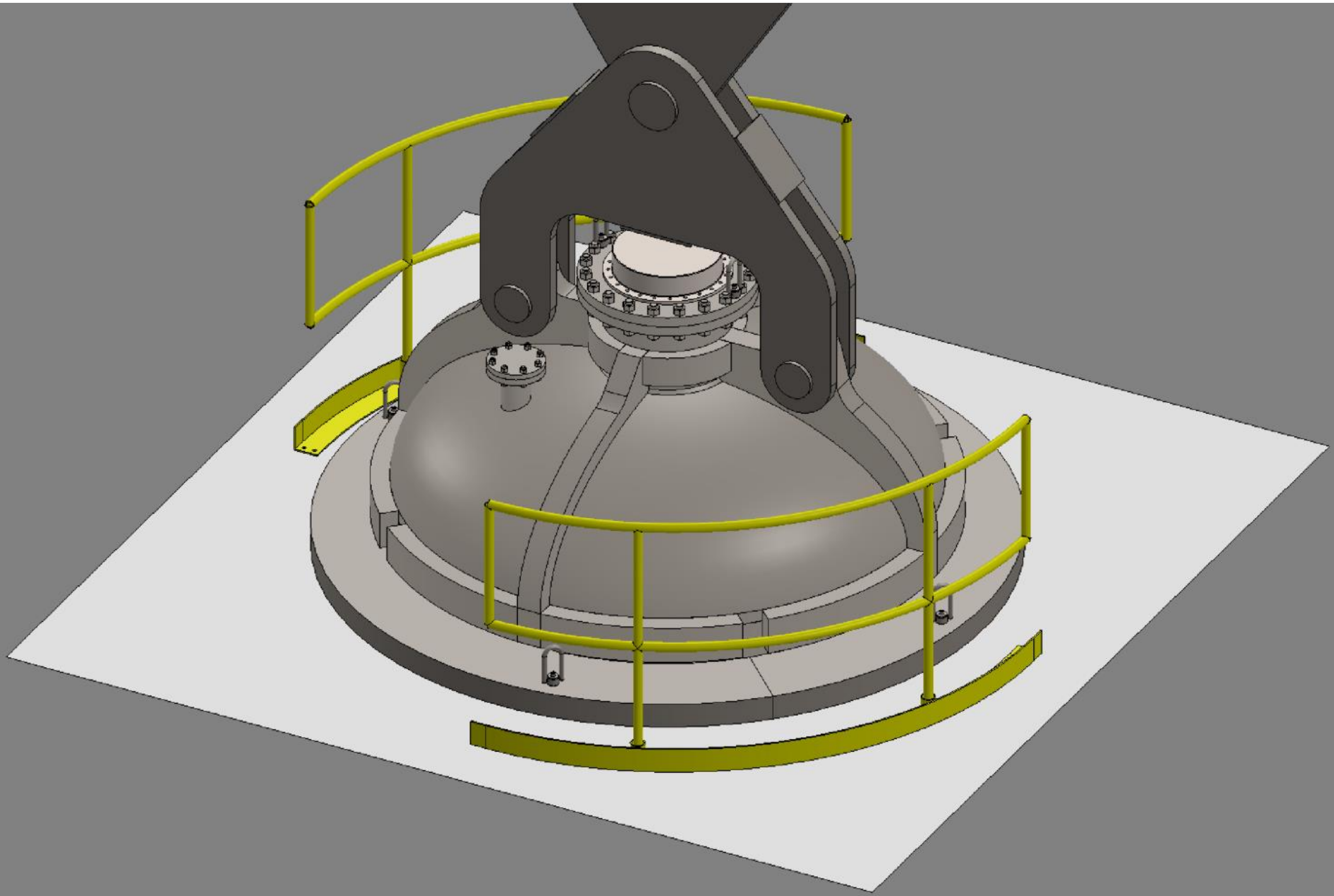
Fragment distance is 1.0 km if Nitromethane level is kept below support ring.



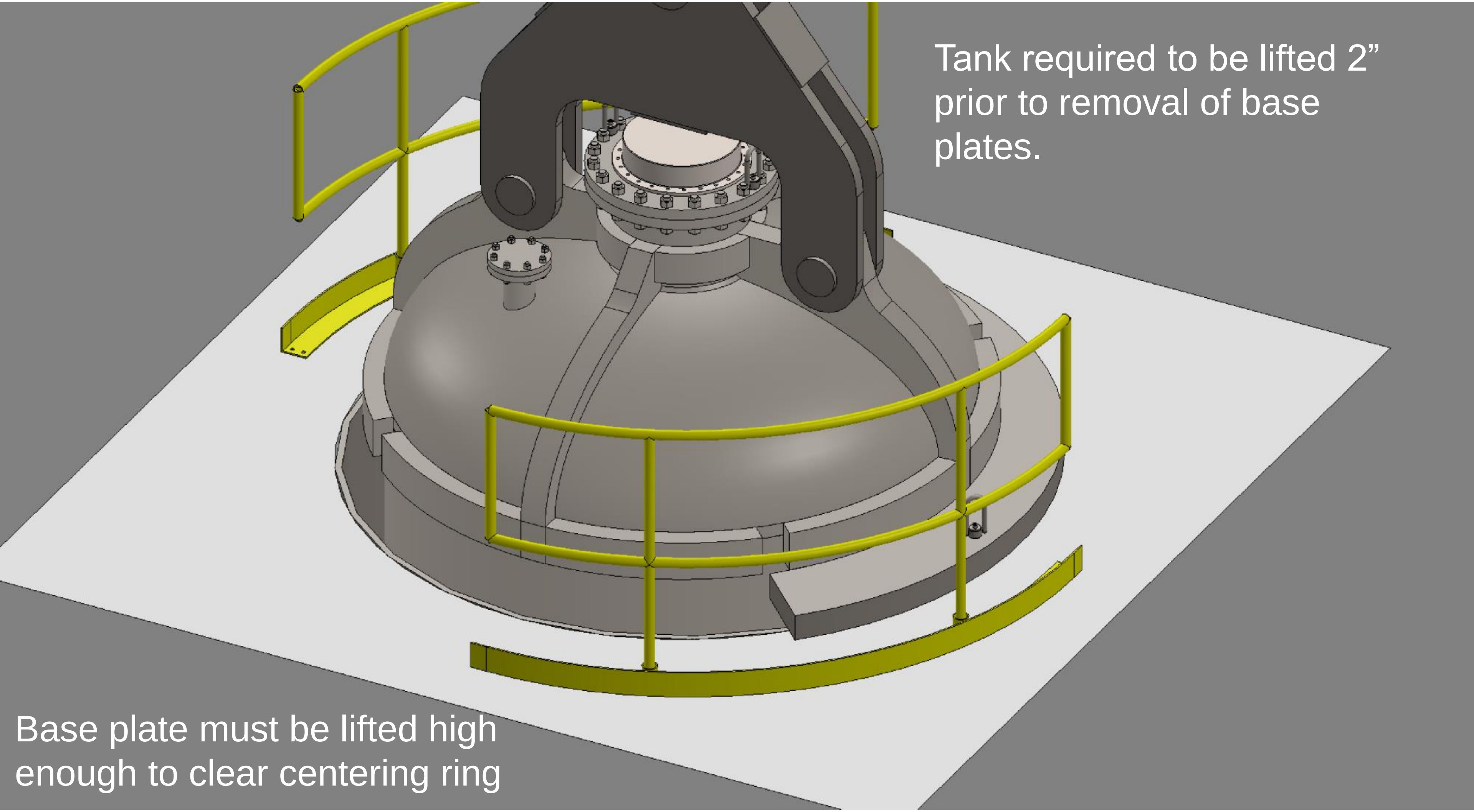
Install Pendants



Reinstall Railings (different configuration)



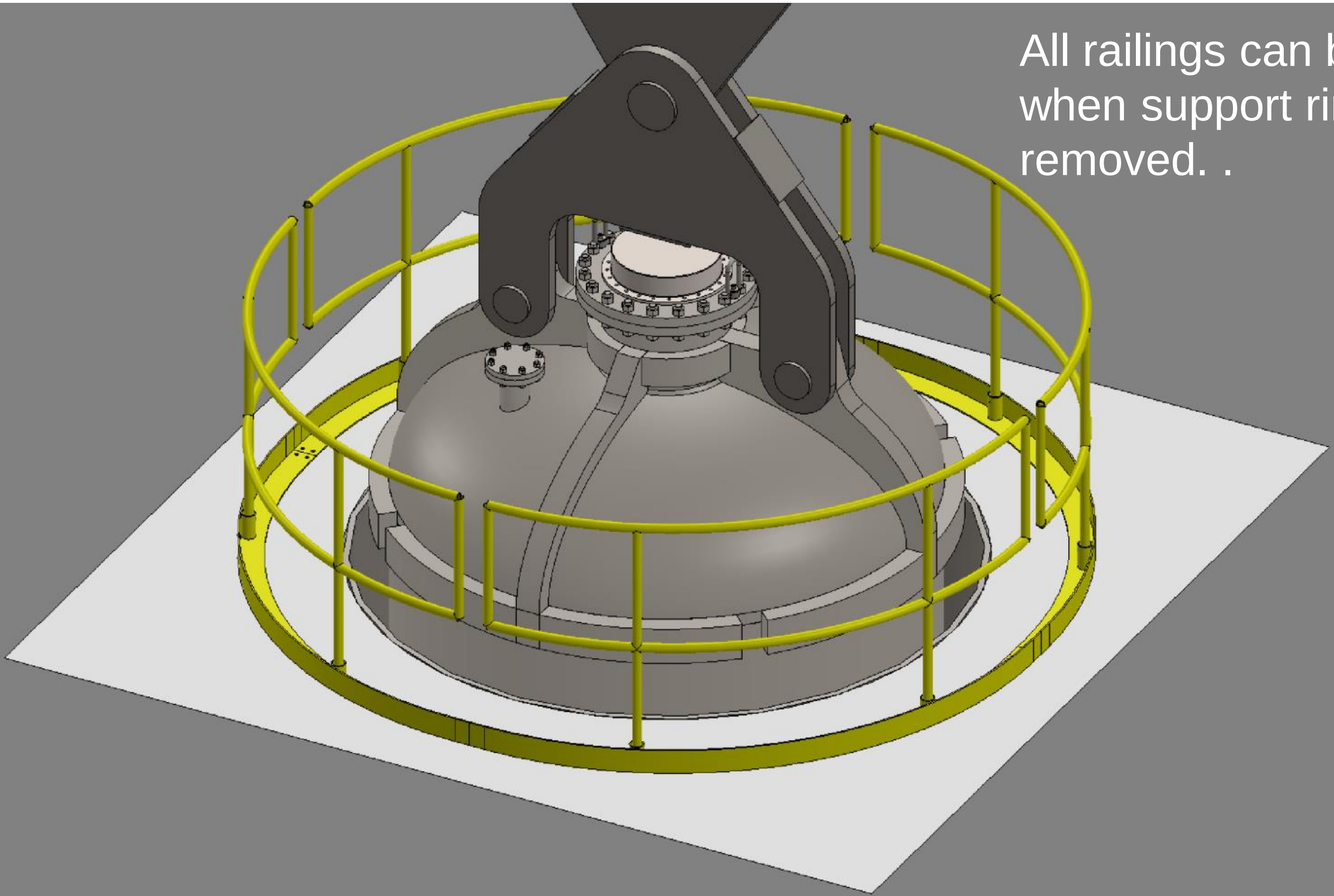
Remove Base Plates



Tank required to be lifted 2" prior to removal of base plates.

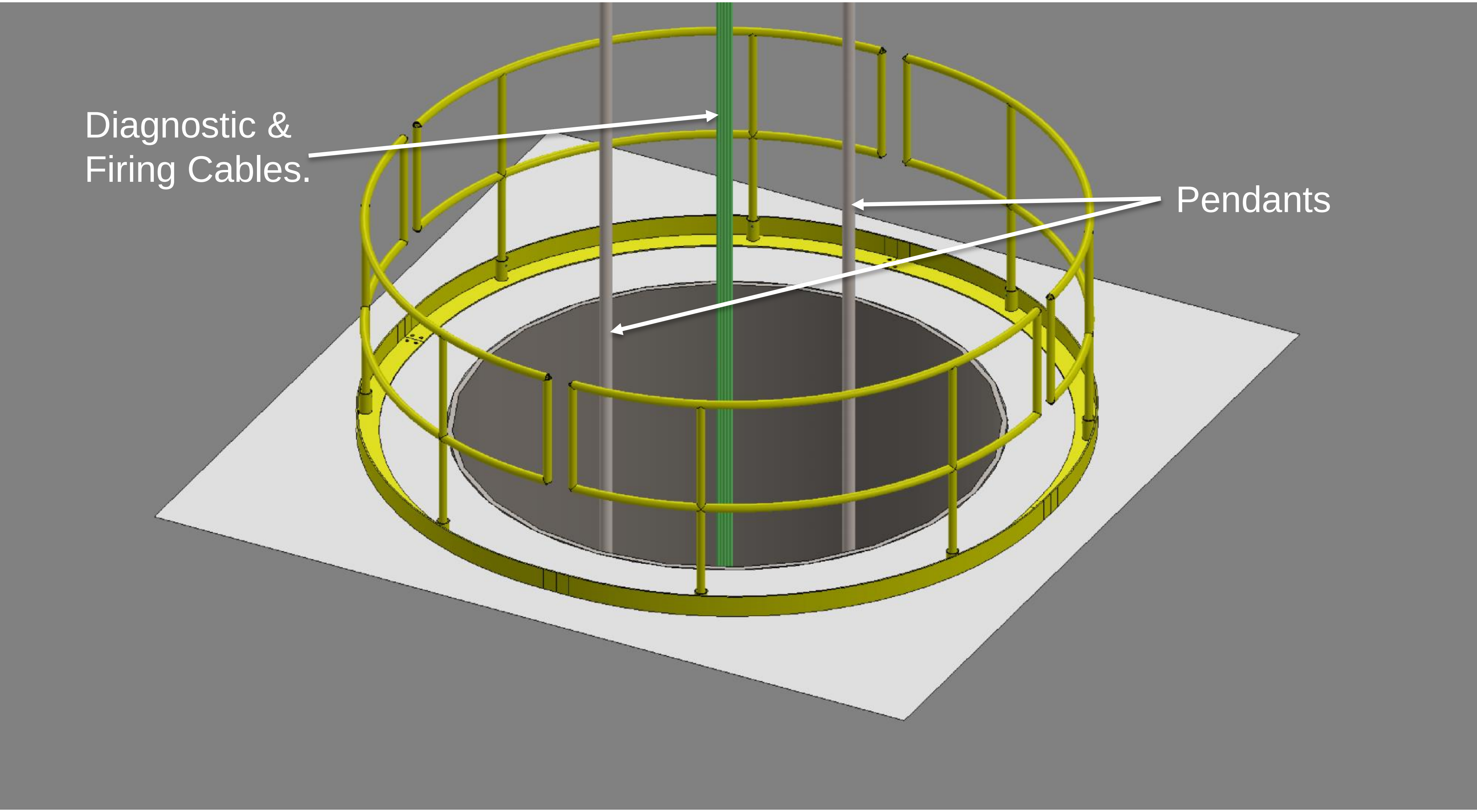
Base plate must be lifted high enough to clear centering ring

Reinstall all Railings

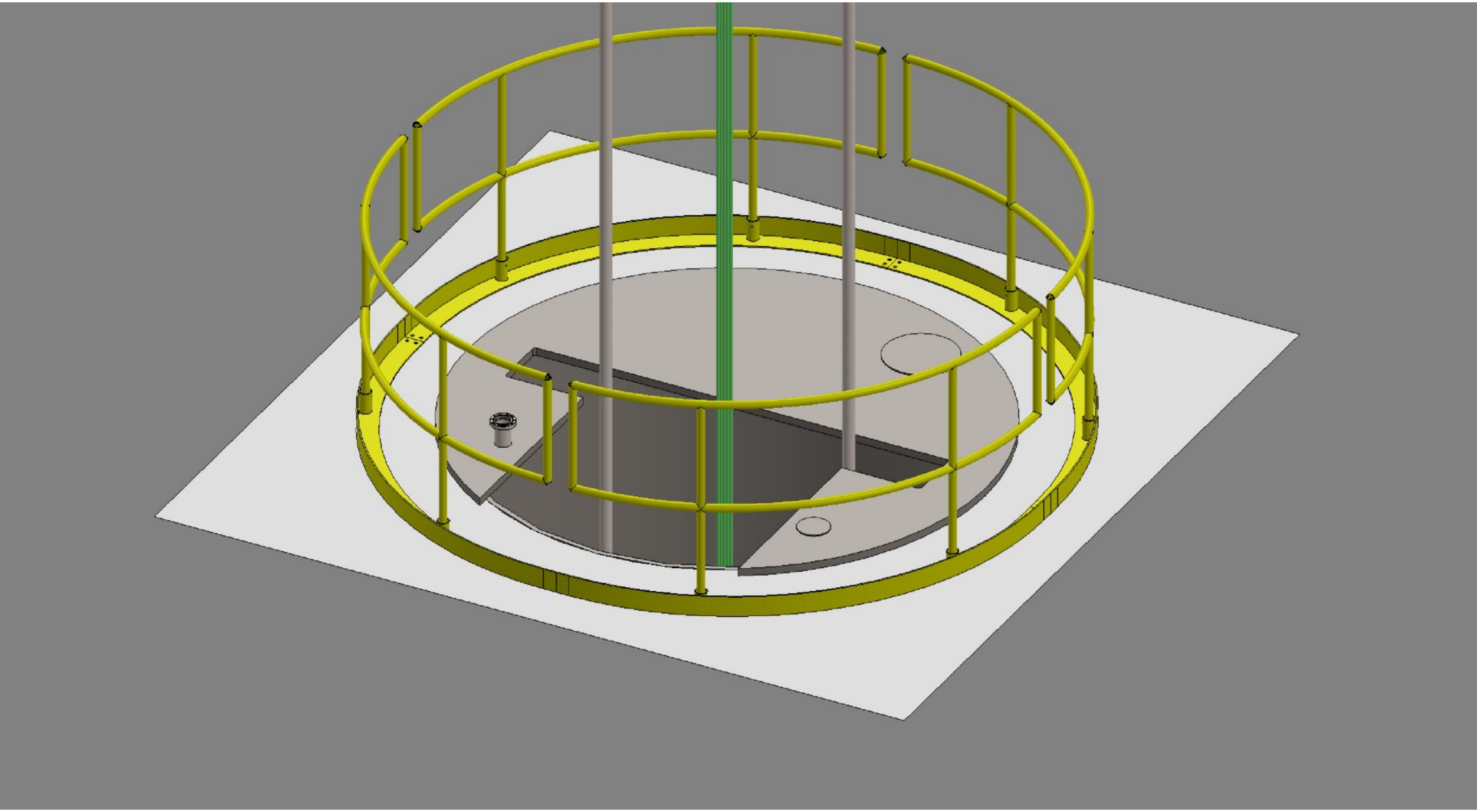


All railings can be reinstalled when support rings are removed. .

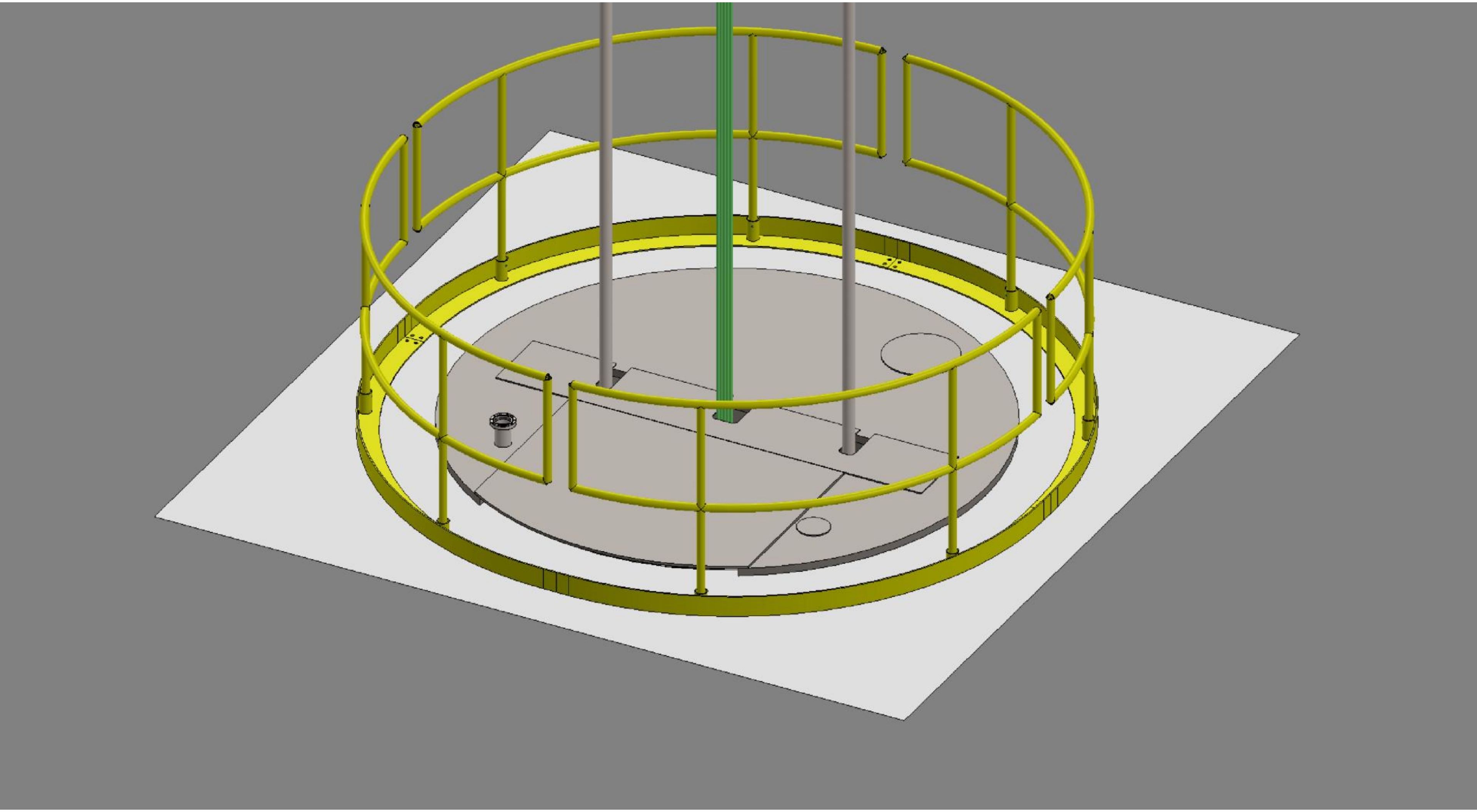
Begin Lowering Tank



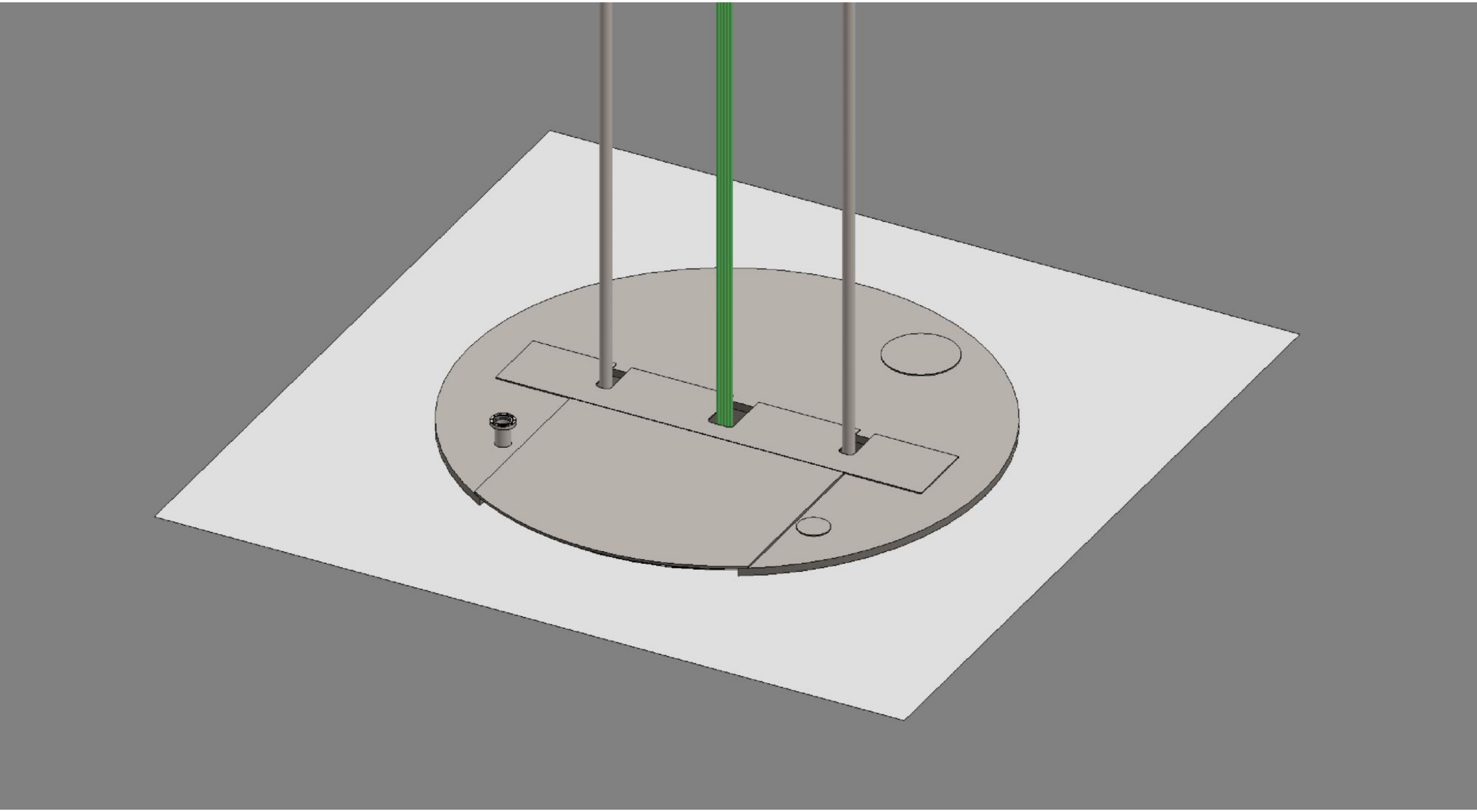
New Hole Cover Installed-1



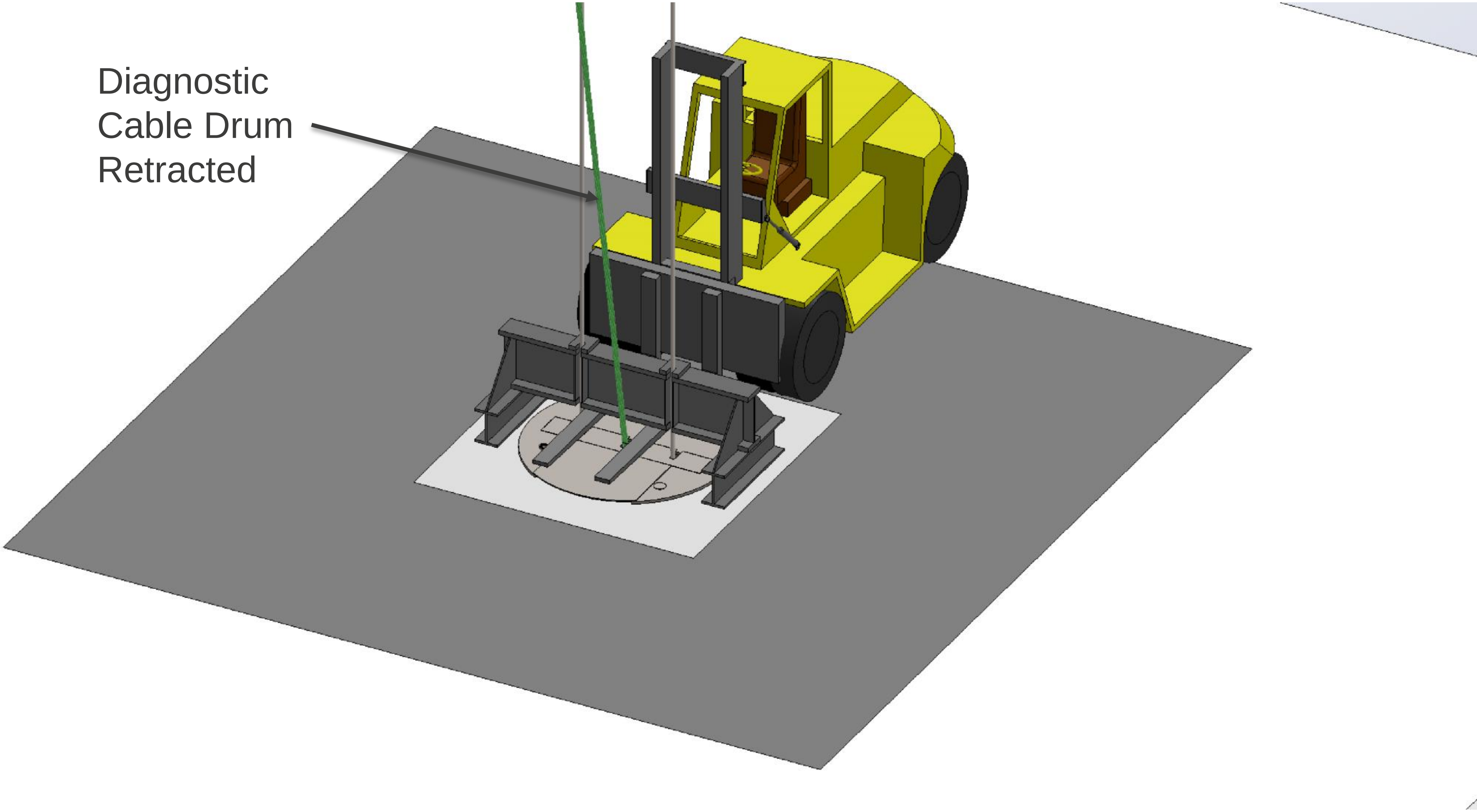
New Hole Cover Installed-2



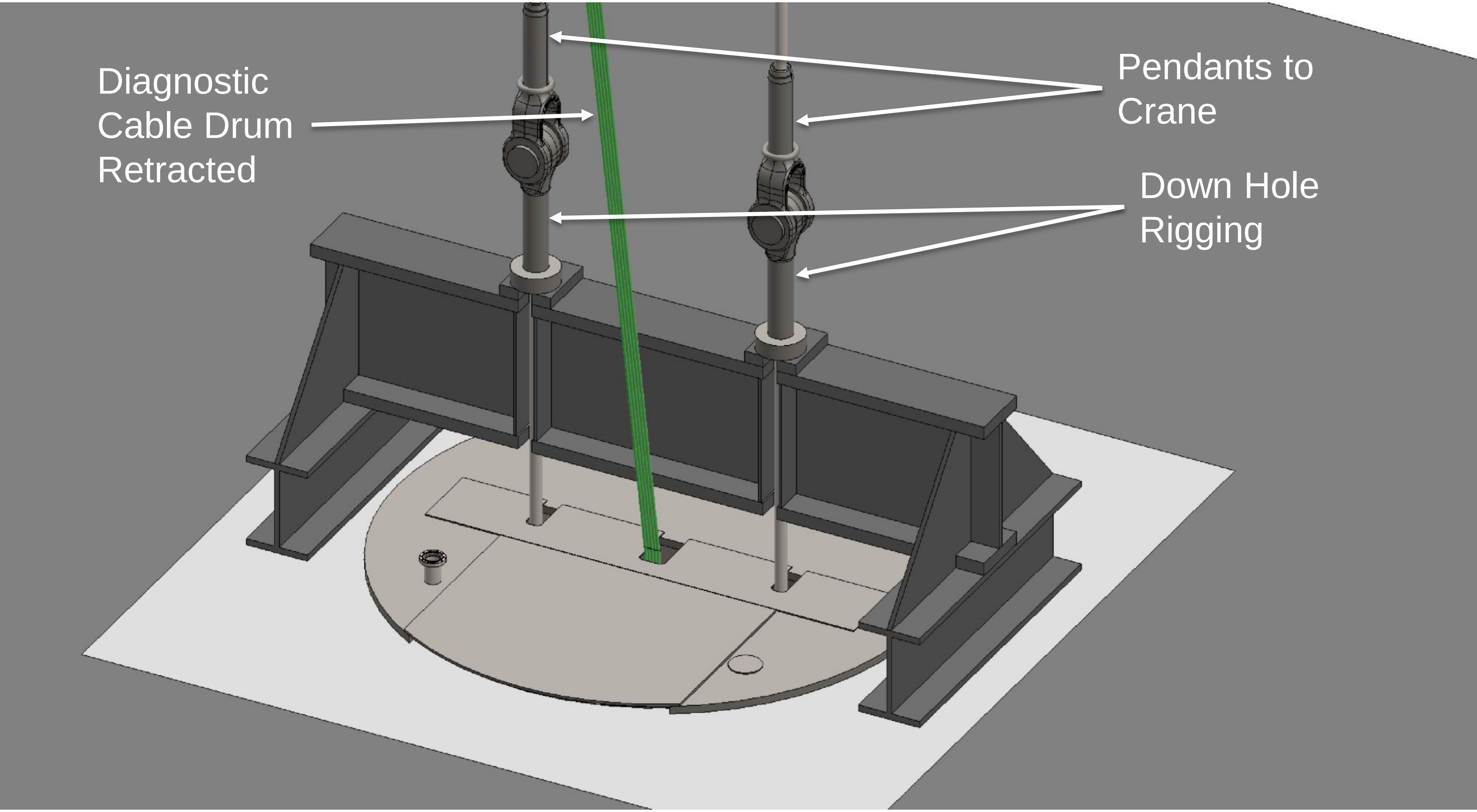
Remove Railing



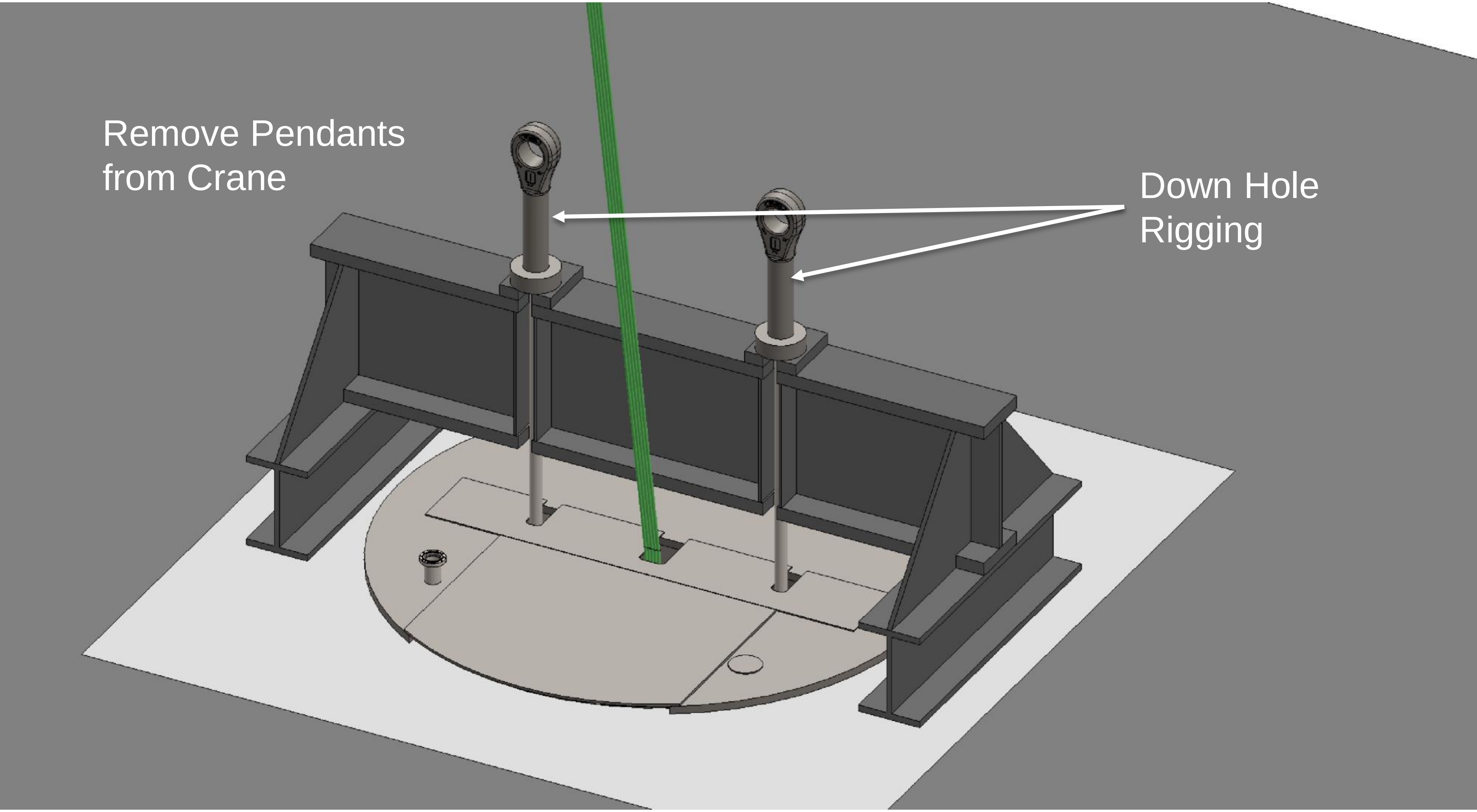
Installing Landing Beam



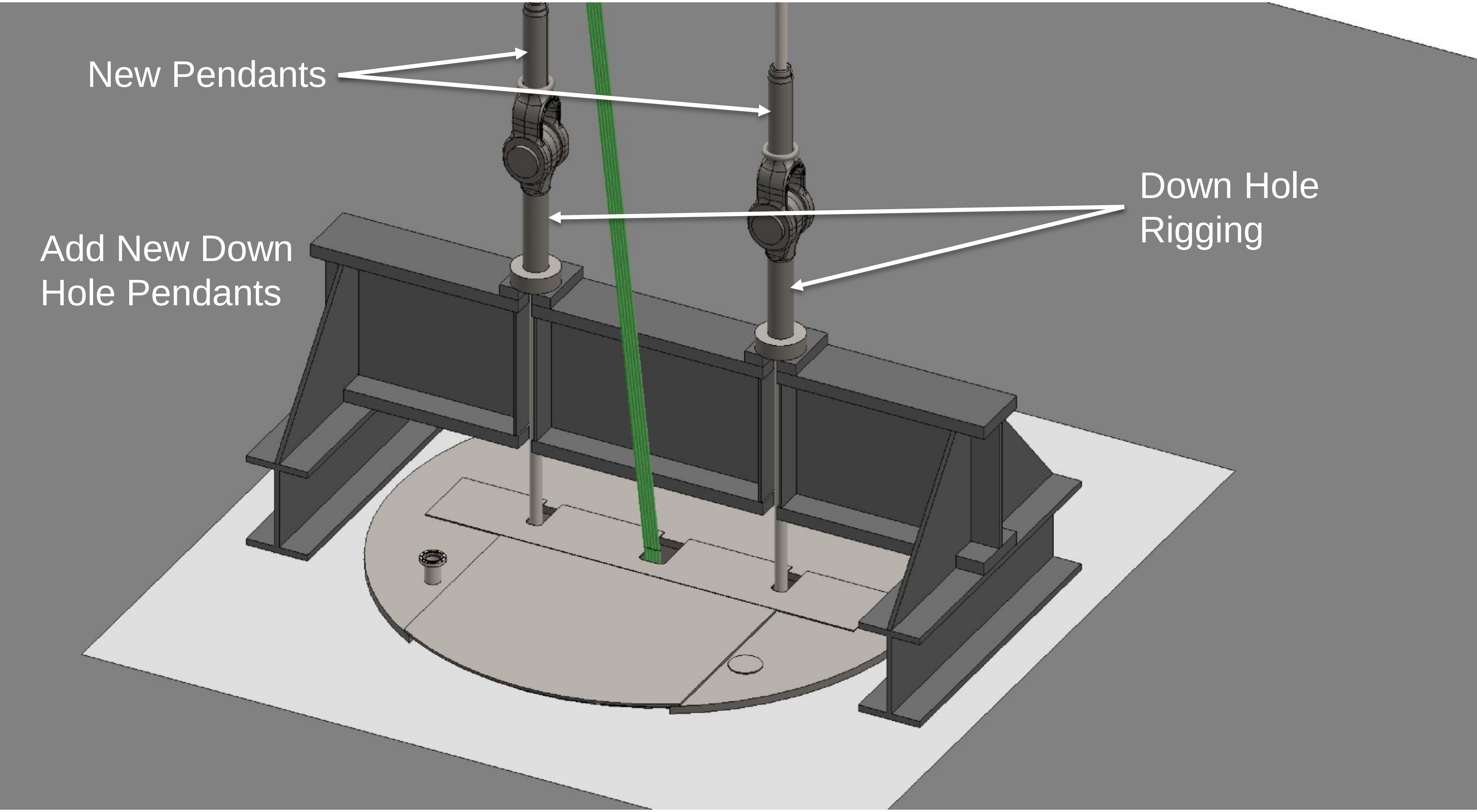
Changing Pendant, Phase 1



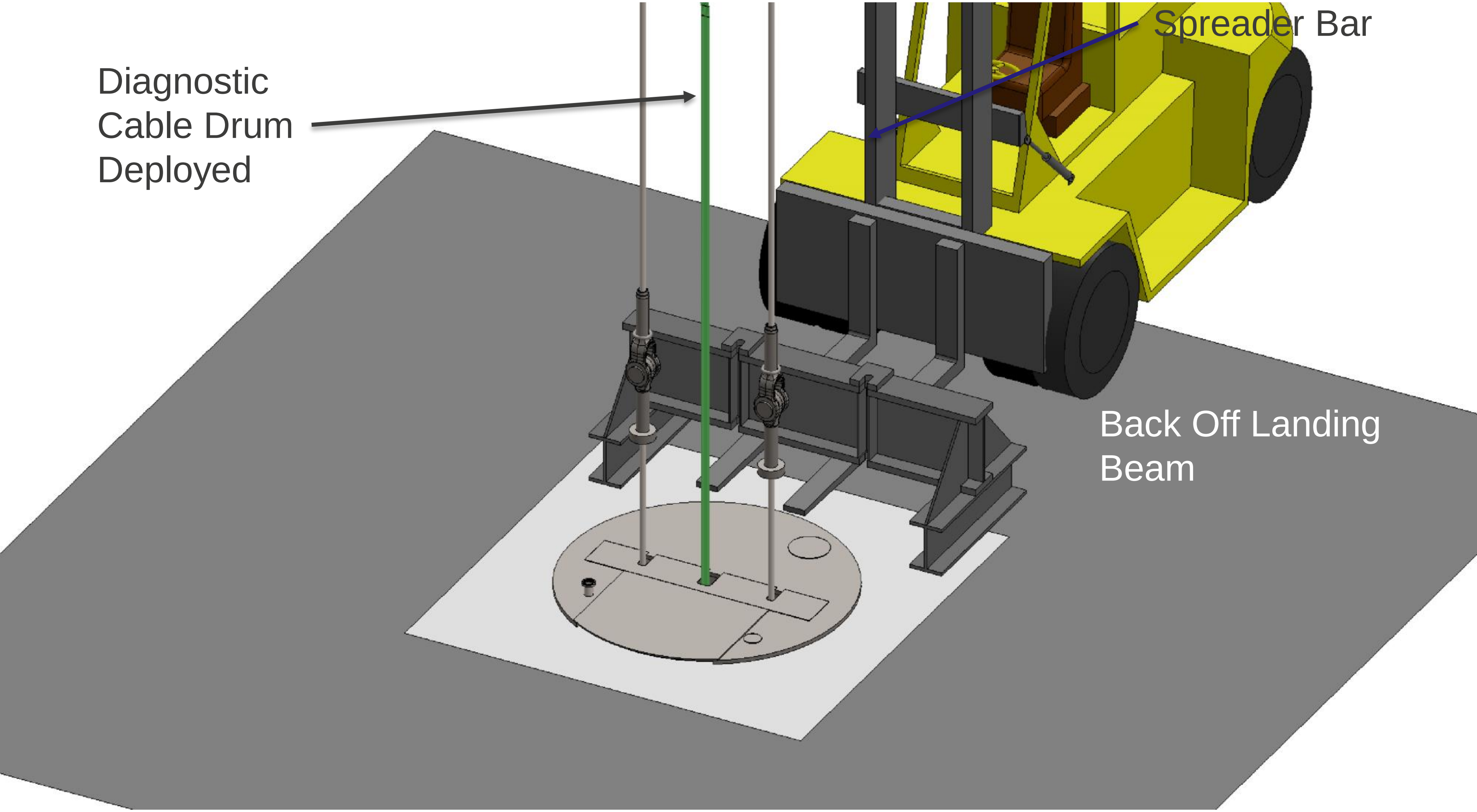
Changing Pendant, Phase 2



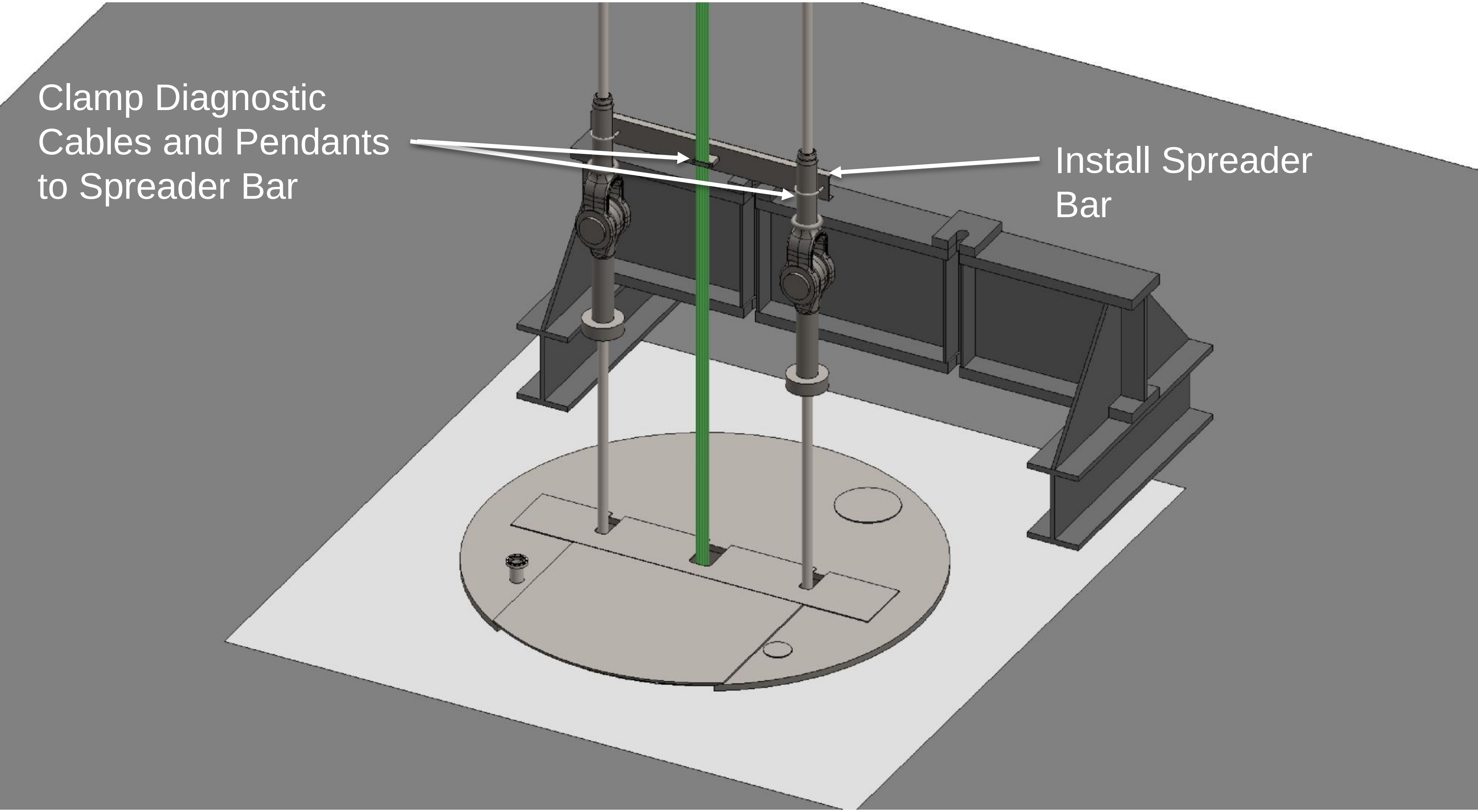
Changing Pendant, Phase 3



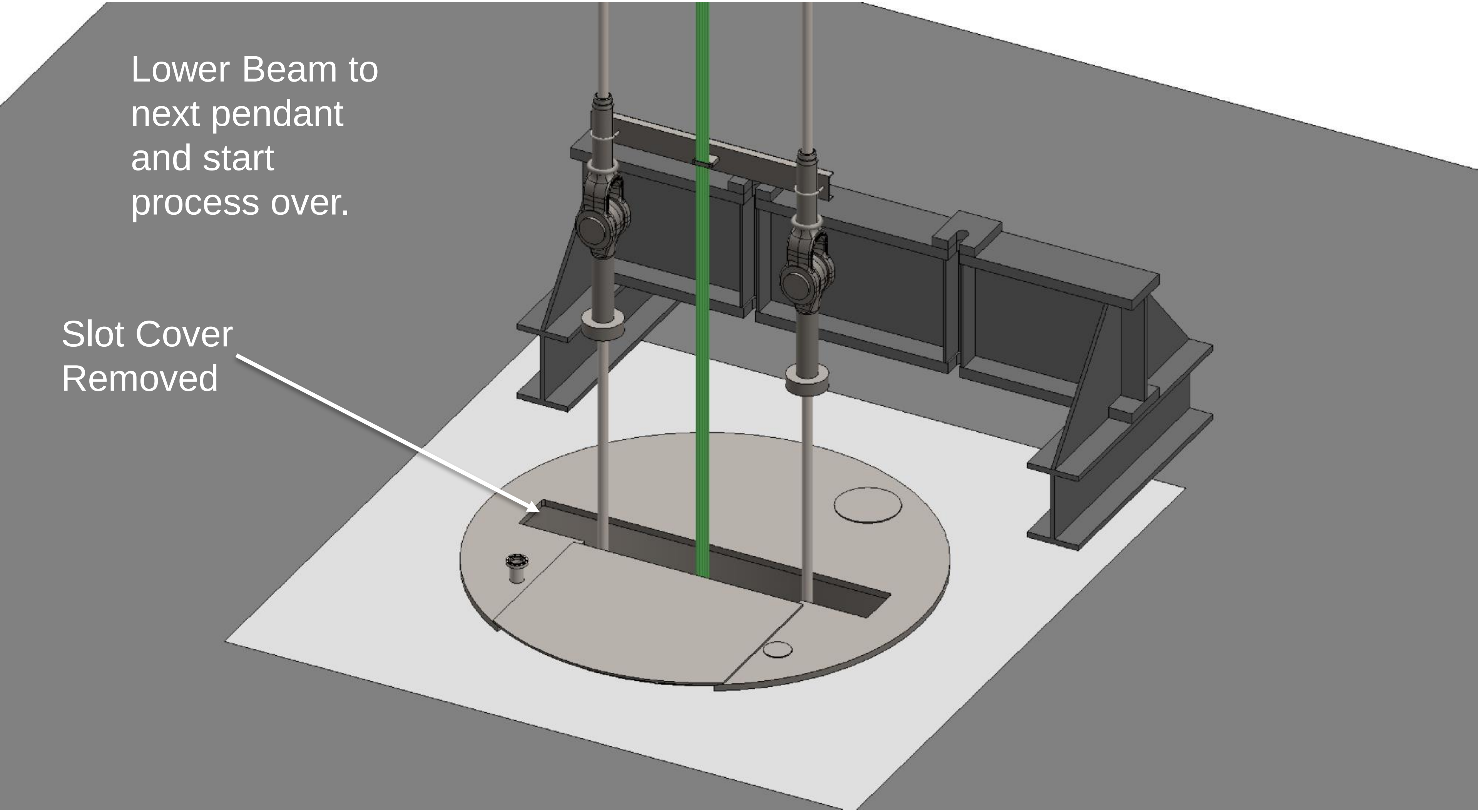
Changing Pendant, Phase 4



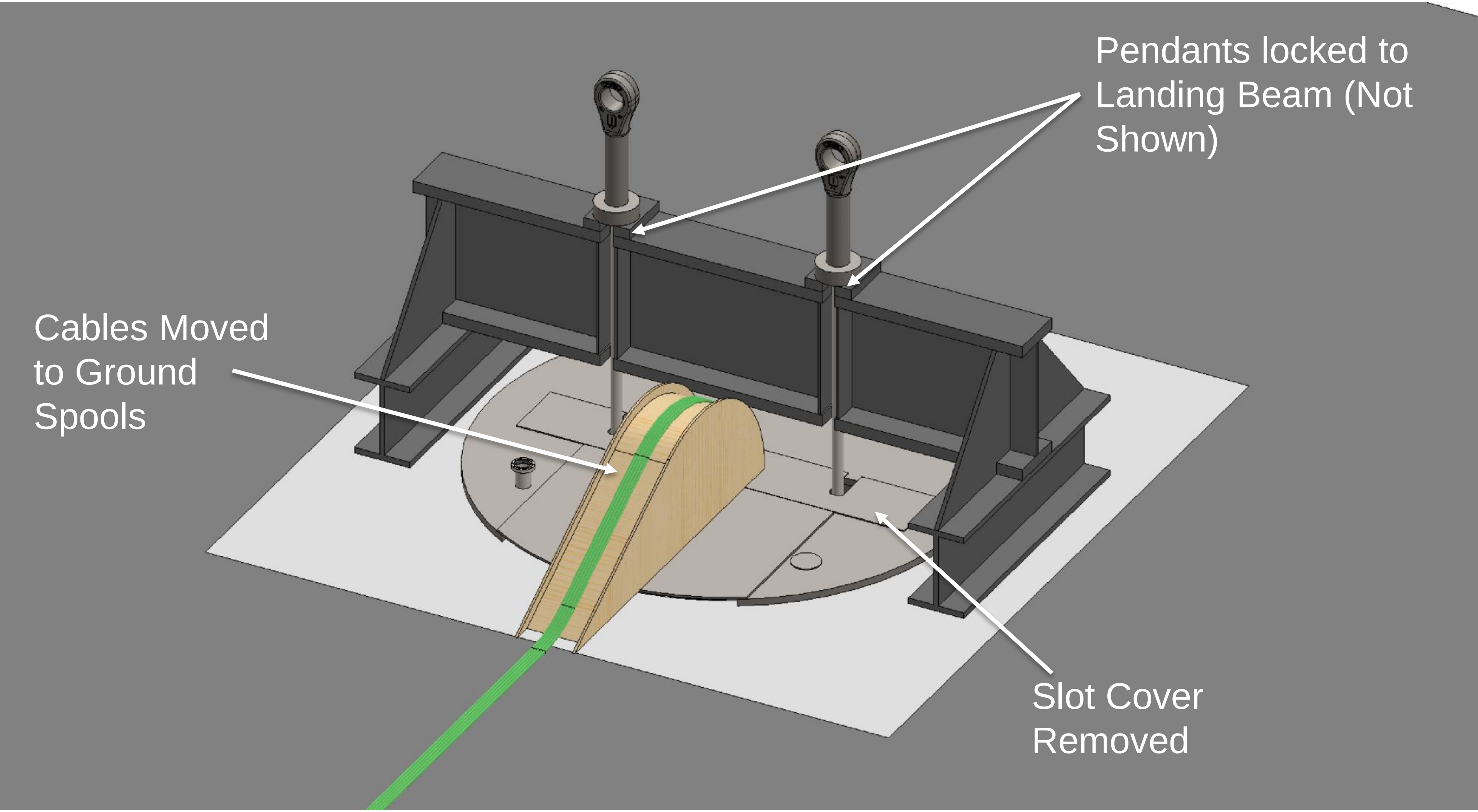
Changing Pendant, Phase 5



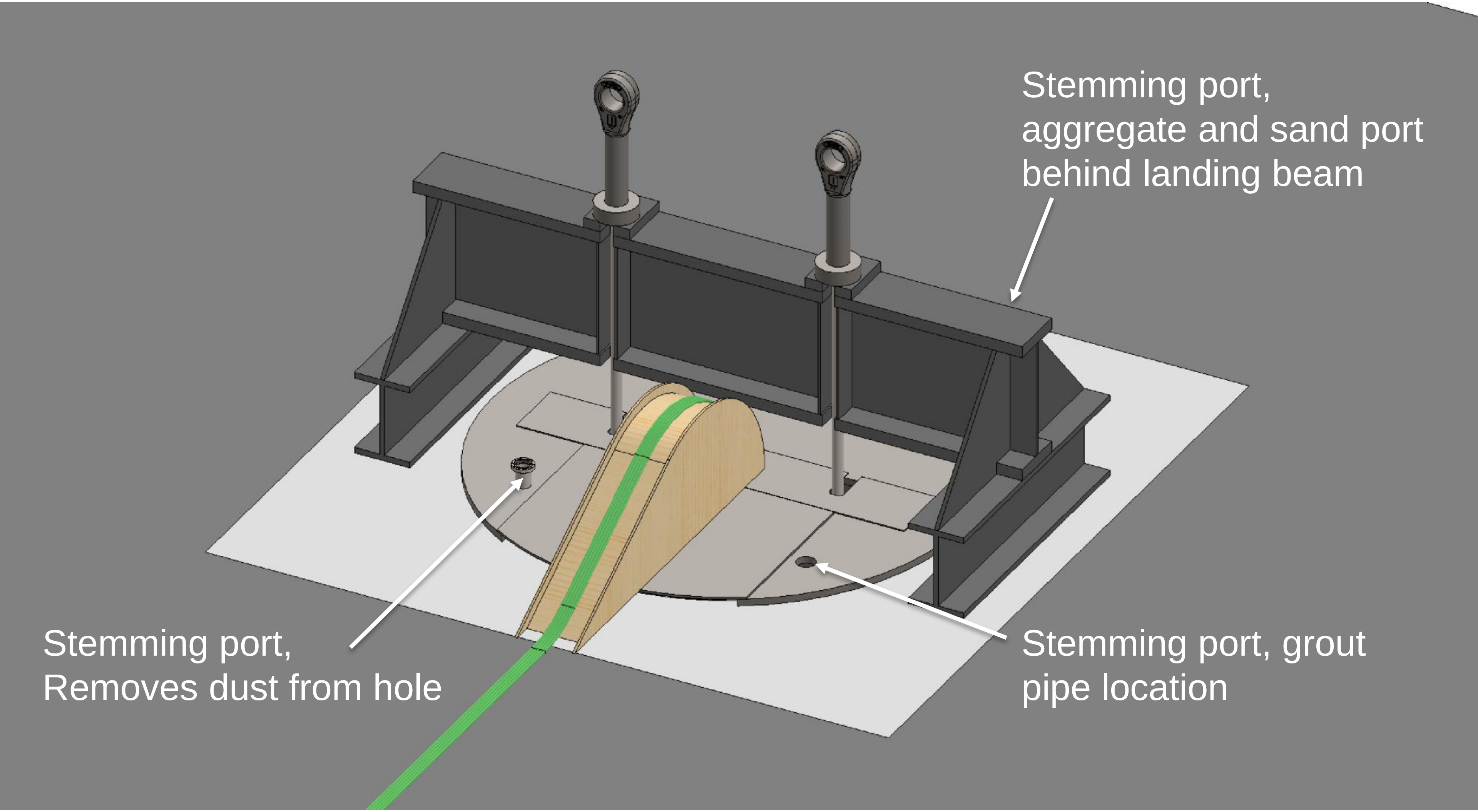
Changing Pendant, Phase 6



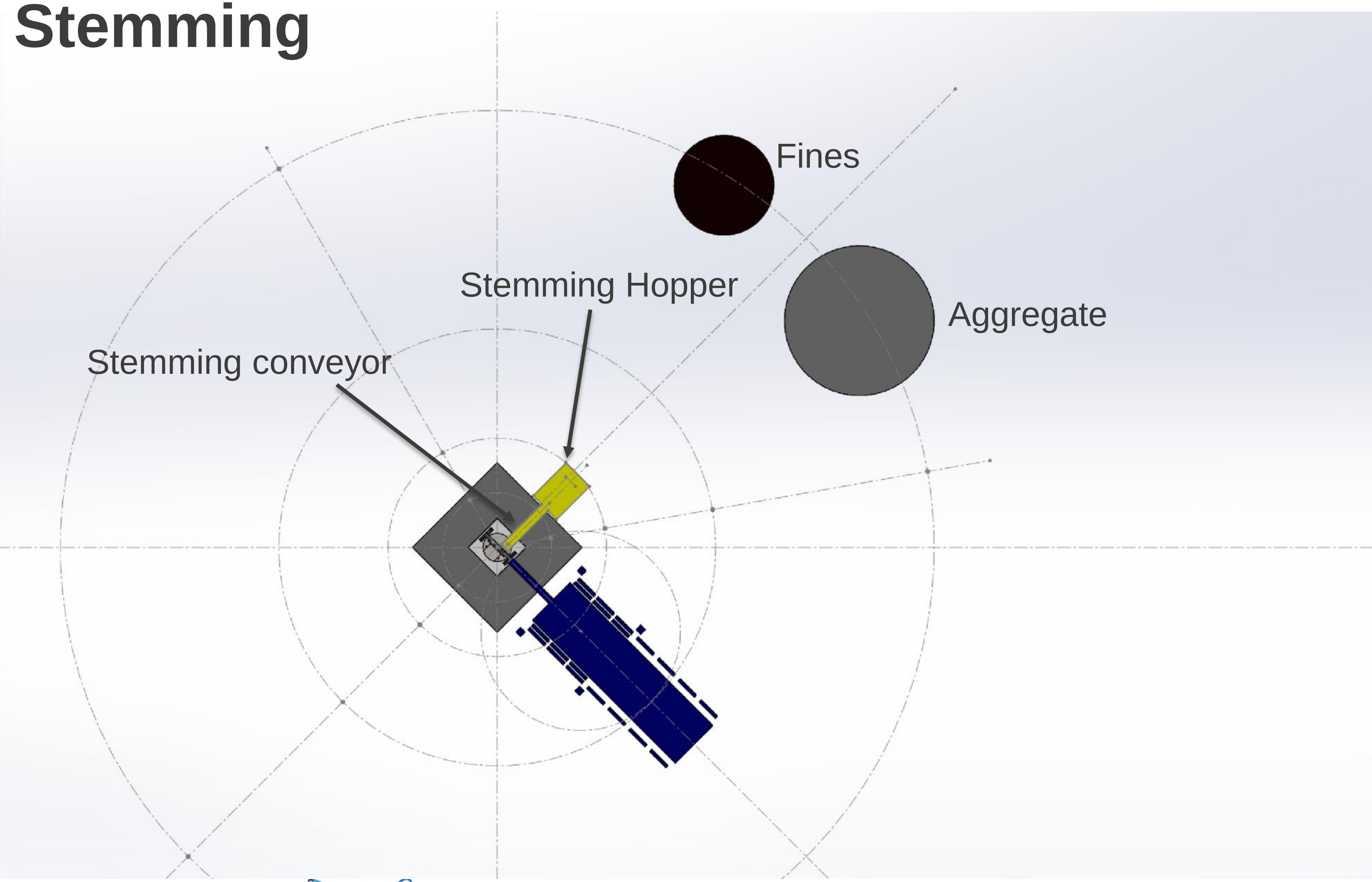
Landing Tank into Final Position



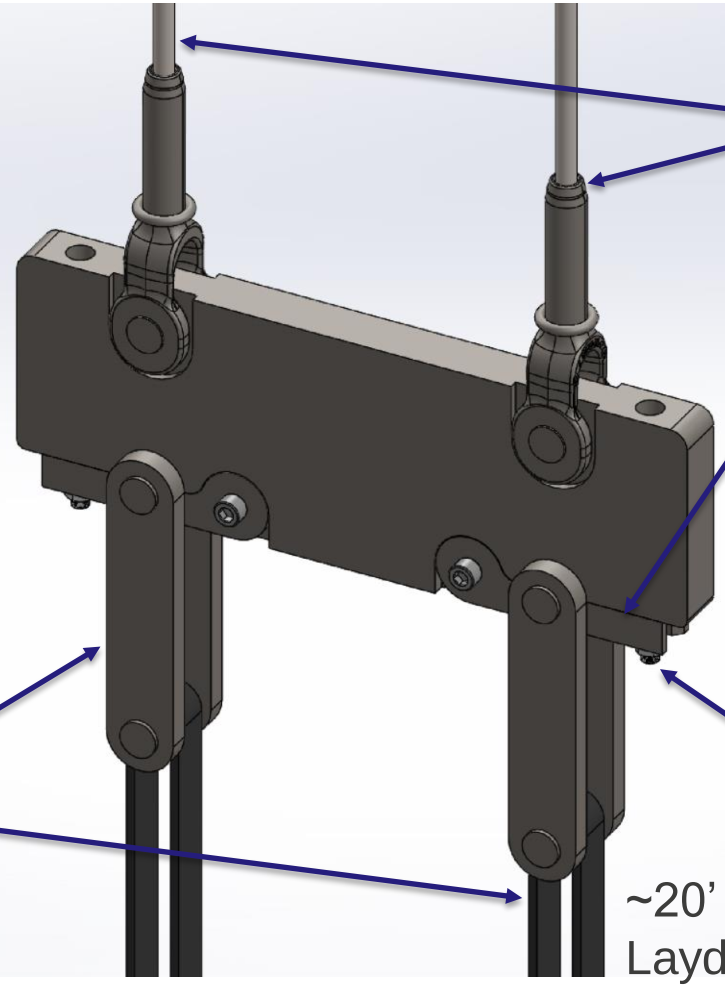
Stemming


Stemming port,
aggregate and sand port
behind landing beam
Stemming port,
Removes dust from hole
Stemming port, grout
pipe location

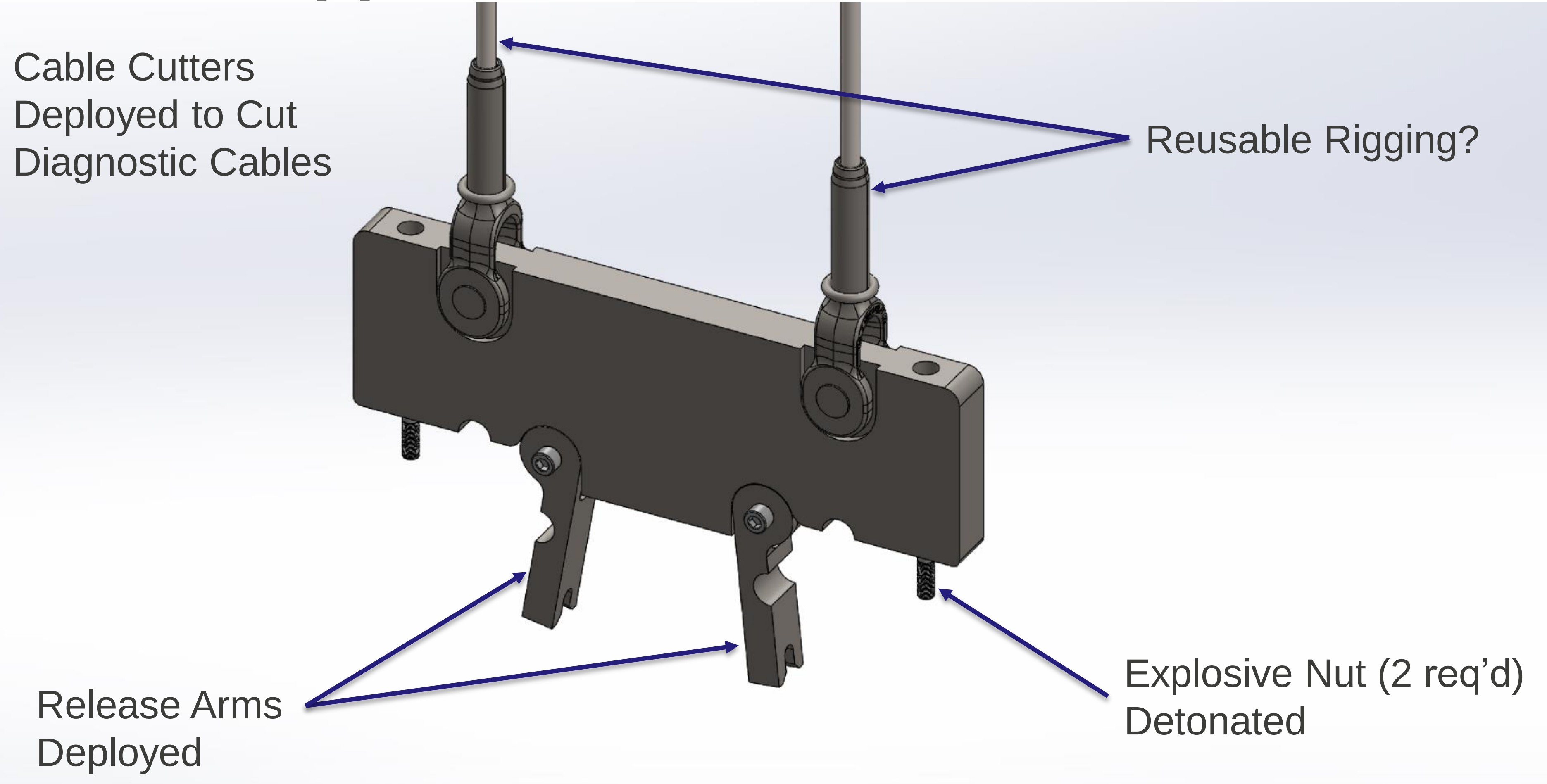
Stemming



Lower Support Beam



Lower Support Beam

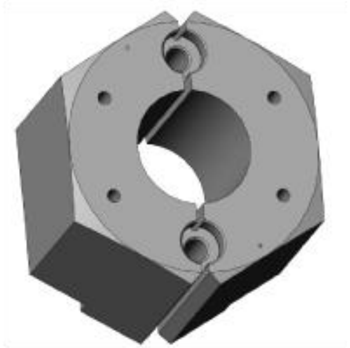


Rigging

- **Pyrotechnic Assemblies**
  - ➢ "On-the-shelf", requires a high voltage detonator/fireset adaption
    - Nasa Qualified 999 reliability
    - Survive Launch Environment

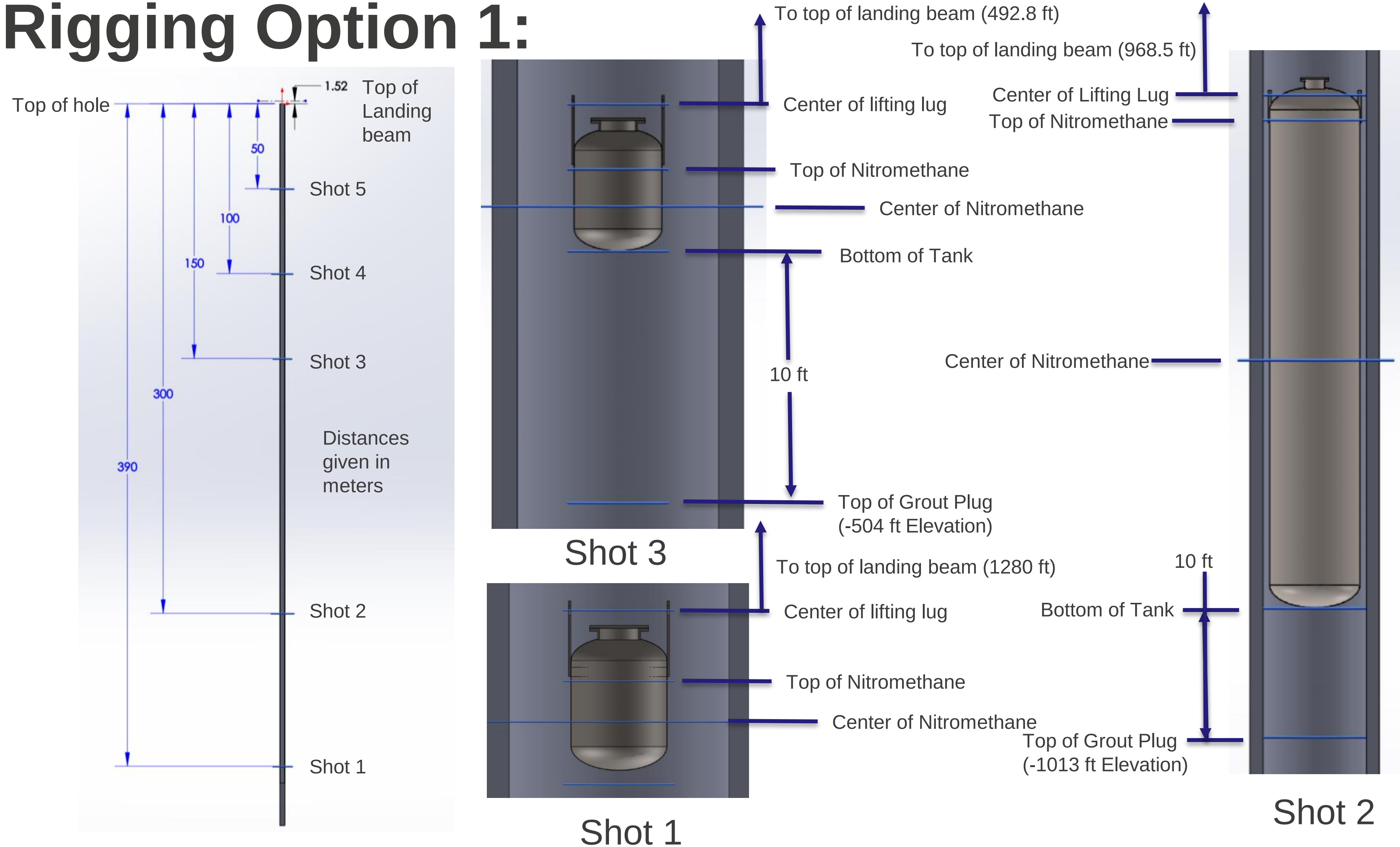
Pyrotechnic Guillotine Cable Cutter

Frangible Nut

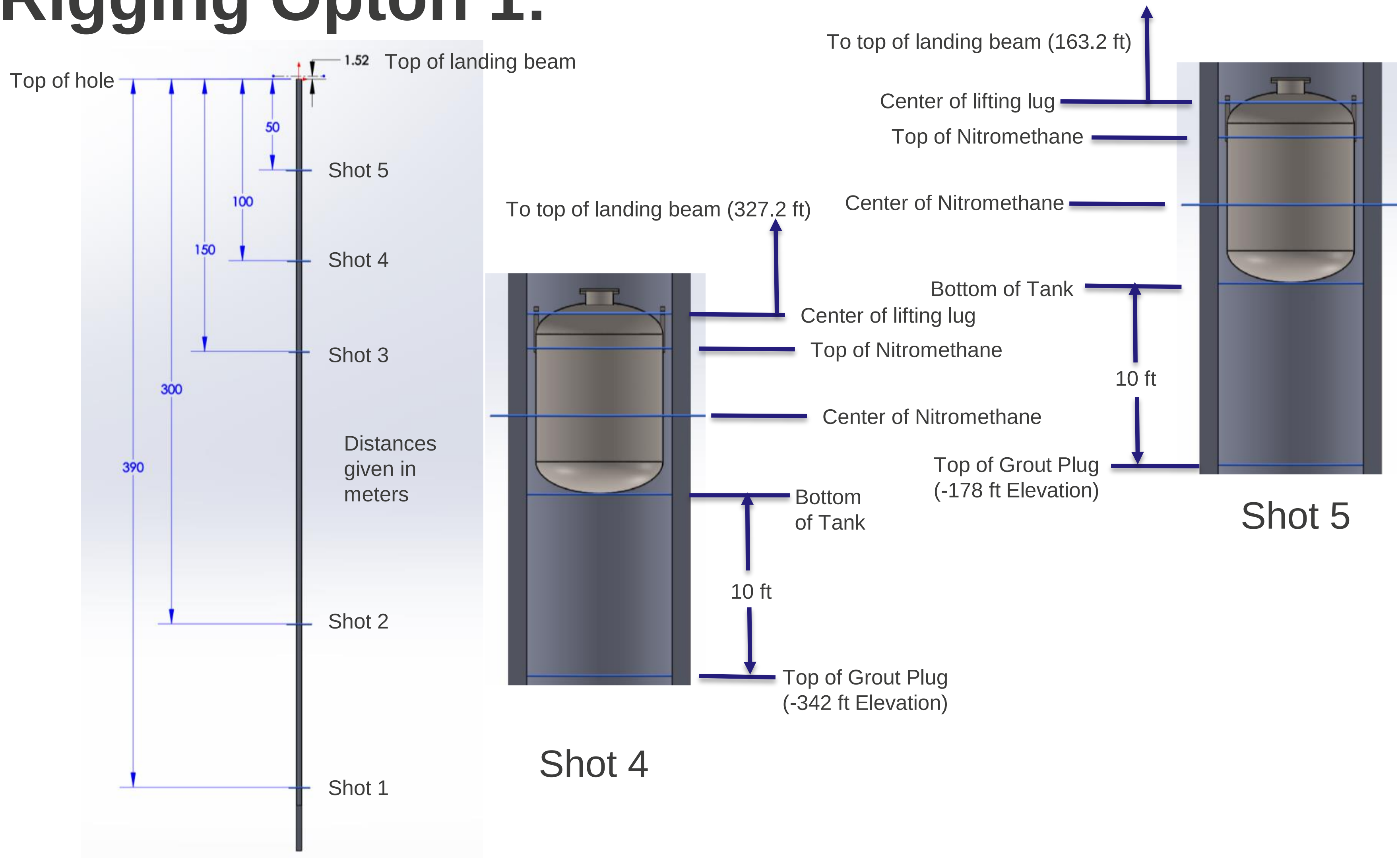


- ➢ Need to verify that industry will not supply the high voltage detonator/fireset.

Rigging Option 1:



Rigging Opton 1:



Rigging:

- Tank is supported from the strongback during all stemming operations
- Tank remains tied to the strongback during the shot
- Rigging is severed after the shot
- All diagnostic cables are tied/supported to the rigging
- Straps are used in addition to the steel diameter rigging to reduce the risk of puncturing the tank above. Straps extend above the grout plug. Fall down onto the grout plug after detonating explosive nuts.
- Diagnostic cables are cut after the shot using modified off-the-shelf cutters.

Rigging (Shot 1)

Top of Landing Beam		5 ft	Above Ground Level	
Length of Nylon Strap		20 ft		
Above Beam Pendants that go to the top of the Landing Beam (Reuseable)				
	Pendant	Numbers	L (ft)	Ø inches
	135	136	40	2.50
	137	138	40	2.50
	153	154	80	2.50
	155	156	80	2.50
	157	158	80	2.25
	159	160	80	2.25
	161	162	80	2.25
	163	164	80	2.25
	170	171	80	2.25
	174	175	80	2.25
	176	177	80	2.25
	185	186	80	2.25
			80	2.25
			47	2.25
Total			1007	
Below Beam Pendants that go to the top of the Canister (Consumed in Stemming)				
	Pendant	Numbers	L (ft)	Ø inches
	187	188	80	2.00
	32	33	80	2.00
			80	2.00
			12	2.00
Total			252	
Grand total including the strap and beam height			1280	

Rigging (Shot 2)

Top of Landing Beam	5	ft	Above Ground Level	
Length of Nylon Strap	18	ft		
Above Beam Pendants that go to the top of the Landing Beam (Reuseable)				
	Pendant	Numbers	L (ft)	Ø inches
	135	136	40	2.50
	137	138	40	2.50
	153	154	80	2.50
	155	156	80	2.50
	157	158	80	2.25
	159	160	80	2.25
	161	162	80	2.25
	117	118	19	2.25
Total			499	
Below Beam Pendants that go to the top of the Canister (Consumed in Stemming)				
	Pendant	Numbers	L (ft)	Ø inches
	163	164	80	2.25
	170	171	80	2.25
	174	175	80	2.25
	176	177	80	2.25
	185	186	80	2.25
	47	48	10	2.25
	14	15	42	2.25
Total			452	
Grand total including the strap and beam height			970	

Rigging (Shot 3)

Top of Landing Beam	5	ft	Above Ground Level	
Length of Nylon Strap	20	ft		
Above Beam Pendants that go to the top of the Landing Beam (Reuseable)				
	Pendant	Numbers	L (ft)	Ø inches
	135	136	40	2.50
	137	138	40	2.50
	153	154	80	2.50
	155	156	80	2.50
	157	158	80	2.25
	39	40	16	2.25
Total			336	
Below Beam Pendants that go to the top of the Canister (Consumed in Stemming)				
	Pendant	Numbers	L (ft)	Ø inches
	191	192	80	2.00
	30	31	37	2.00
	55	56	19	2.00
Total			136	
Grand total including the strap and beam height			493	

Rigging (Shot 4)

Top of Landing Beam	5	ft	Above Ground Level	
Length of Nylon Strap	22	ft		
Above Beam Pendants that go to the top of the Landing Beam (Reuseable)				
	Pendant	Numbers	L (ft)	Ø inches
	135	136	40	2.50
	153	154	80	2.50
	178	179	52	2.25
Total			172	
Below Beam Pendants that go to the top of the Canister (Consumed in Stemming)				
	Pendant	Numbers	L (ft)	Ø inches
	172	173	80	2.00
	81	82	10	2.00
	16	17	23	2.00
	49	50	19	2.00
Total			132	
Grand total including the strap and beam height			327	

Rigging (Shot 5)

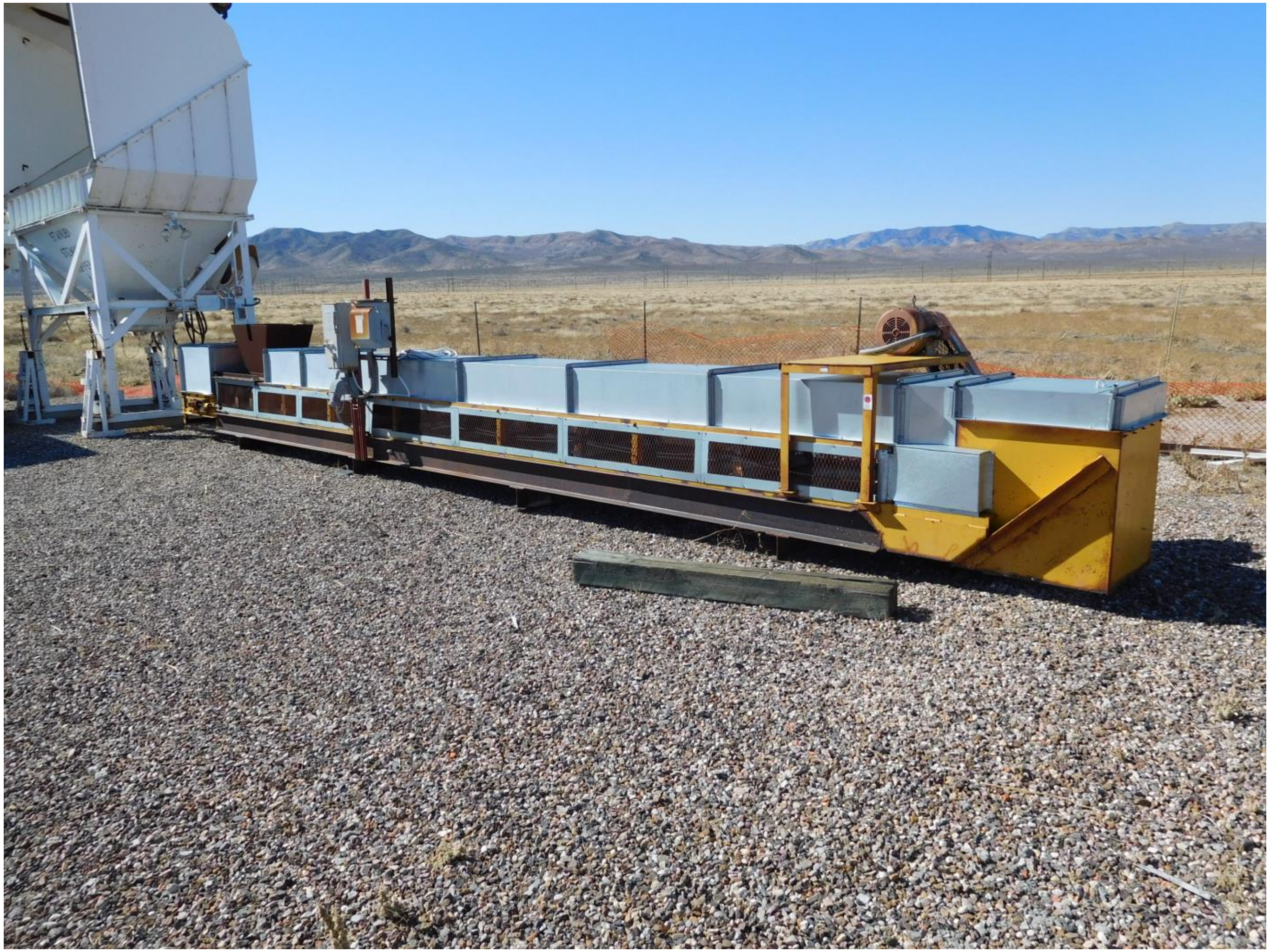
Top of Landing Beam	5	ft	Above Ground Level	
Clearance from bottom of tank to grout plug	10	ft		
Depth of shot	164	ft	50	meters
Elevation of the Tank Lug	158		1900.88	inches
Length from center of tank lug to top of hole	158	ft		
Length from center of tank lug to top of Landing Beam	163	ft		
Required Length of Pendants	163	ft		
Below Beam Pendants that go to the top of the Canister (Consumed in Stemming)				
	Pendant	Numbers	L (ft)	Ø inches
	167	168	80	2.00
	165	166	80	2.00
Total			160	
Grand total including the strap and beam height			160	

Legacy Rigging Located at LANL (TA-60):




NNSS Equipment:

NNSS Equipment:



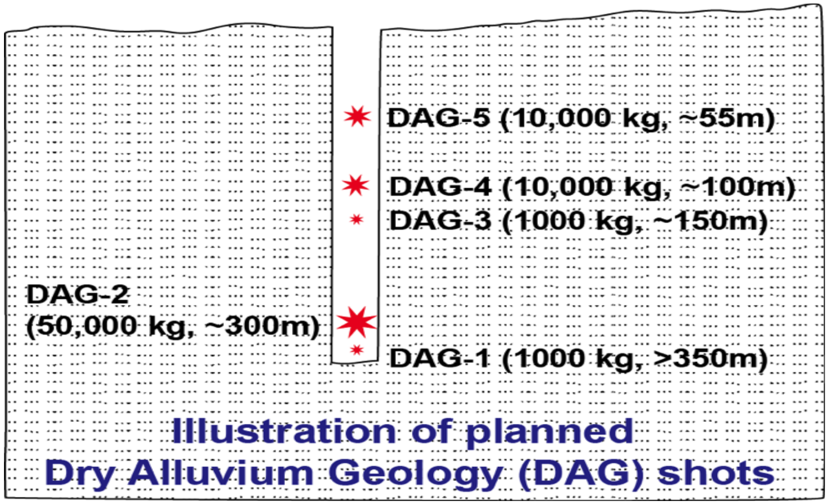
NNSS Equipment:

Dry Alluvium Geology (DAG)
PDR - Nitromethane Pressure Vessels

Pressure Vessel Design Scope

- **Five pressure vessels are required for DAG experiments**
  - DAG-1: 1000 kg, >350m
  - DAG-2: 50000 kg, ~300m
  - DAG-3: 1000 kg, ~150m
  - DAG-4: 10000 kg, ~100m
  - DAG-5: 10000 kg, ~55m (50m??)
  - *Depths shown for approximate location – may not be up to date.*

Shot Size [kg]	NM Qty [kg]	Density @ 20C [kg/m^3]	Volume @ 20 C [m^3]	[in^3]	[gal]
50000	44248	1138	38.88	2372307	10270
10000	8850	1138	7.78	474461	2054
1000	885	1138	0.78	47446	205.4



Basic Requirements

- **Contain quantity of Nitromethane (205.4, 2054, 10270 gallons)**
  - Per hazard analysis, have NM fill be below the surface of the hole
  - Nitromethane quantities based on TNT-equivalent mass (1.13X more output for NM)
- **Interface with:**
  - Nitromethane handling system (fill / empty)
    - Inert gas may be used to force NM out of tank in the event it must be emptied
  - Top-of-the-hole support (ring)
  - Crane pendants (rigging)
  - Inert gas purge
  - Fireset / initiator system
  - Instrumentation (internal / external)
- **Pressure vessel construction meeting / exceeding ASME BPVC section 8, div. 1**
  - Vessels will not be code-stamped

Derived requirements

- **Design pressure = nominal pressure + worst case pressure rise + static pressure head + operational margin**
  - Minimum temperature: 20 deg. F (-6.7 deg. C)
  - Maximum temperature: 100 deg. F (37.8 deg. C)
  - Nominal pressure @ Fill: 5 PSI gage
    - Slight positive pressure to help keep inert gas "blanket" over NM
  - Worst case pressure: 28.4 PSI gage
    - Assumes a cold fill (20 deg. F); tank and fluid reach equilibrium at maximum temperature (100 deg. F)
  - Static pressure head (for largest tank):
    - 20 PSI (~480 inches @ 1.1382 g/mL)
  - Design pressure used for tank thickness: 60 PSI gage
    - Maximum allowable operating pressure typically 90% of maximum allowable working pressure
    - Do not want relief valve to operate or leak during normal operation
- **Current design allows for ~30 PSI gage to be used to evacuate NM from pressure vessels**

Materials

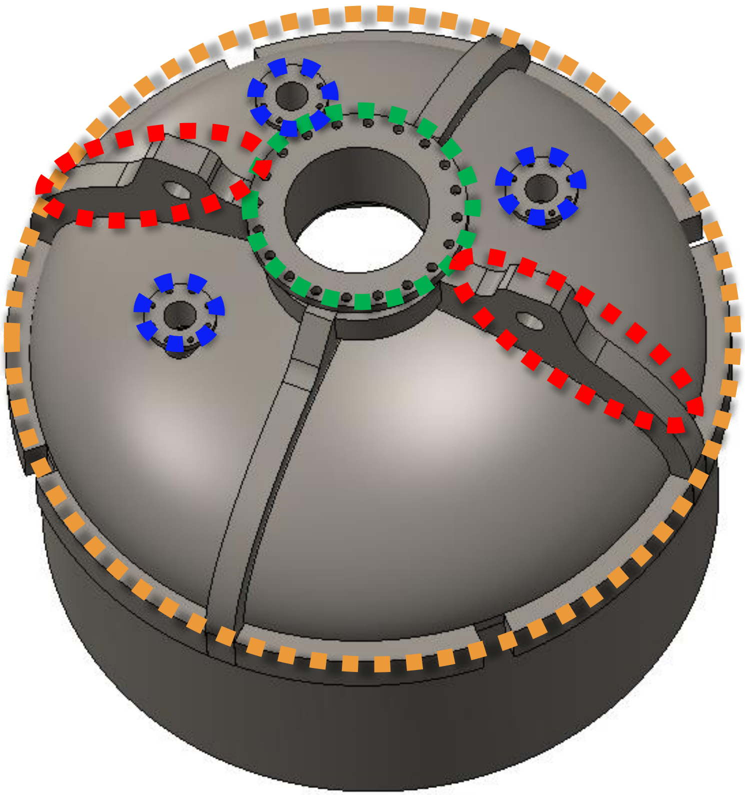
- **A516 grade 70: most common pressure vessel carbon steel**
  - Pressure vessel construction (<500 deg. F service): 20 KSI max per BPVC section 2, part D (Max Allowable Stress for Ferrous Materials)
  - 38 KSI yield; determines 10.85 KSI maximum stress in structural features if using rigging FoS requirements (3.5 on yield)
  - 70 KSI ultimate;
- **Due to size constraints / weight, certain vessel features will be made from HSLA-80 or HSLA-100 (material on hand @ LANL)**
  - Lifting lugs
  - Central nozzle neck reinforcement

DAG Factors of Safety

- **Pressure vessels (ASME BPVC)**
  - VIII-1: 3.5 on Ultimate Strength
  - Stamped vessels require hydrostatic proof test (1.3 on maximum allowable working pressure * lowest stress ratio)
    - Water fill / drain and air bleed nozzles will be incorporated into top head
    - Despite not stamping the vessels, we will hydrostat to code requirements for division 1.
- **DAG selected FoS for vessel structural features:**
  - 3.5 on yield, 5 on ultimate:
    - SA-516 Grade 70: 10.85 KSI max stress (yield limiting)
    - HSLA-80: 20 KSI max stress (ultimate limiting)

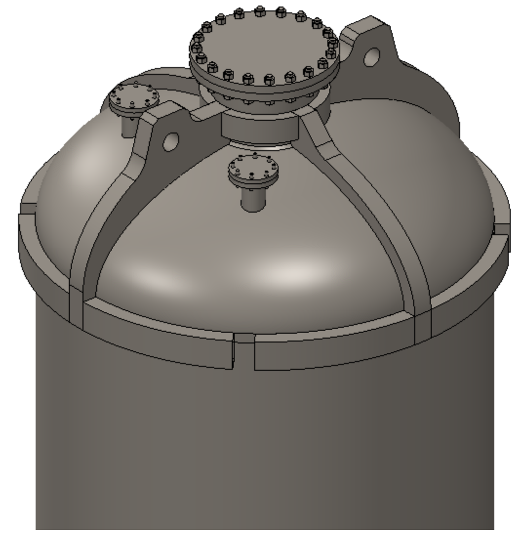
Vessel Mechanical Interfaces

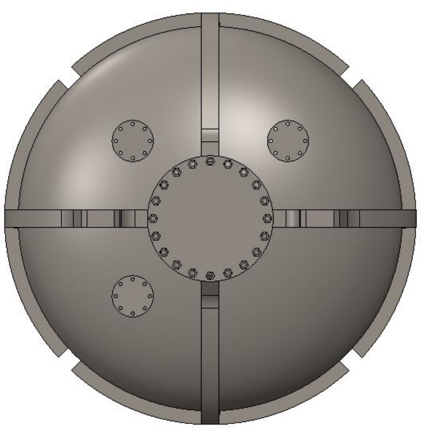
- **Structural:**
  - ➢ Lifting lugs
  - ➢ Support ring
- **Vessel nozzles:**
  - ➢ Central nozzle: 17"+ clearance min opening for initiator
    - 20" schedule 80 pipe selected as nozzle neck (17.938" nominal ID)
    - Class 150 flange (ASME B16.5)
  - ➢ Ancillary nozzles:
    - 3X required (4 easily placed):
      - NM fill (including dip-tube)
      - Air out during NM fill / pressure relief during use or purge
      - TBD level indicating sensor
    - 4.5" schedule 40 pipe as nozzle neck (4.0" nominal ID)
    - Class 150 flanges
  - ➢ Hydrostat flanges (not yet incorporated in designs)
    - Fill (hill-side-bottom), air out (hill-side-top);
    - 1" NPT connection; capped after fabrication



10270 Gallon Vessel

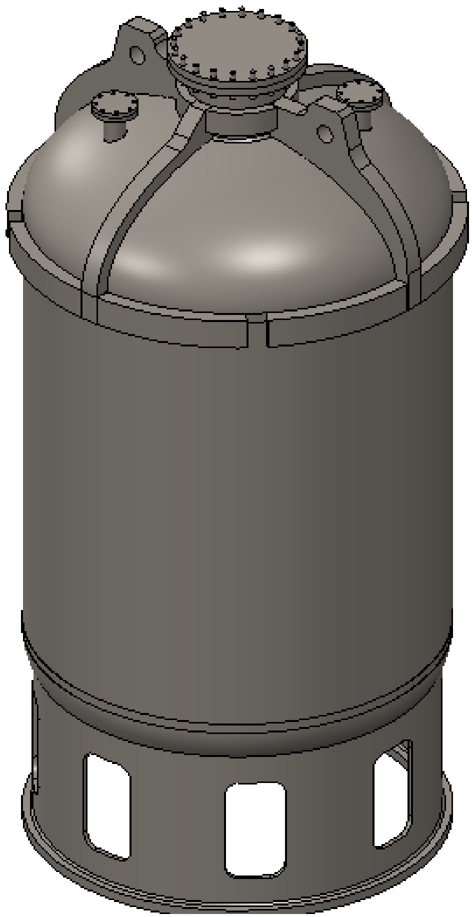
- **Weights:**
  - Vessel: 15215 lbs
    - With covers / studs / nuts: ~ 15582 lbs
  - NM: 44248 kg (97550 lbs)
- **Vessel parameters:**
  - 84" outer diameter
  - 0.25" wall thickness (top head: 0.50" thick)
  - Cyl section length: 443.31"
  - Heads: 2:1 ratio ASME type
  - Openings: 1 X 17.9"dia, 3 X 4"dia
  - Skirt: ~36" tall, 1" thick, 2.0" thick ring foot on bottom
  - Overall length: 517.680" (43'1.6")
    - Skirt foot to central flange
  - 48" pendant spacing





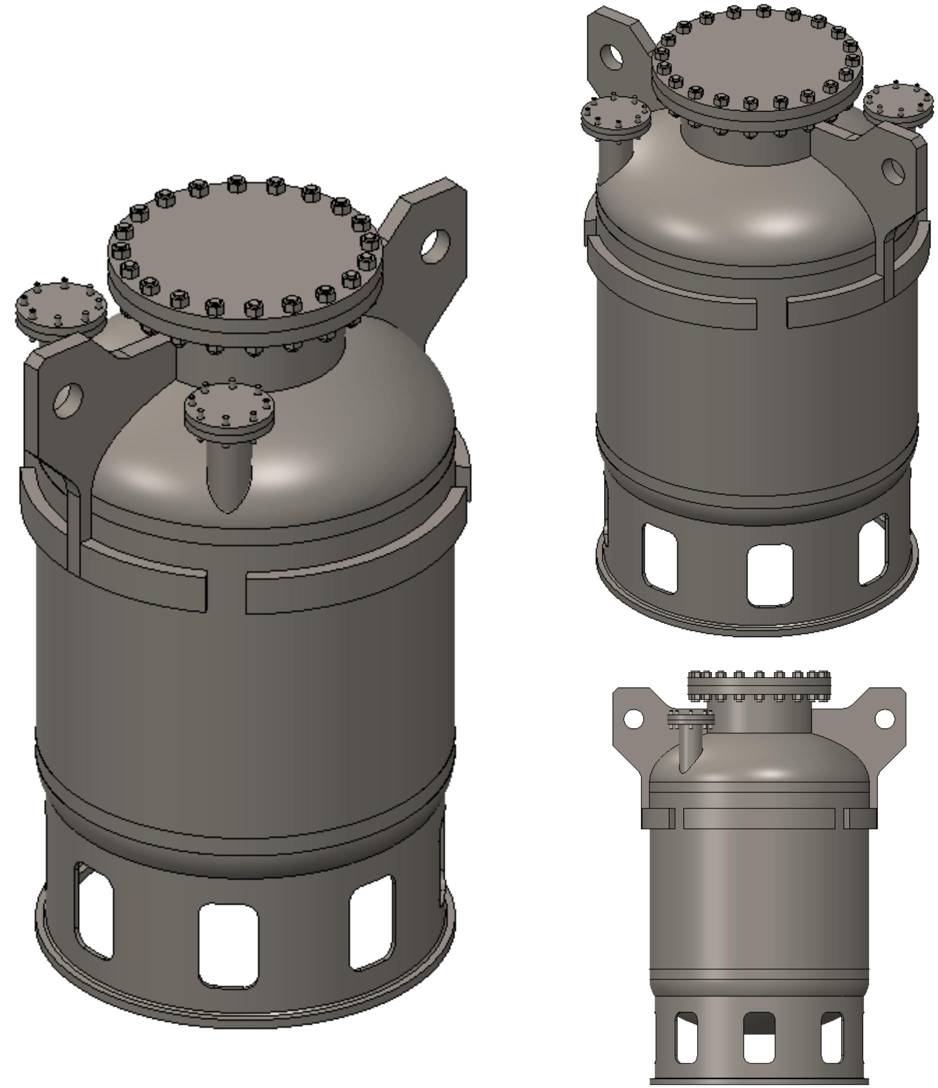
2054 Gallon Vessel

- **Weights:**
  - Vessel: 8751 lbs
    - With covers / studs / nuts: ~ 9116 lbs
  - NM: 8850 kg (19511 lbs)
- **Vessel parameters:**
  - 84" outer diameter
  - 0.25" wall thickness (top head: 0.50" thick)
  - Cyl section length: 96.73"*
  - Heads: 2:1 ratio ASME type
  - Openings: 1 X 17.9"dia, 3 X 4"dia
  - Skirt: ~36" tall, 1" thick, 2.0" thick ring foot on bottom
  - Overall length: 172.720" (14'4.7")
    - Skirt foot to central flange
  - 48" pendant spacing



205.4 Gallon Vessel

- **Weights:**
  - Vessel: 1284 lbs
    - With covers / studs / nuts: ~ 1649 lbs
  - NM: 885 kg (1951 lbs)
- **Vessel parameters:**
  - 42" outer diameter
  - 0.125" wall thickness
  - Cyl section length: 39.8"
  - Heads: 2:1 ratio ASME type
  - Openings: 1 X 18.8"dia, 3 X 4"dia
  - Skirt: ~17" tall, 0.5" thick, 1.0" thick ring foot on bottom
  - Overall length: 76.17" (6'4.17")
    - Skirt foot to central flange
  - 48" pendant spacing



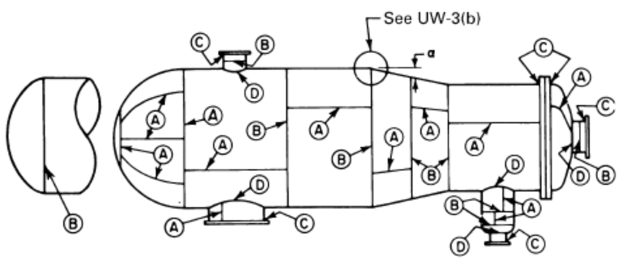
Design Status

- **Pressure vessel:**
  - ➢ Thickness selected (BPVC hand calculations)
  - ➢ Nozzles selected (Sched. 40 / 80 pipe / Class 150 flat face flanges)
  - ➢ Joint and nozzle FEA: will do in Compress (starting next week)
- **Structural / lifting features:**
  - ➢ Lifting lugs
    - Detailed FEA complete for base lug / confirmed with hand calculations
      - Required a change from SA-516-70 to HSLA-80 to keep size reasonable.
    - Weld attachment FEA done for 84" vessels. Minor adjustment needed for small areas of higher stress on vessel head.
  - ➢ Support ring
    - Basic FEA complete for support on top of hole for 84" vessels. Design is substantial.
    - Attachment to lifting lugs / head reinforcement looks adequate.
  - ➢ 42" vessel has not been analyzed

Analysis, ASME BPVC VIII-1

- **BPVC calculations based on 60 PSI design pressure**
- **0.70 assumed for non-backed, double sided weld joint efficiency**
  - Does not require inspection
  - Requires same quality weld on both sides
  - 0.70 is the max allowed for this as a design assumption before requiring spot (0.85) or full radiographic inspection (1.0)
- **20 KSI max stress incorporates code's factor of safety (500 deg F or less)**

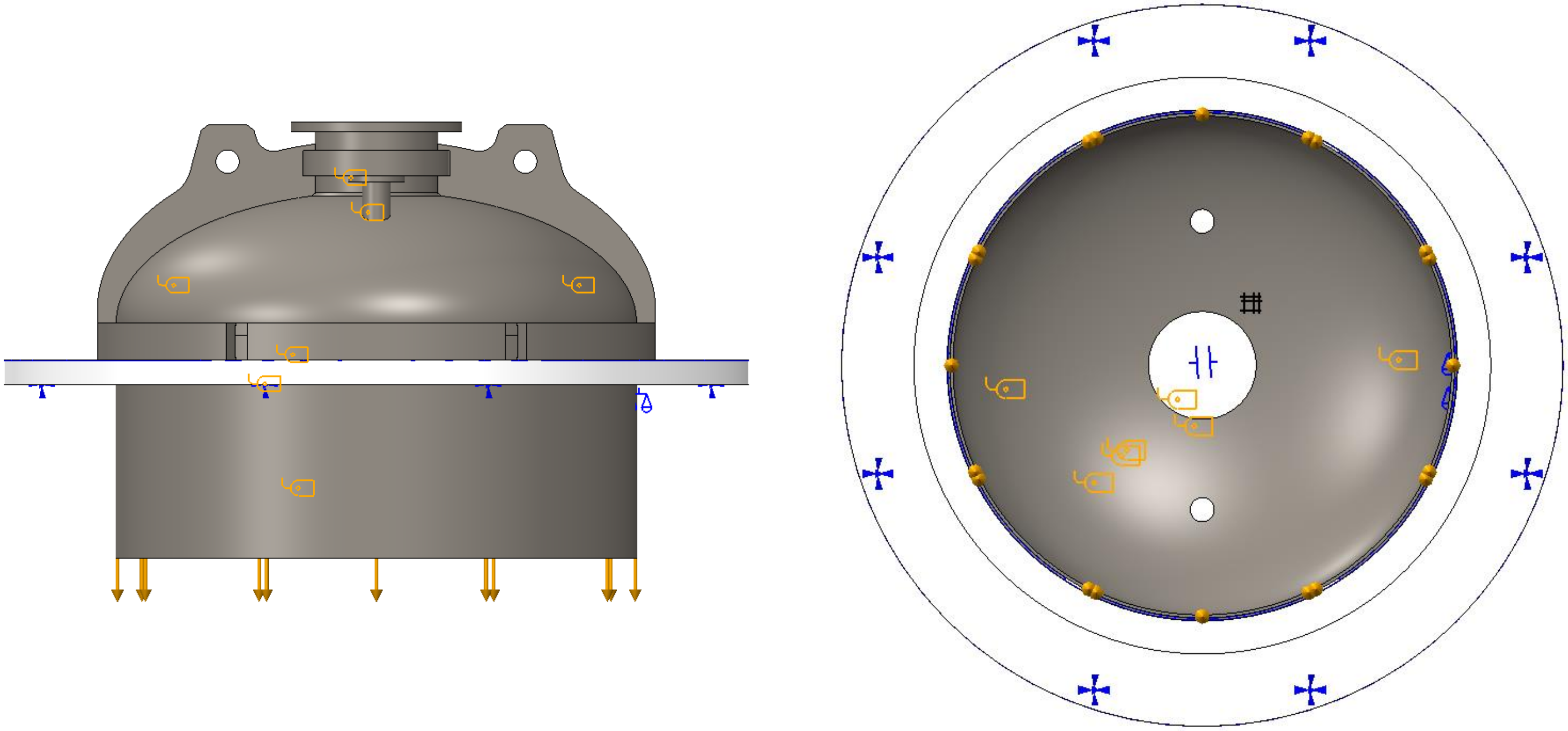
Figure UW-3
Illustration of Welded Joint Locations Typical of Categories A, B, C, and D



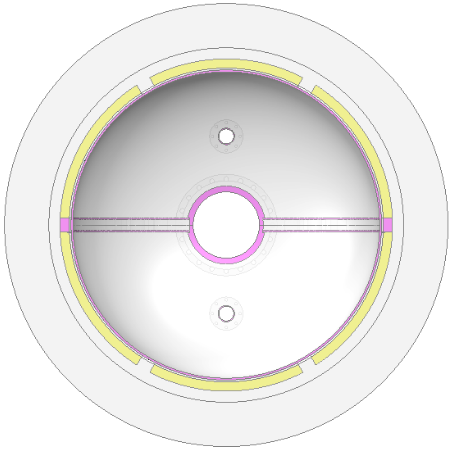
Category A: Longitudinal welded joints
Category B: Circumferential welded joints

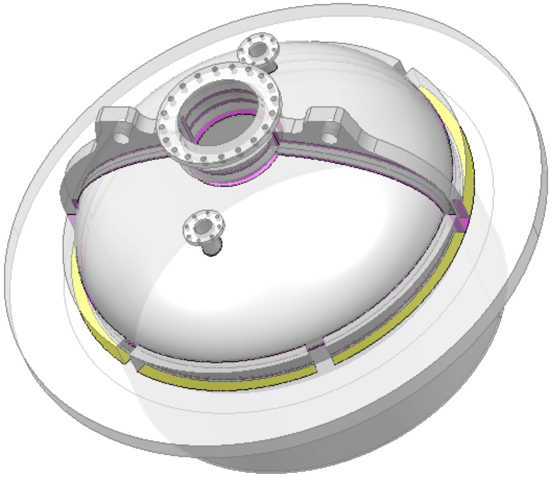
Vessel	Joint Efficiency		Min Reqd Thickness		Selected	Theoretical Max P	
	Longit	Circum	Longit	Circum	Thickness	Longit	Circum
[gal]	[-]	[-]	[in]	[in]	[in]	[psi]	[psi]
205.4	0.7	0.7	0.082	0.041	0.125	83.5	168
2054	0.7	0.7	0.164	0.082	0.25	83.5	168
10270	0.7	0.7	0.164	0.082	0.25	83.5	168

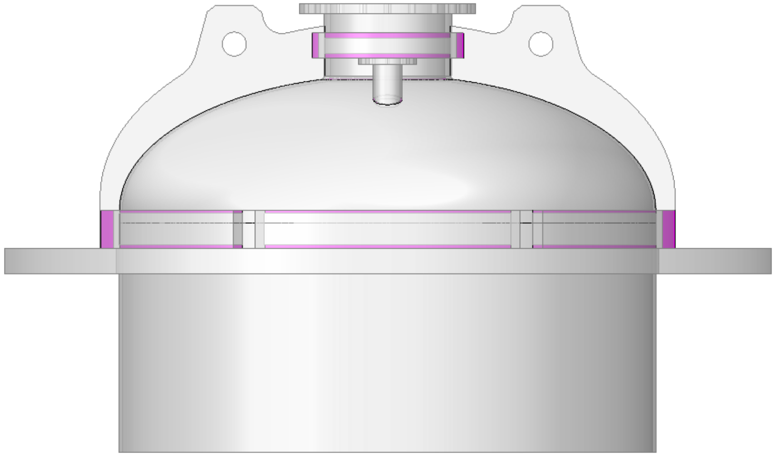
Pressure Vessel Analysis (10270 Gallon Size)



Contact Analysis: Support Ring Interfaces





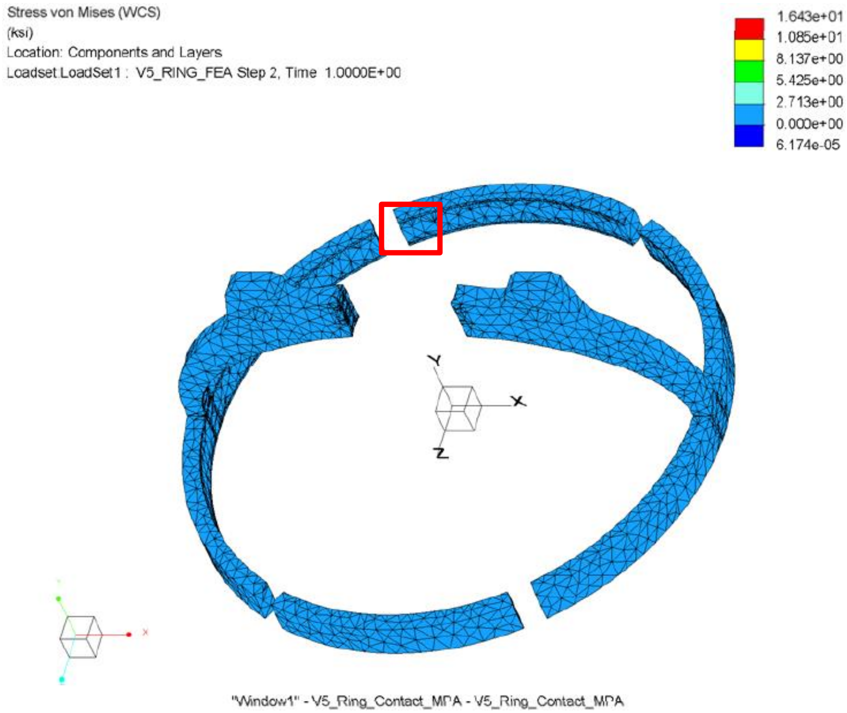


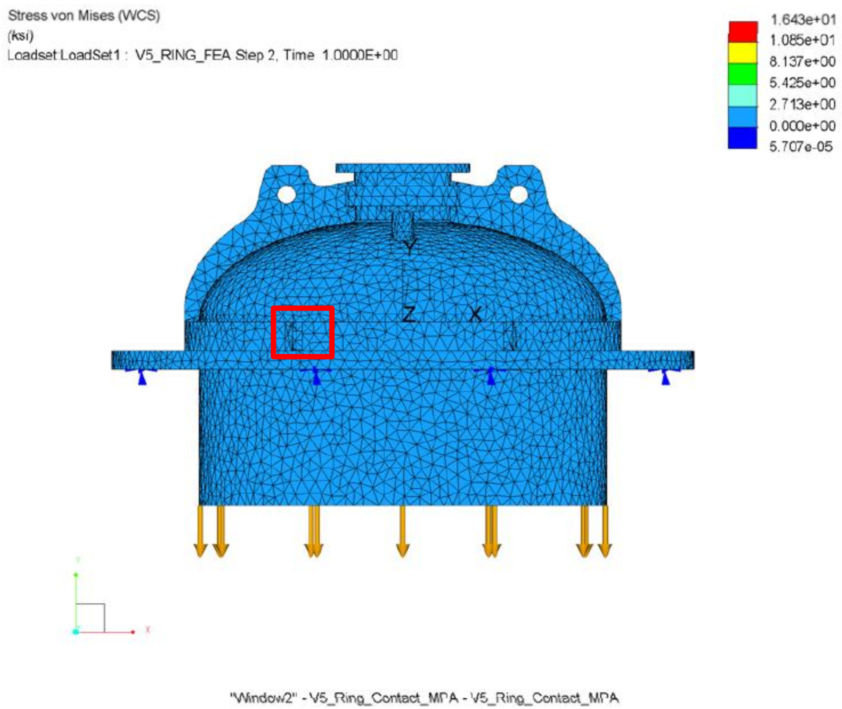
Purple: Bonded (Welds)
Yellow: Contact

Note: analysis done for previous tank design with less reinforcement

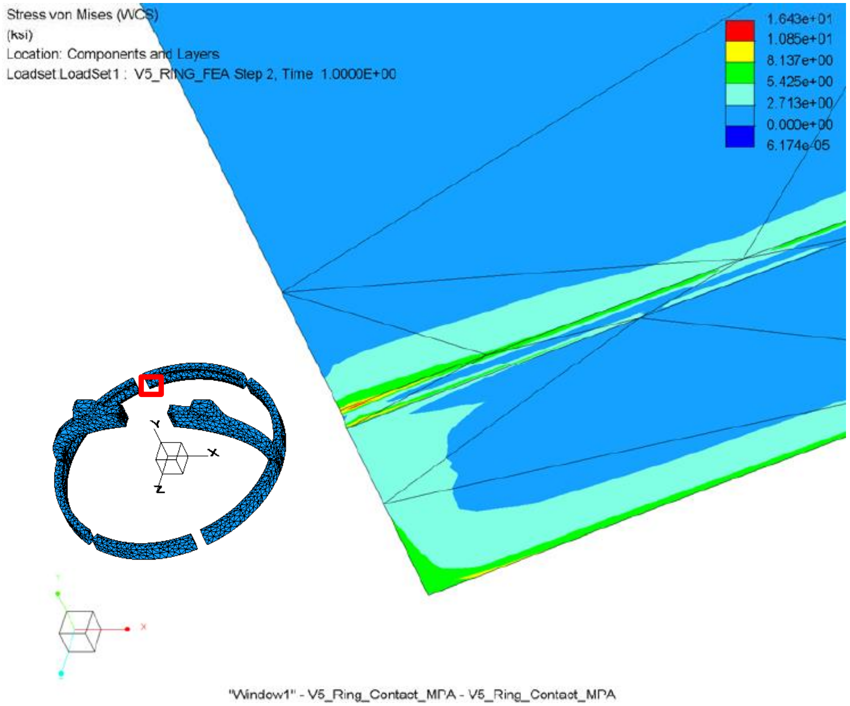
Support Ring Stresses (Contact)

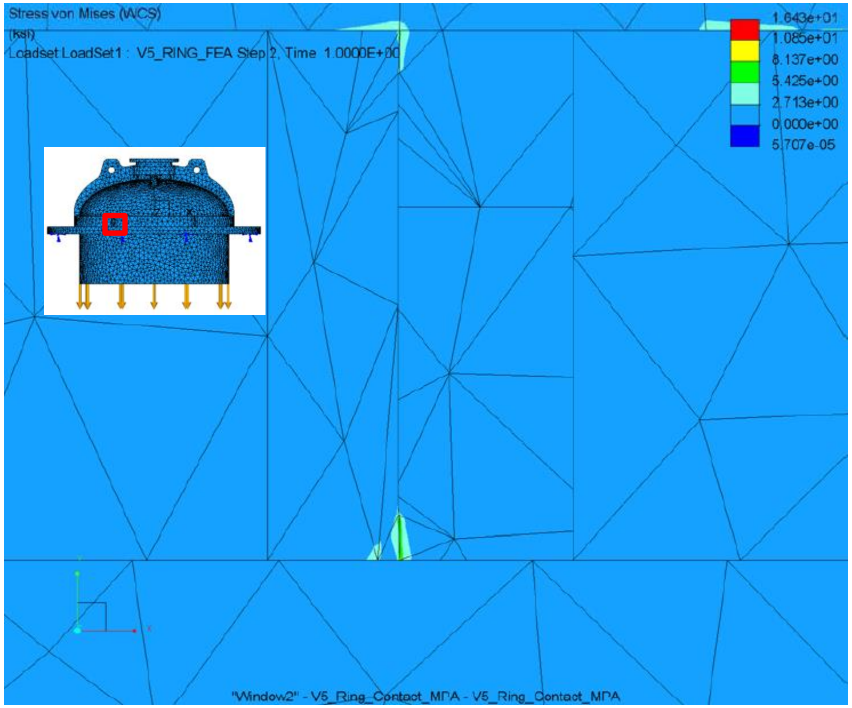
Note: stress range is for SA-516-70
FoS of 3.5 on yield is 10.85 KSI
HSLA-80 limited by 5 on ultimate: 20KSI



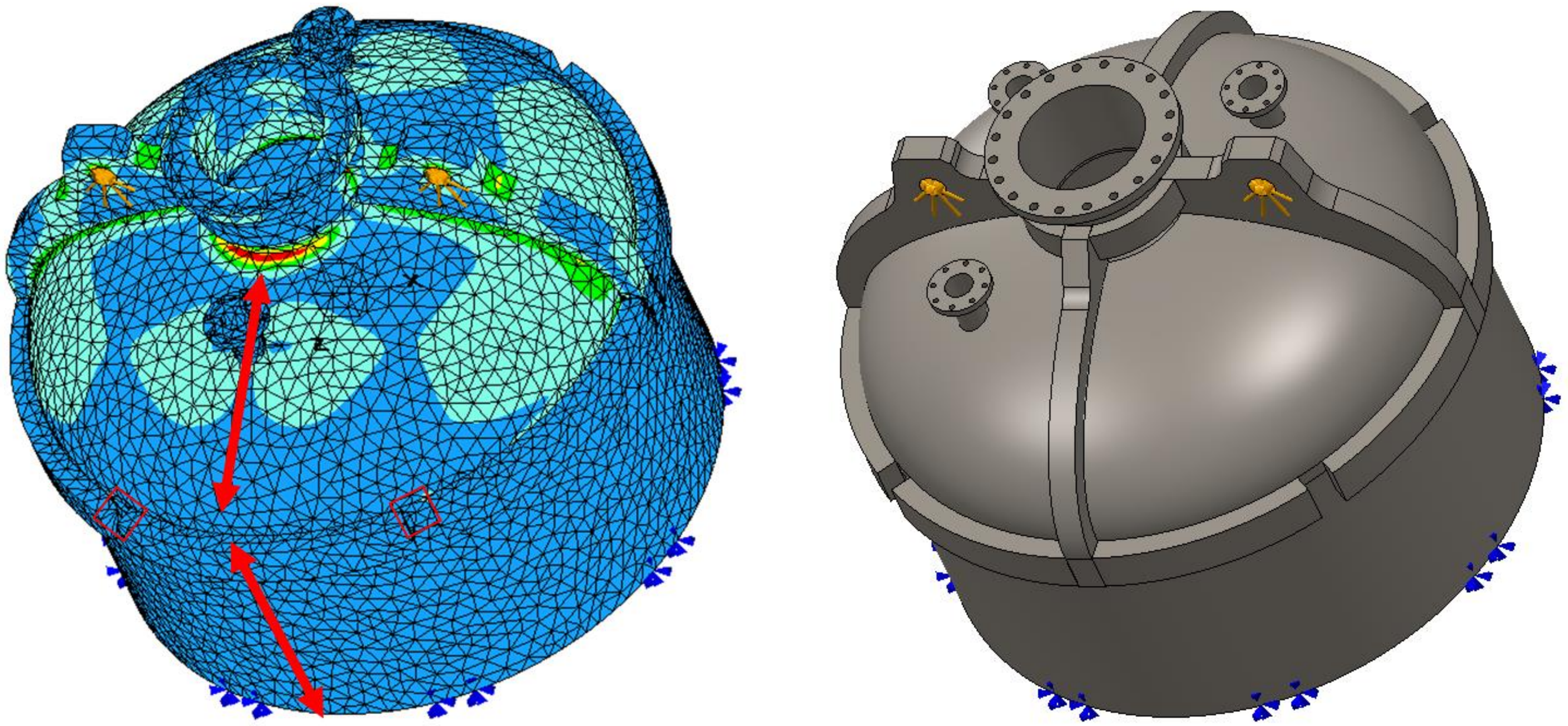


Support Ring Stresses (Contact)

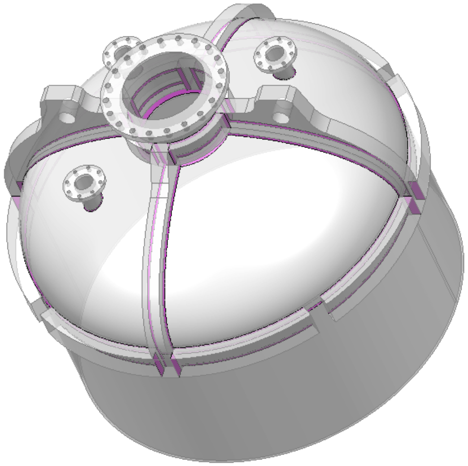
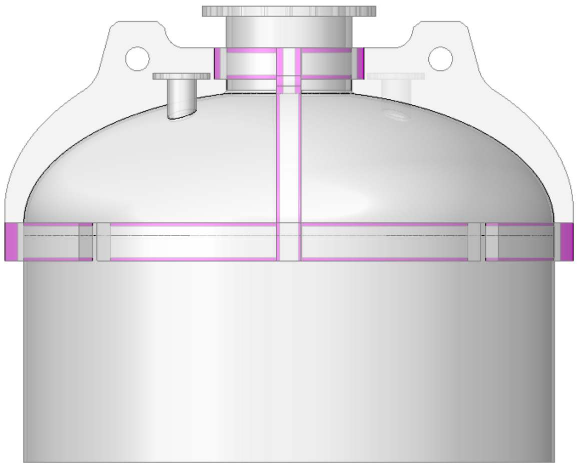
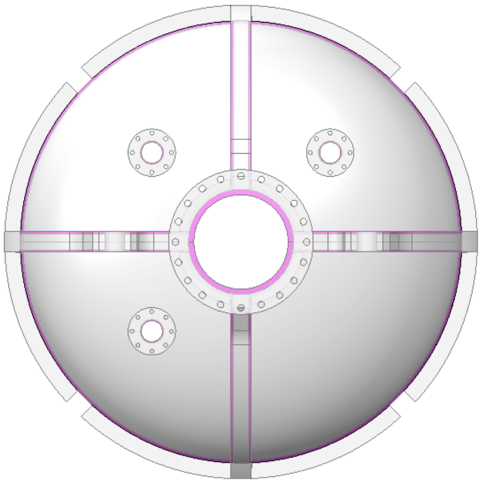




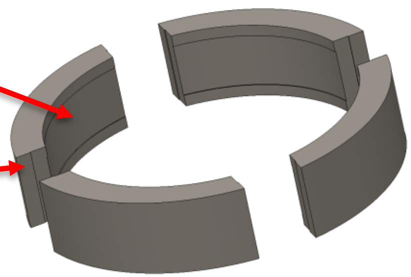
Lug Design / Head Reinforcement



Lifting Lug Analysis: Interfaces

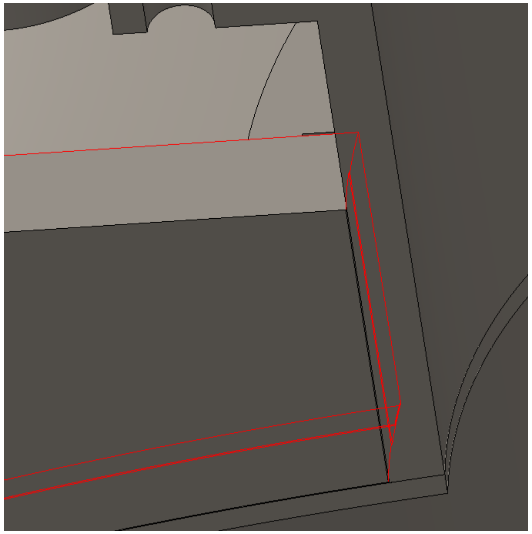




0.50" Fillet @ Central Nozzle / Head Interface
0.50" Groove @ Lug / Reinforcement to Head
2.00" Groove @ Lug / Reinforcement to Support Ring
0.75" Groove @ Nozzle Neck to Nozzle Neck Reinforcement
1.00" Groove @ Nozzle Neck Reinforcement to Lugs / Head Reinforcement



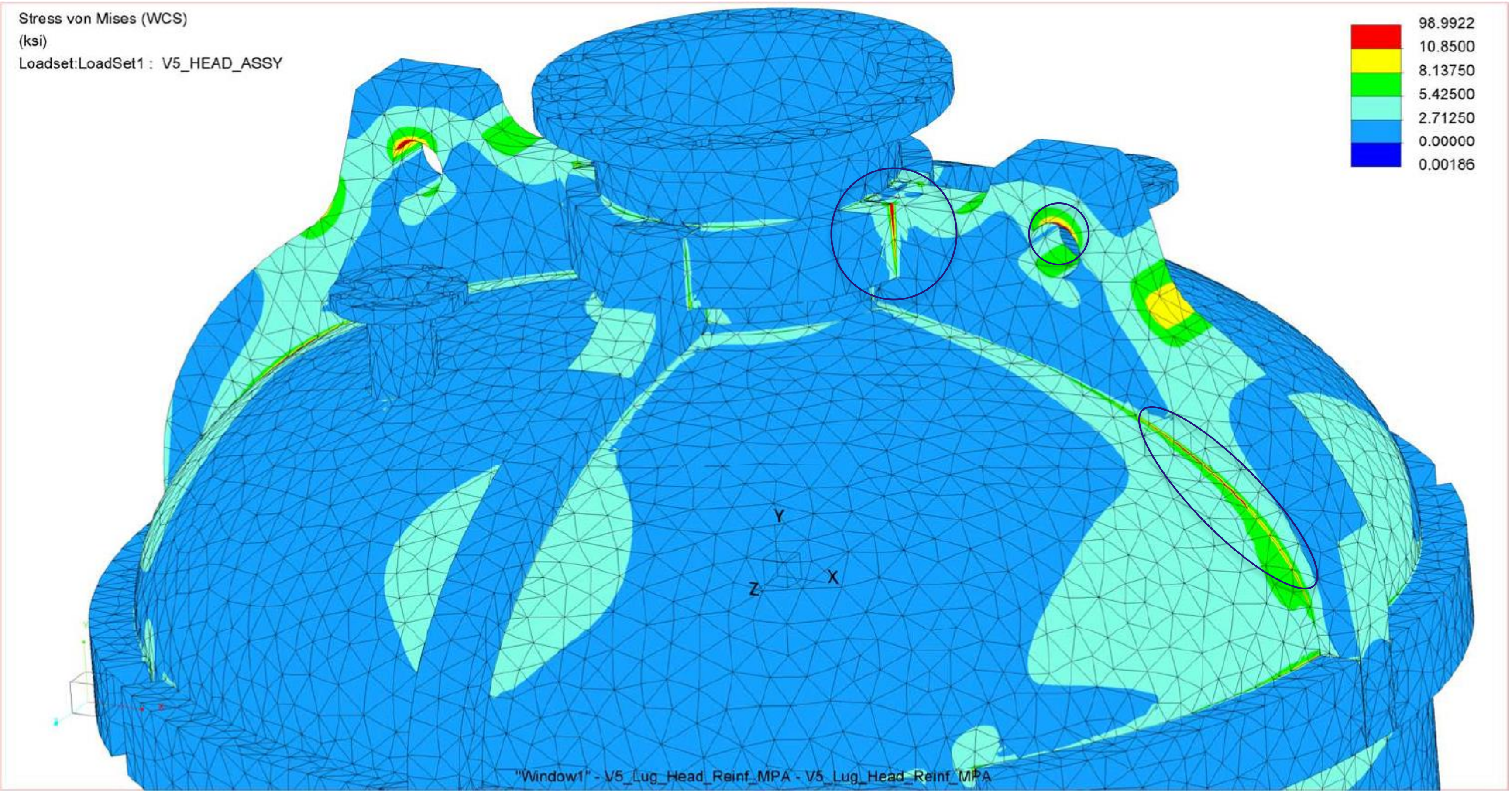
Clearance

Surfaces Raised and Bonded

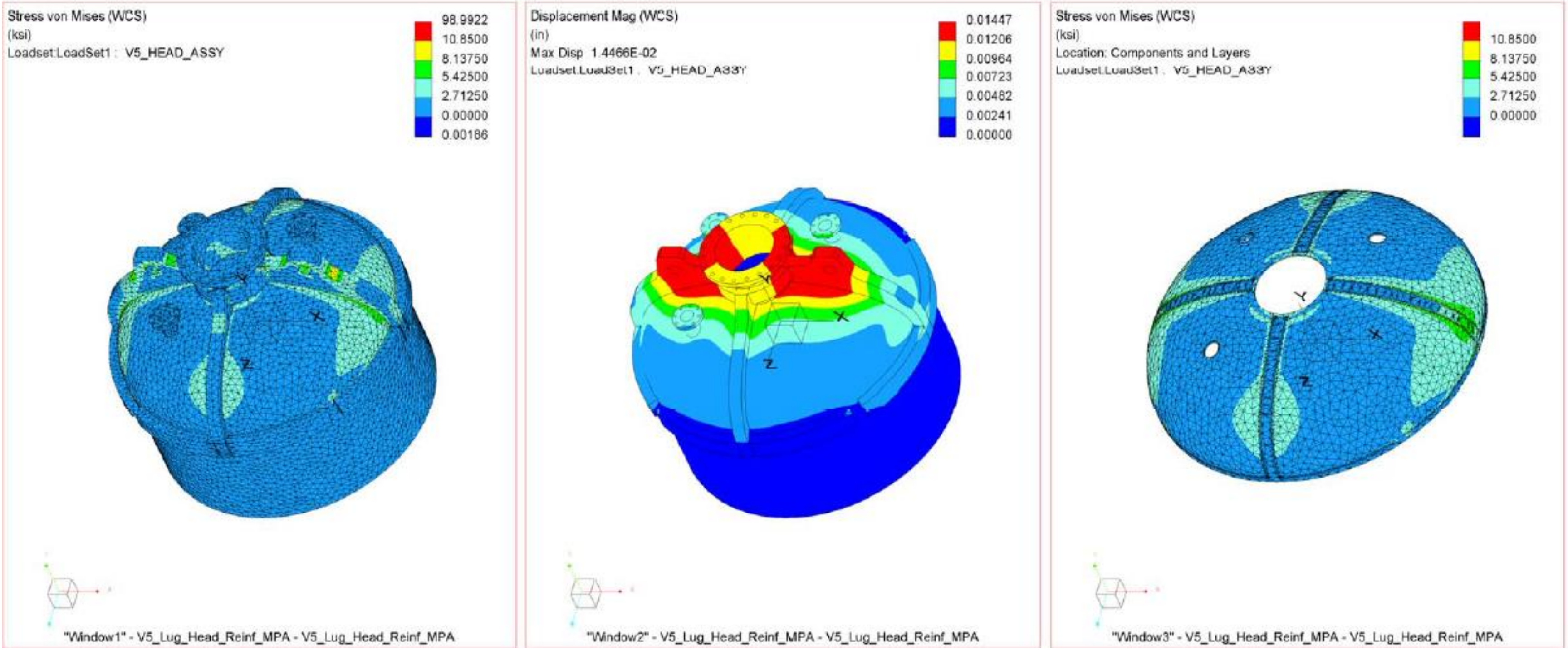


Vessel Lifting Stresses

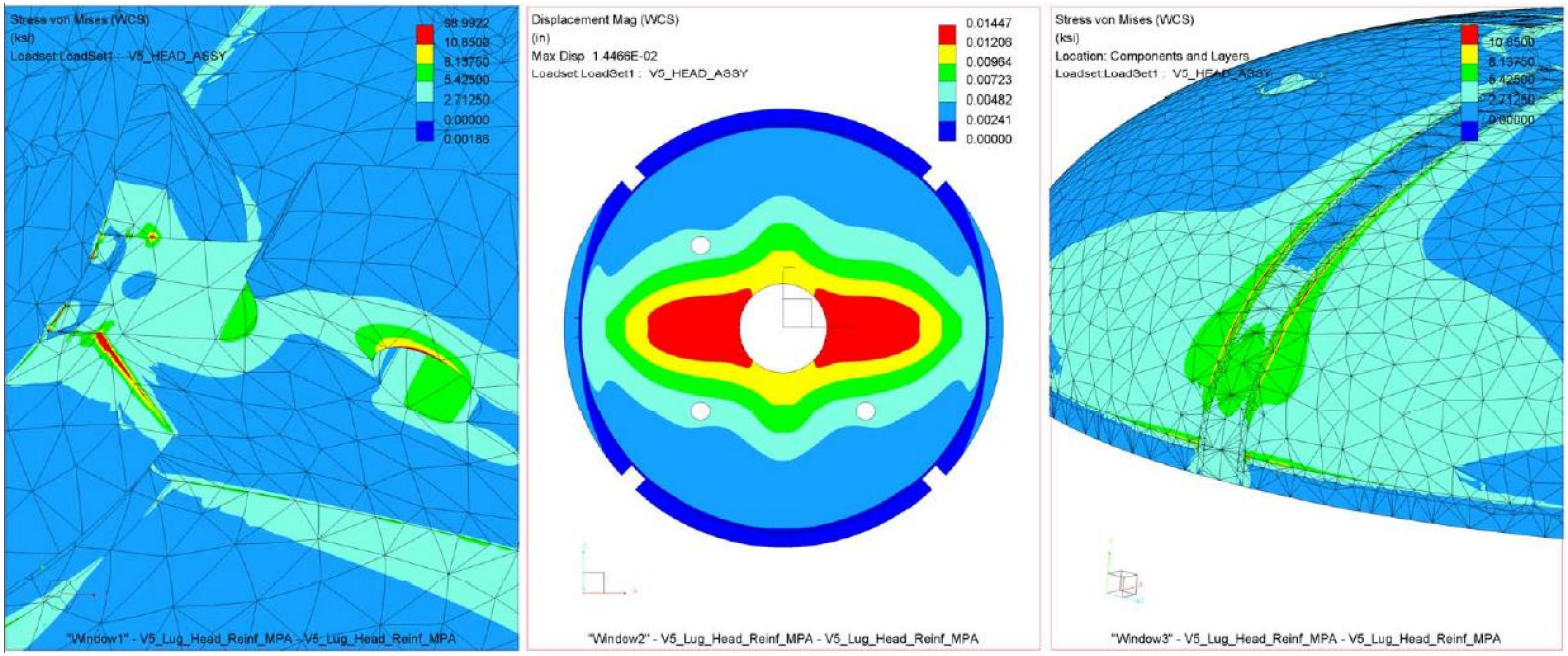
Note: HSLA-80 (HSLA-100) for lugs



Vessel Lifting Stresses / Displacements

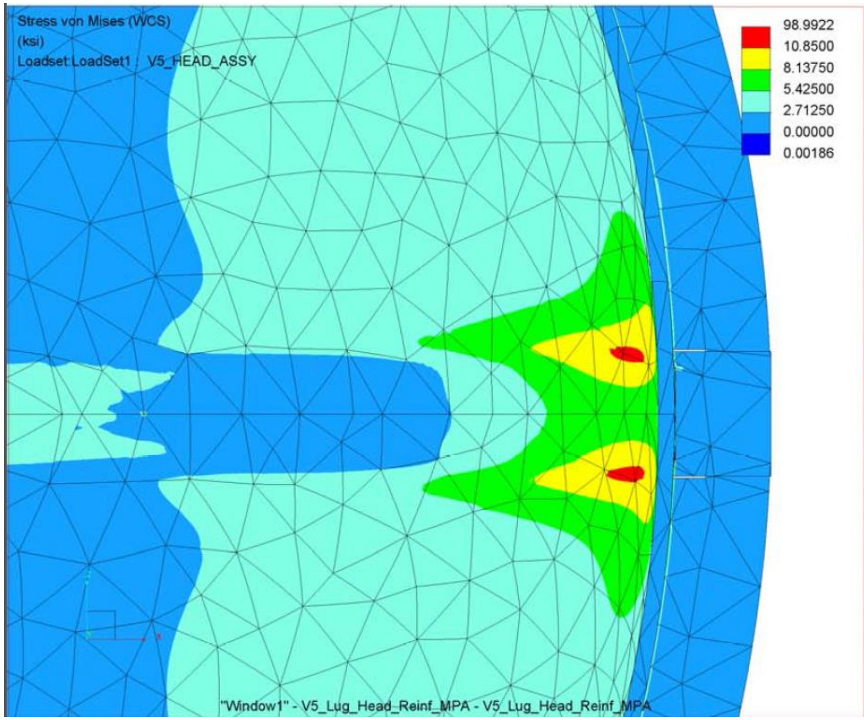


Vessel Lifting Stresses / Displacements

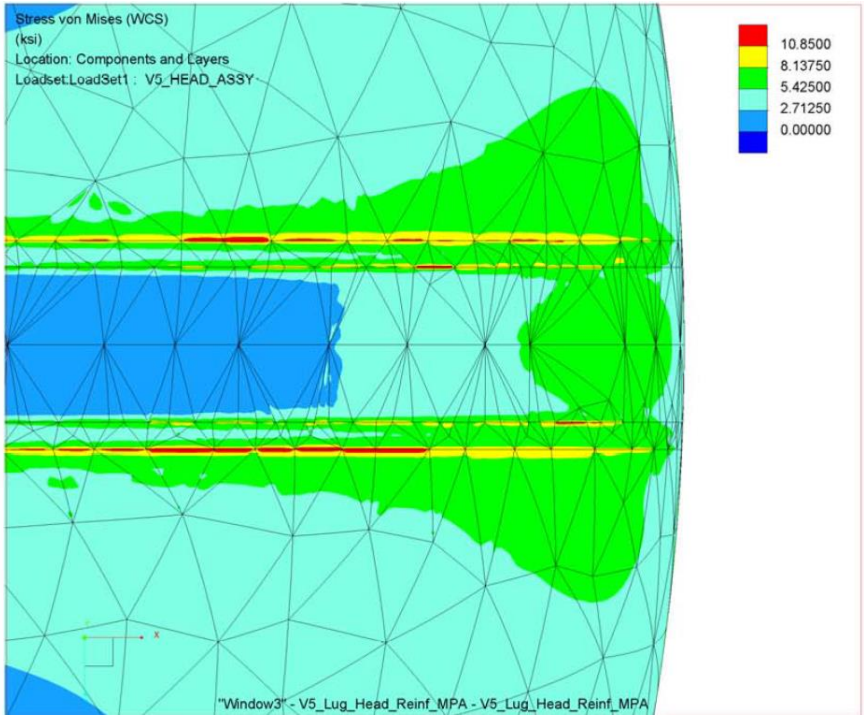


Bottom View

Head Stresses: Work in progress…

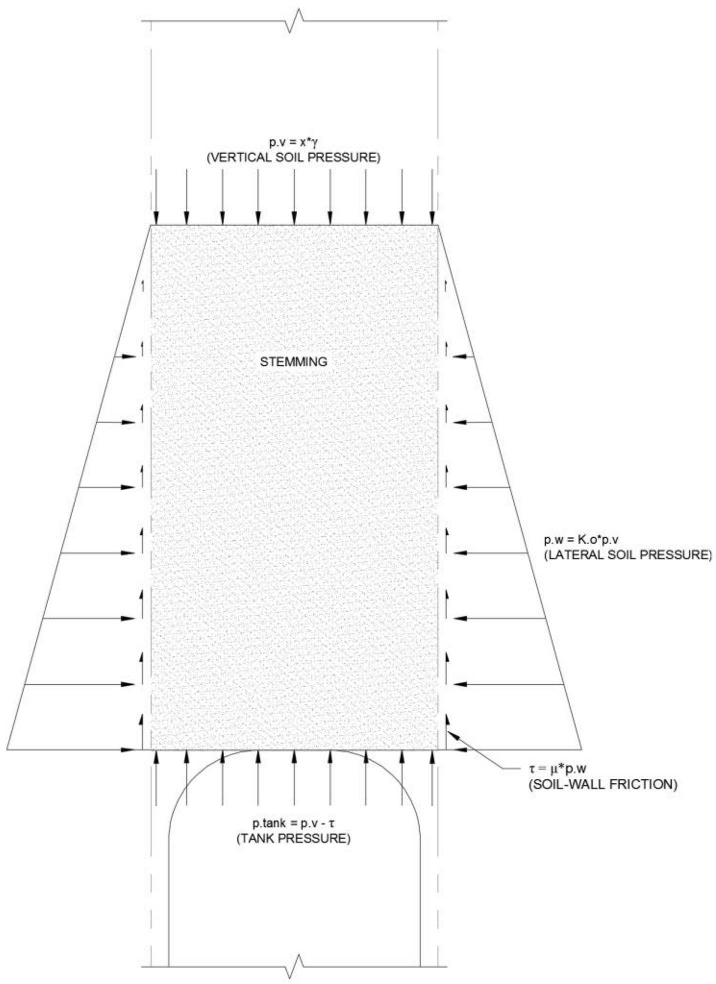


Bottom View



Top View

Soil Bearing Pressure on Vessels*



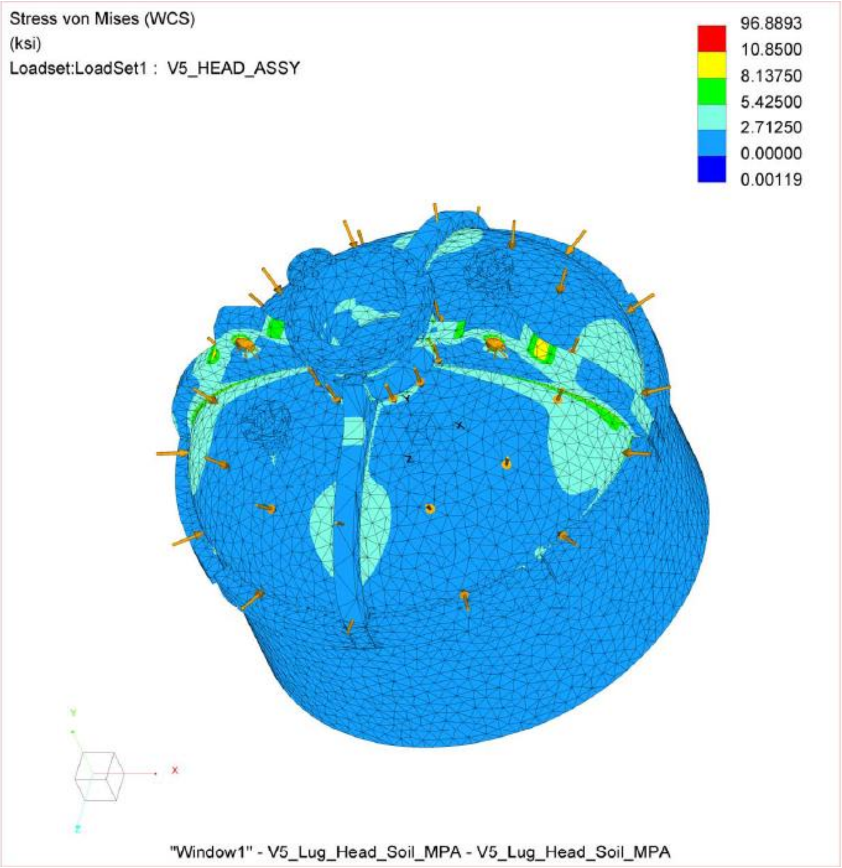
SOIL BEARING PRESSURE = 3.81 psi

- The wall's friction force acting upwards due to lateral bearing pressure will overcome the vertical load of the stemming acting downwards.
- The top of the tank will experience a peak stress of 3.81 psi when the stemming reaches a depth of 7.3 ft.
- The stress will essentially go to zero once the stemming reaches a depth of 14.6 ft. At this point the stemming's lateral bearing pressure will engage the walls of the hole with a friction force greater than the vertical bearing pressure of the soil.
- There will be some remaining bearing pressure on the tank from the stemming in the shape of an arch that will not be effectively supported by wall friction. This bearing pressure will be substantially less than the peak stress.

*Courtesy of Kyle Deines

Soil Bearing Pressure Brief Analysis

- **Uniform pressure of 5 PSI**
  - Simplistic, but adequate for initial check.
  - Used in combination with lifting load.
- **Insignificant changes to stresses from modeling lifting load only.**
- **Will be simulated later with a non-uniform pressure.**
- **External pressure case will be further studied when doing ASME BPVC calculations.**



Vessel Analysis: Summary to Date

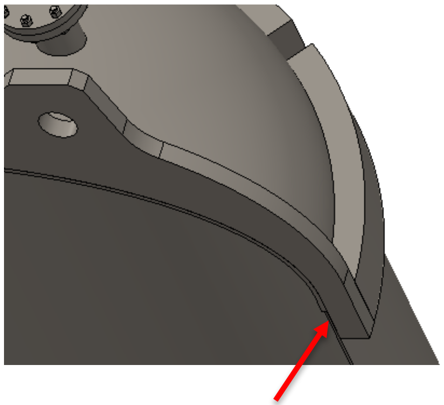
- **Several lug designs / orientations have been analyzed**
  - Current design has eccentric / bending loading, but puts pendant spacing at 48" and allows for load-equalization design to ensure tank stays plumb.
    - Reduced width of pendant spacing keeps separation beam away from hole edge
  - Minor elevated stress at welds to tank heads being addressed.
- **Support ring design is substantial, no concerns about supporting vessel from perimeter at the top of the hole**
  - Allows for 4X 4" wide cutouts at 45 degrees from cardinal directions (diagnostic cables).
  - Required head reinforcement rib to transfer forces to lifting lugs (through the central nozzle neck / neck reinforcement ring).
- **Hand calculations done for:**
  - Vessel thickness for internal pressure

Vessel Analysis: Future effort

- **Add water fill / drain nozzles and verify adequacy of placement (hill-side tangent @ tank head)**
- **ASME BPVC design / analysis in COMPRESS**
  - Vessel thickness / weld construction / head attachment
  - Nozzle stresses
- **Transportation loading**
  - Design / analyze transportation fixtures
    - To prevent tank collapse while being secured to a trailer
  - Horizontal to vertical transition via 2 cranes
  - If additional thickness is needed for strength: ~2400 lb per 1/16" increase for 10270 gallon vessel
- **Repeat lug design / analysis steps for 42" diameter vessel**

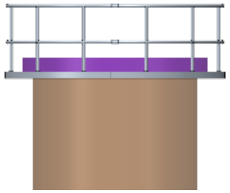
Design Items Being Resolved

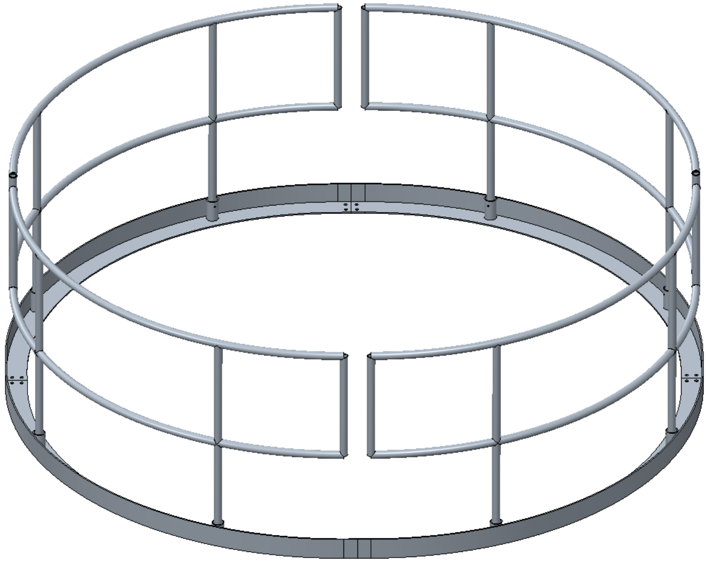
- **Fluid level sensor implementation in work.**
- **ASME BPVC design for vessels with COMPRESS to commence week of 2/27.**
  - Weld seam type / locations
  - Vessel thickness transitions (as needed)
  - Nozzle design / attachment method selection
- **Alternate design options to increase robustness or simplicity are being investigated.**
  - Lifting lugs / reinforcement / support ring
- **Design of a removable "dip tube" to evacuate nitromethane underway.**



Dry Alluvium Geology (DAG)
PDR - Safety and Lifting Equipment

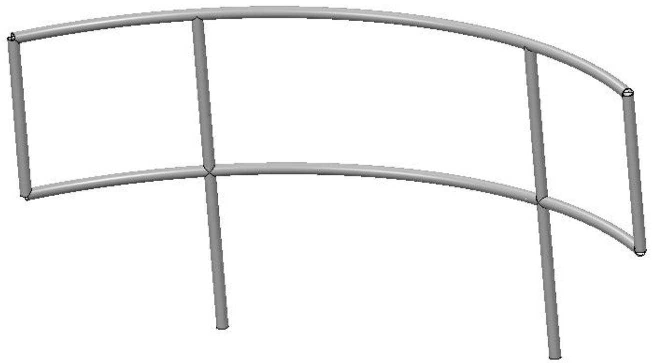
Fall Protection





- **National Safety Council I-747 specifications**
  - Top Rail – 42" tall
  - Mid Rail – 24" tall
  - Kick Plate – 4" tall
- **10' diameter foot print**
- **Similar to the railing used on the centrifuge**

Railing

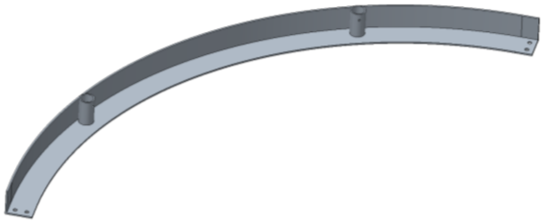


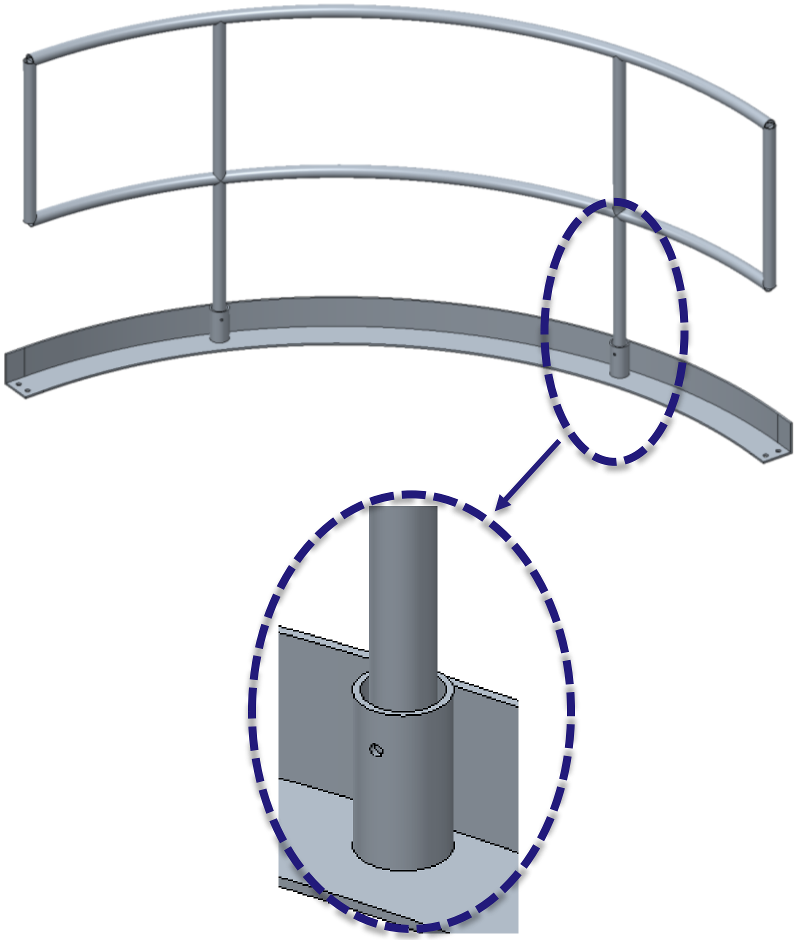
Material

- ➢ 1020 Tube Steel
- ➢ 1.5" OD
- ➢ 1/8" thick walls

- ➢ **4x sections total**
- ➢ **< 50 lbs / section**

Kick Plate





Material

- A36 Steel
- 4"x4" angle

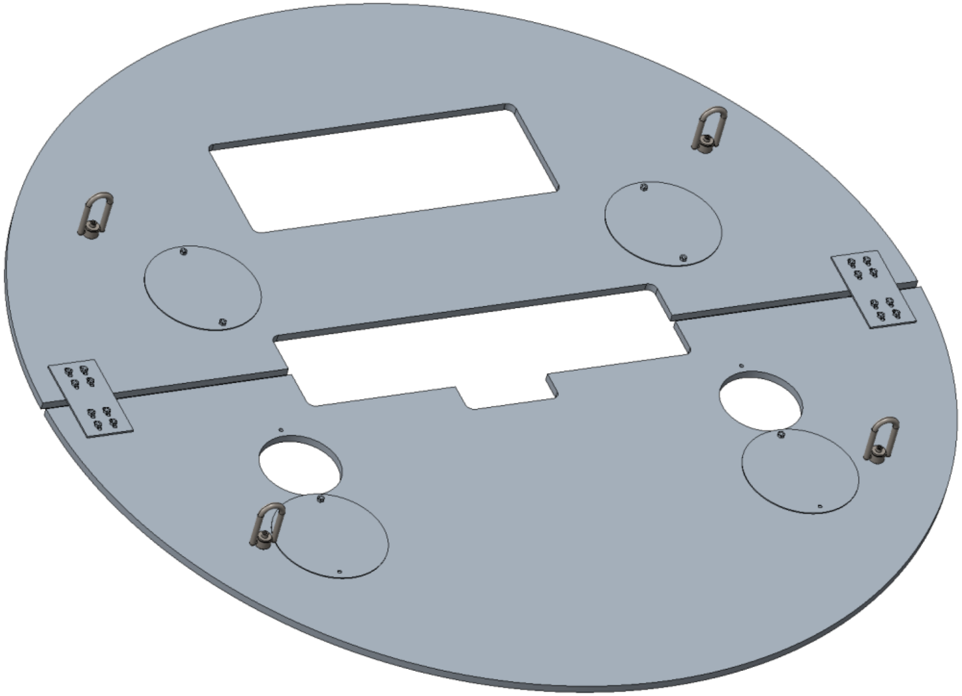
Interface to Rails

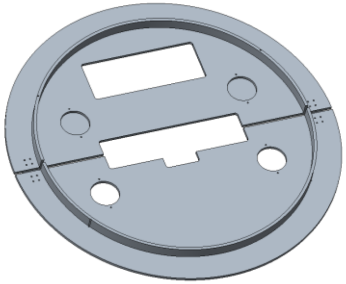
- 3" ID tube welded to kick plate
- Set screw locking mechanism

Interface to ground

- Bolts to inserts in the concrete around the hole

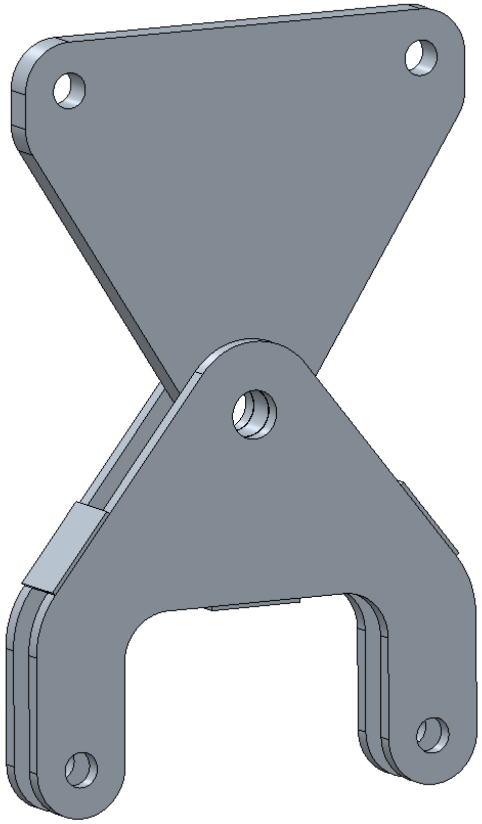
Hole Cover





- A36 steel
- 9' OD
- 2 sections
- 40"x15" stem port (1x)
- 10" stem ports (4x)
- Hoist rings (2x per side)
- Alignment ring for centering
- To be load rated to
  ASCE 7-10, table 4-1

Leveling Assembly



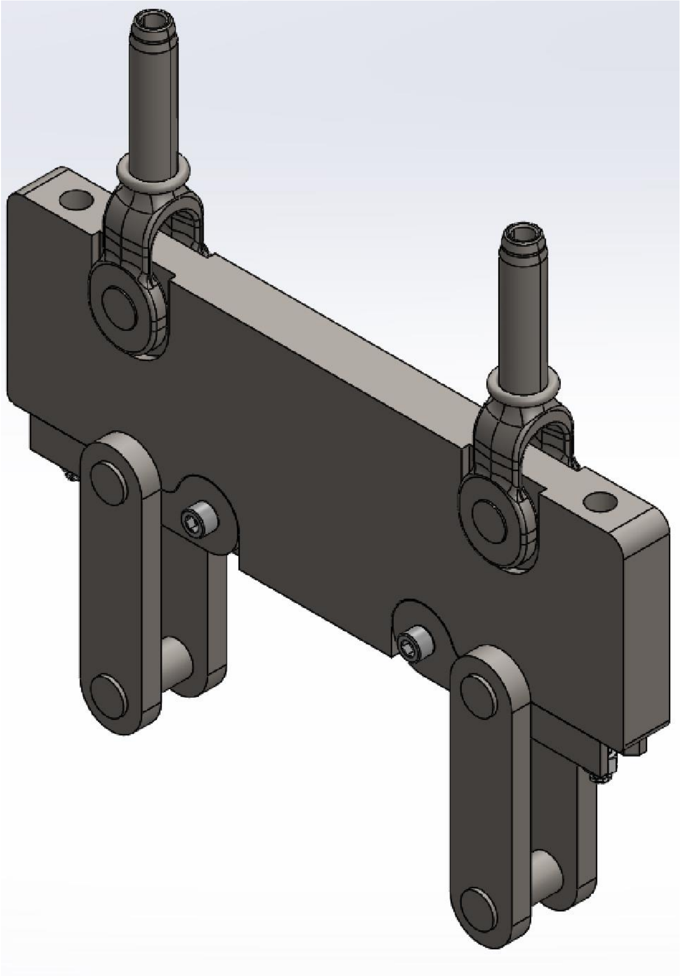
Details

- HSLA 80 Steel
- Pivots to provide compliance
- Connects directly to the tank
- Connects to Separator Beam via pendants / nylon straps
- Top Plate - 3.75" thick
- Bottom Plates - 2" thick
- Central Pin - 6" diam
- Pendant pins - 4.325" diam

Analysis

- Max stress < 20 ksi
- SF > 5 on UTS and 3.5 on yield

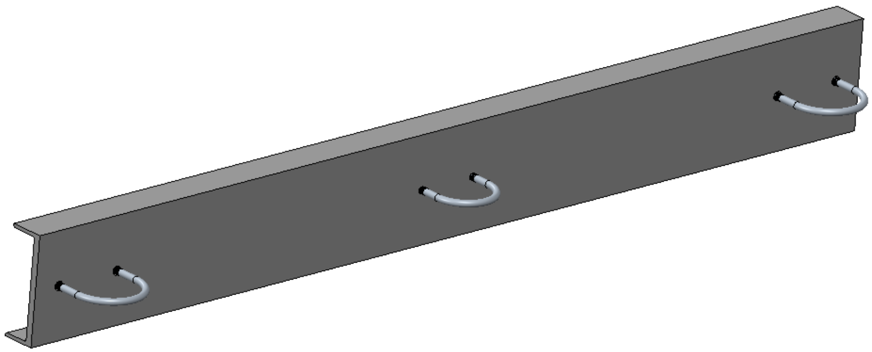
Separation Beam



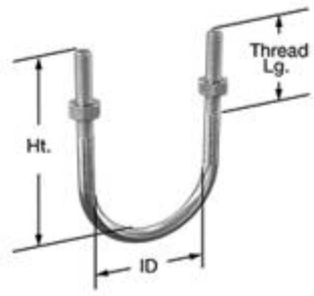
Conceptual Phase

- Nylon Straps connect to leveling assembly
- Pendants connect up to the crane
- Frangible (explosive) nuts for separation
- Pyrotechnic cutters to cut diagnostic cables. (Not shown)
- Clamp/ strain relief for 3x diagnostic cables

Spreader Bar



- A36 C - channel
- 48" between center of U-bolts
- < 50 lbs

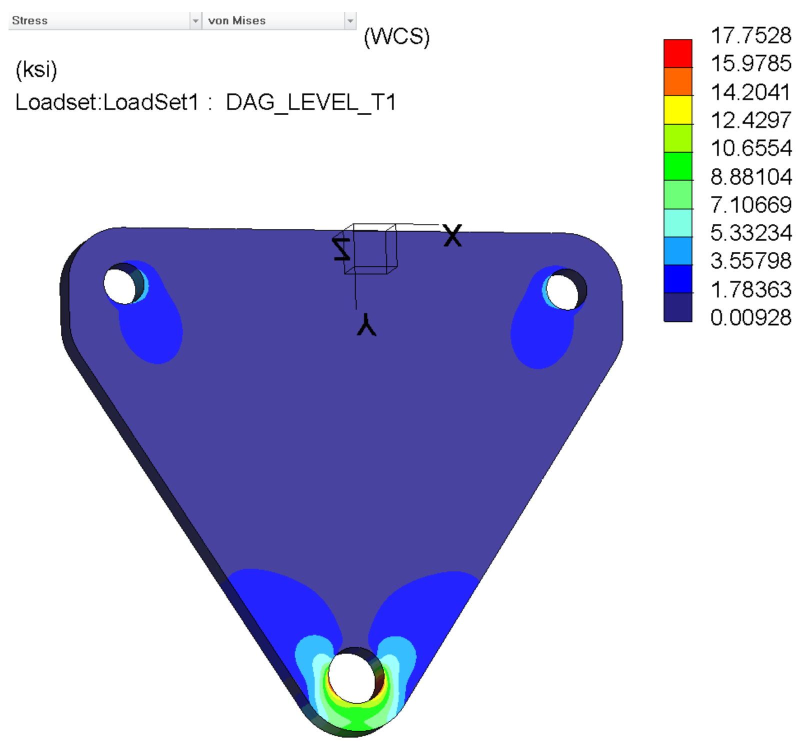

U-Bolts

Black-oxide steel U-bolts offer some corrosion resistance. Zinc-plated steel U-bolts have good corrosion resistance in most environments. Galvanized steel U-bolts have better corrosion resistance than black-oxide and zinc-plated steel. Aluminum U-bolts are lighter weight and more corrosion resistant than steel, but aren't as strong. 304 and 316 stainless steel U-bolts are the most corrosion resistant.

CAD For technical drawings and 3-D models, click on a part number.

Appendix - FEA

Central Pin - Max Stress



Center Pin Connection
[Leveling Plate - Red Male]

$F := 160\ kip$

$d := 6\ in$

$w := 12\ in$

$h := 6\ in$

$t := 3.75\ in$

$d \cdot w^{-1} = 0.5$

$k_t := 2.6$ From Chart

$\sigma_{nom} := F \cdot ((w - d) \cdot t)^{-1} = 7.111\ ksi$

$\sigma_{act} := \sigma_{nom} \cdot k_t = 18.489\ ksi$

$\sigma_{YS} := 80\ ksi$ HSLA 80 Steel

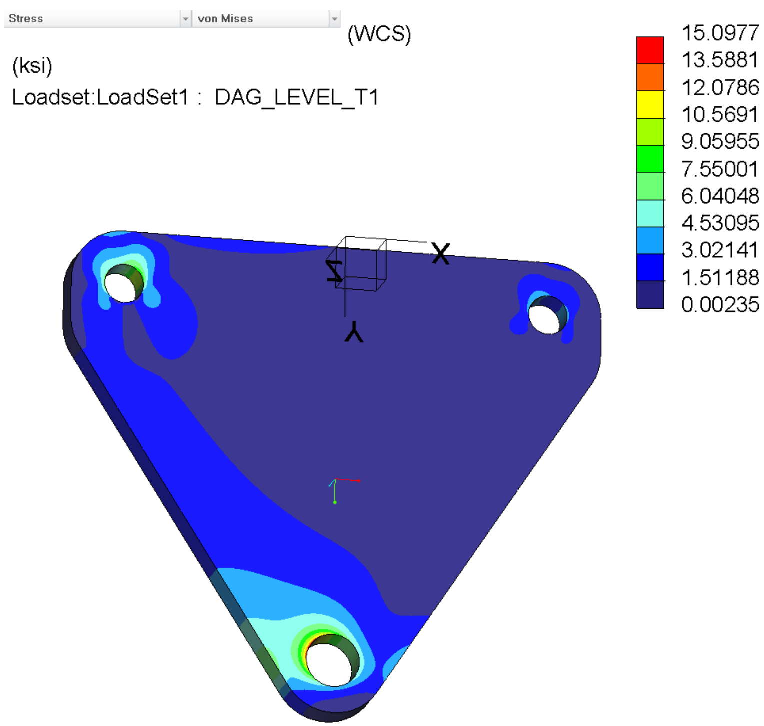
$\sigma_{US} := 100\ ksi$

$SF_y := \sigma_{YS} \cdot \sigma_{act}^{-1} = 4.327$

$SF_u := \sigma_{US} \cdot \sigma_{act}^{-1} = 5.409$

- **FEA and hand calculations are within 1 ksi**
- **Design criteria: 3.5 on yield and 5 on ultimate**

Top Connection (Male) - Max Stress



Pendant Connections Top
[Leveling Plate - Blue Male]

$F := 80\ kip$

$d := 4.325\ in$

$w := 12\ in$

$h := 6\ in$

$t := 3.75\ in$

$d \cdot w^{-1} = 0.36$

$k_t := 3.4$ From Chart

$\sigma_{nom} := F \cdot ((w - d) \cdot t)^{-1} = 2.78\ ksi$

$\sigma_{act} := \sigma_{nom} \cdot k_t = 9.451\ ksi$

$\sigma_{YS} := 80\ ksi$ HSLA 80 Steel

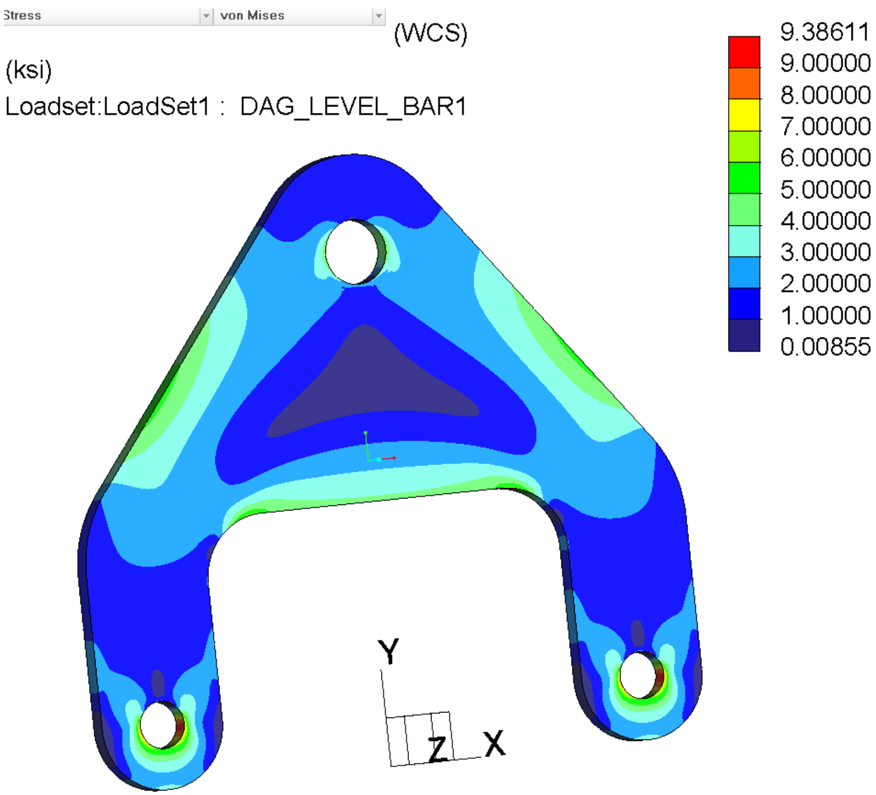
$\sigma_{US} := 100\ ksi$

$SF_y := \sigma_{YS} \cdot \sigma_{act}^{-1} = 8.465$

$SF_u := \sigma_{US} \cdot \sigma_{act}^{-1} = 10.581$

- **FEA and hand calculations are within 6 ksi**
- **Design criteria: 3.5 on yield and 5 on ultimate**

Bottom Connection (Female) - Max Stress



Pendant Connections Bottom
[Leveling Plate - Yellow Female (2x Pieces)]

$F := 40\ kip$

$d := 4.325\ in$

$w := 12\ in$

$h := 6\ in$

$t := 2\ in$

$d \cdot w^{-1} = 0.36$

$k_t := 3.4$ From Chart

$\sigma_{nom} := F \cdot ((w - d) \cdot t)^{-1} = 2.606\ ksi$

$\sigma_{act} := \sigma_{nom} \cdot k_t = 8.86\ ksi$

$\sigma_{YS} := 80\ ksi$ HSLA 80 Steel

$\sigma_{US} := 100\ ksi$

$SF_y := \sigma_{YS} \cdot \sigma_{act}^{-1} = 9.029$

$SF_u := \sigma_{US} \cdot \sigma_{act}^{-1} = 11.287$

- **FEA and hand calculations are within 1 ksi**
- **Design criteria: 3.5 on yield and 5 on ultimate**

Dry Alluvium Geology (DAG) PDR - Top-of-the-Hole Support

Support Structure Design Scope

- **Landing beam to support tanks and rigging for DAG experiments**
  - Three tank sizes

- **Support rings to hold tank at top of hole for filling**
  - Two tank diameters

Unicorn Landing Beam

Previous Support Rings

Requirements

- **Interface with:**
  - Pressure vessels
  - Foundation
  - Crane pendants (rigging)
  - Instrumentation
- **Limit height of Support Ring for tank interface**
  - Per hazard analysis, have NM fill be below the surface of the hole
- **Multiple tank sizes**
  - Two sets of support rings
- **Rigging sizes**
  - Rigging varies from 2" to 2.5" in diameter
  - Plates to capture different sizes accordingly
- **Instrumentation Accommodation**
  - Gaps in support rings for instrumentation cables

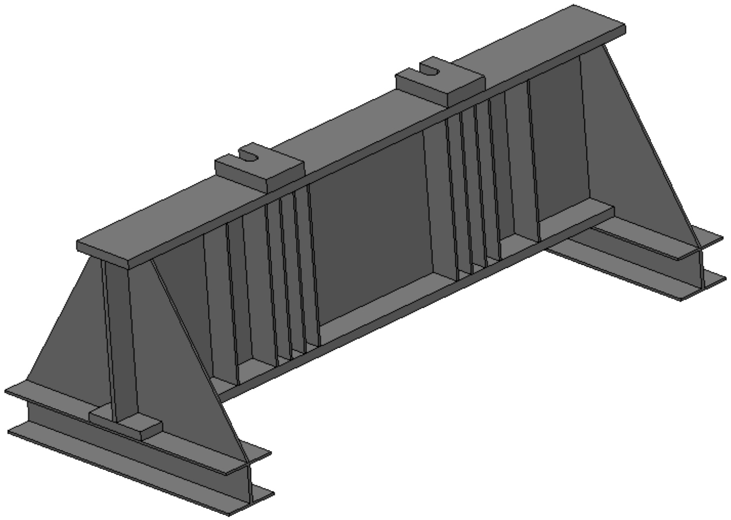
Factors of Safety

- **ASME BTH-10-2014 and ASME B30.20-2010**
  - 3.5 on Yield Strength
  - 5 on Ultimate
  - Proof load test: 200% of rated load

- **Carbon Steel – A36 or similar**
  - Yield - 36 ksi
  - Design Stress ~ 10.29 ksi

Landing Beam Parameters

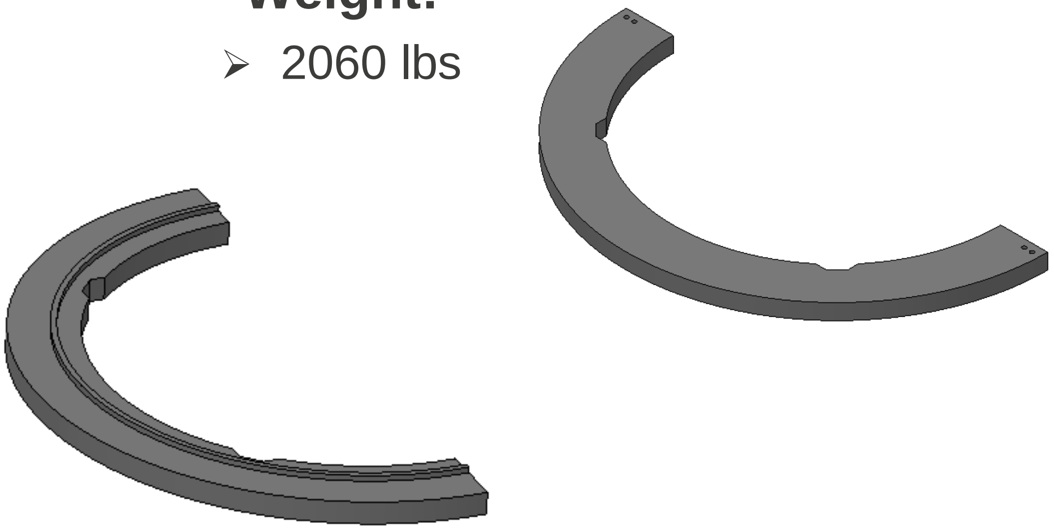
- Main Beam:
  - Length – 132"
  - Width – 14"*
  - Height – 38"*
  - Flange Thickness – 2"*
  - Web Thickness – 1"*
  - Stiffener Thickness – 0.5"*
- Feet:
  - Length – 60"
  - Width – 12"
  - Height – 9"*
  - Flange Thickness – 0.5"*
  - Web Thickness – 0.75"*
  - Brace Thickness – 0.5"*
- Plate:
  - Thickness – 3"*
  - Width – 14"*
  - Length – 10"*
- Overall:
  - Height – 50"*
  - Weight – 5230 lbs*

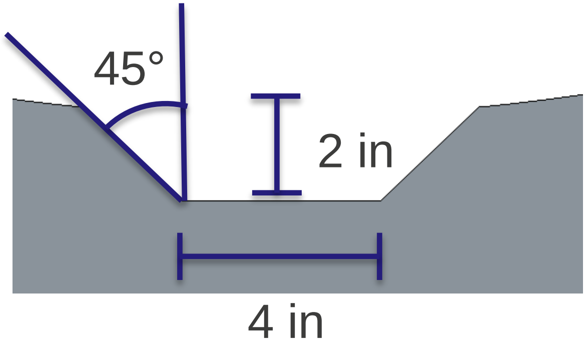


Support Rings Large Tank

- **Ring parameters:**
  - Outer Diameter: 108”
  - Inner Diameter: 84”*
  - Thickness: 4”
  - Guide Ring:
    - Height - 1”
    - Width - 1”
    - Outer Diameter – 94”

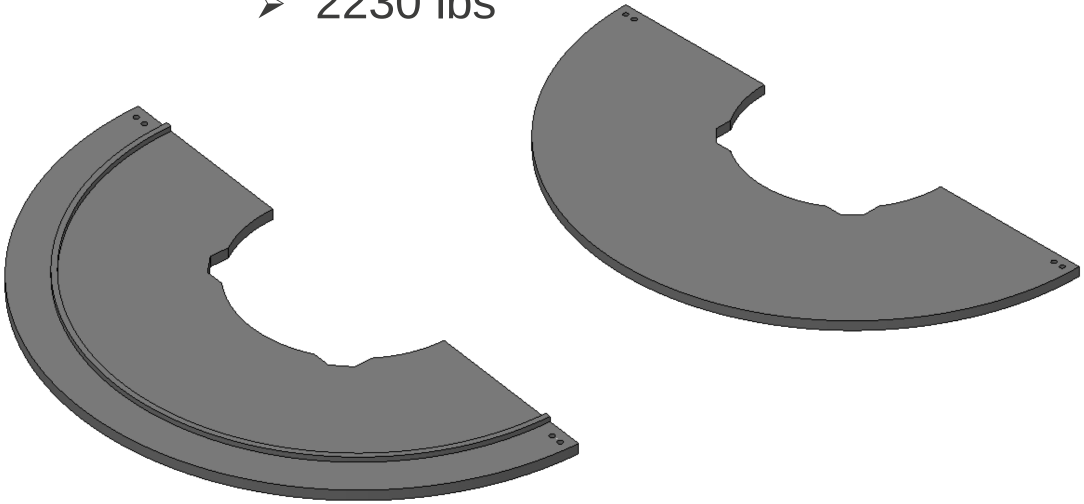
- **Weight:**
  - 2060 lbs

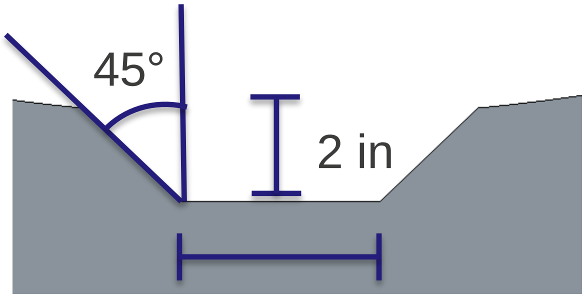




Support Rings Small Tank

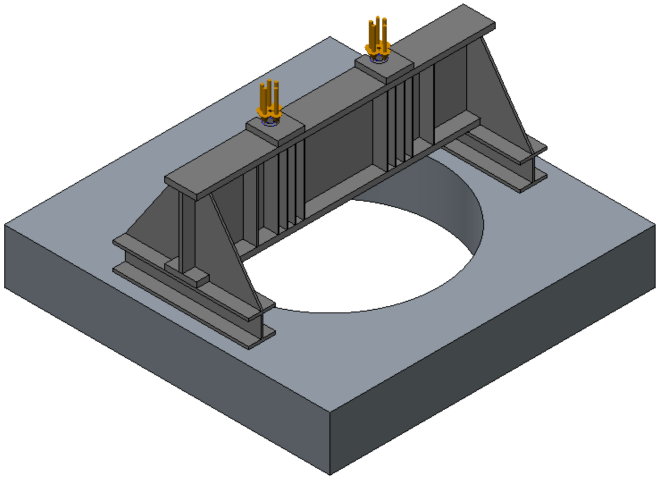
- **Ring parameters:**
  - Outer Diameter: 108"
  - Inner Diameter: 42"*
  - Thickness: 2"*
  - Guide Ring:
    - Height - 1"
    - Width - 1"
    - Outer Diameter – 94"
- **Weight:**
  - 2230 lbs

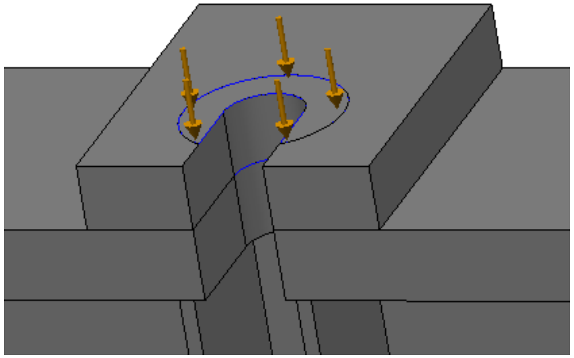


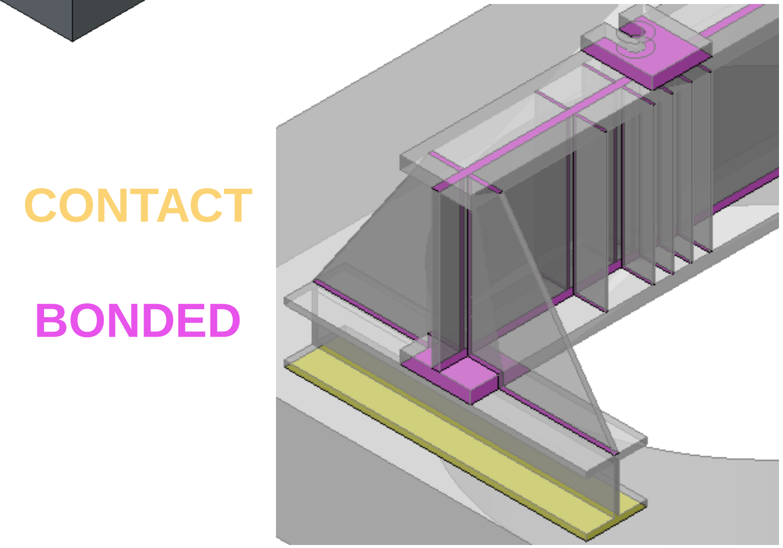


Analysis, in work – Landing Beam

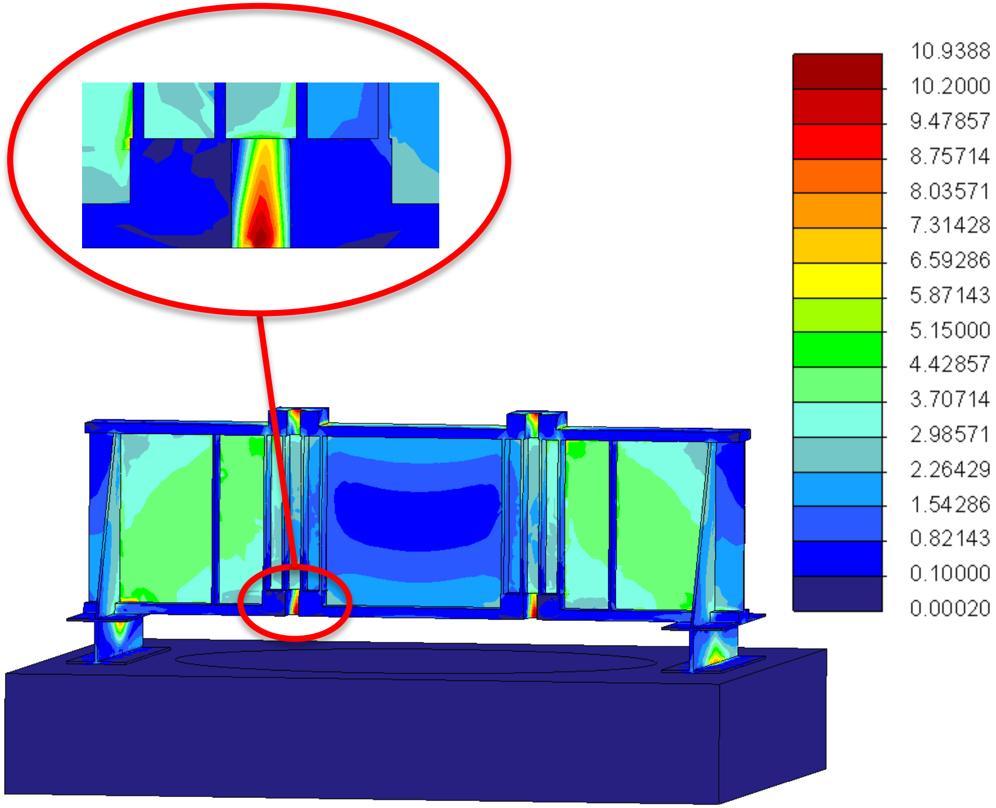
- **Constraints**
  - Fix lower surface of 'ground'
- **Loads**
  - 150,000 lbs applied to surface area
- **Interfaces**
  - Contact
    - Ground and bottom surface of feet
  - Bonded
    - Weldment



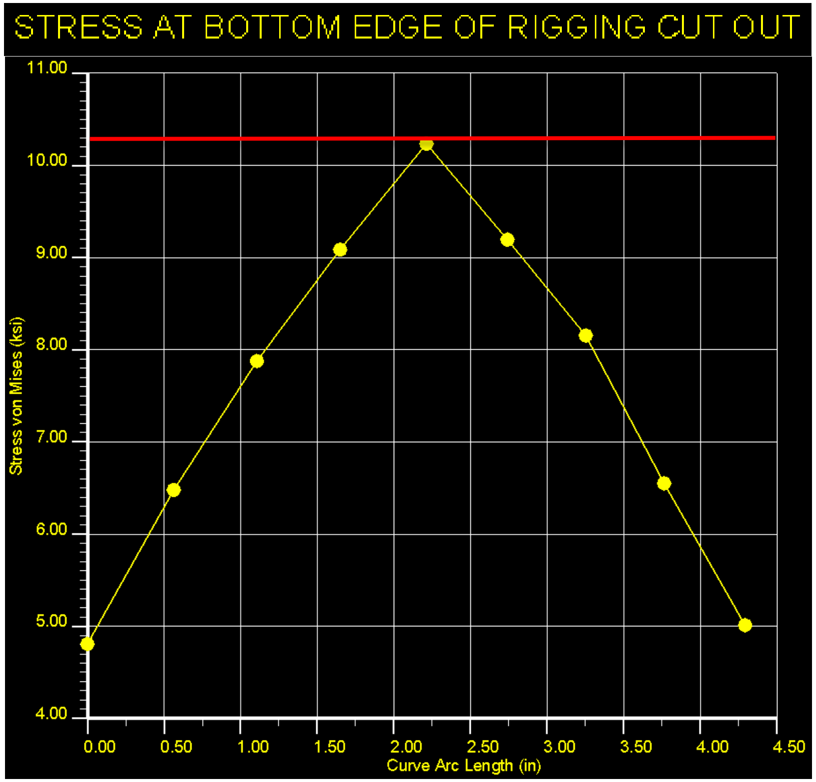




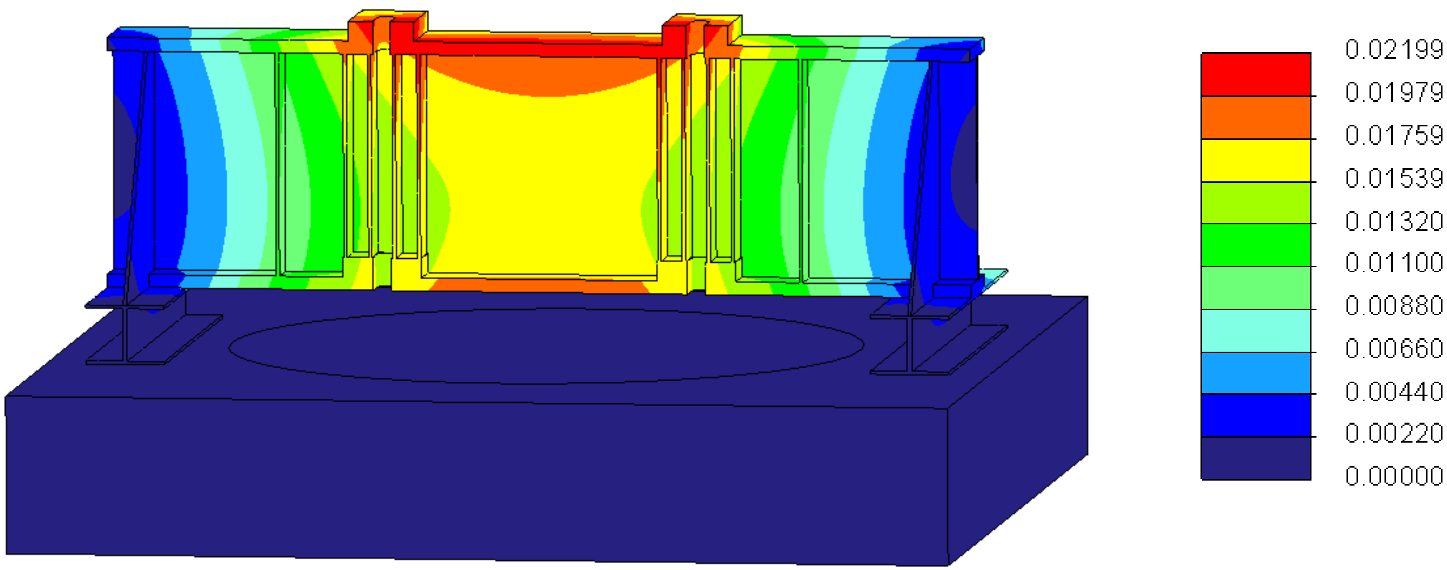
Analysis, in work – Landing Beam



STRESS (ksi)



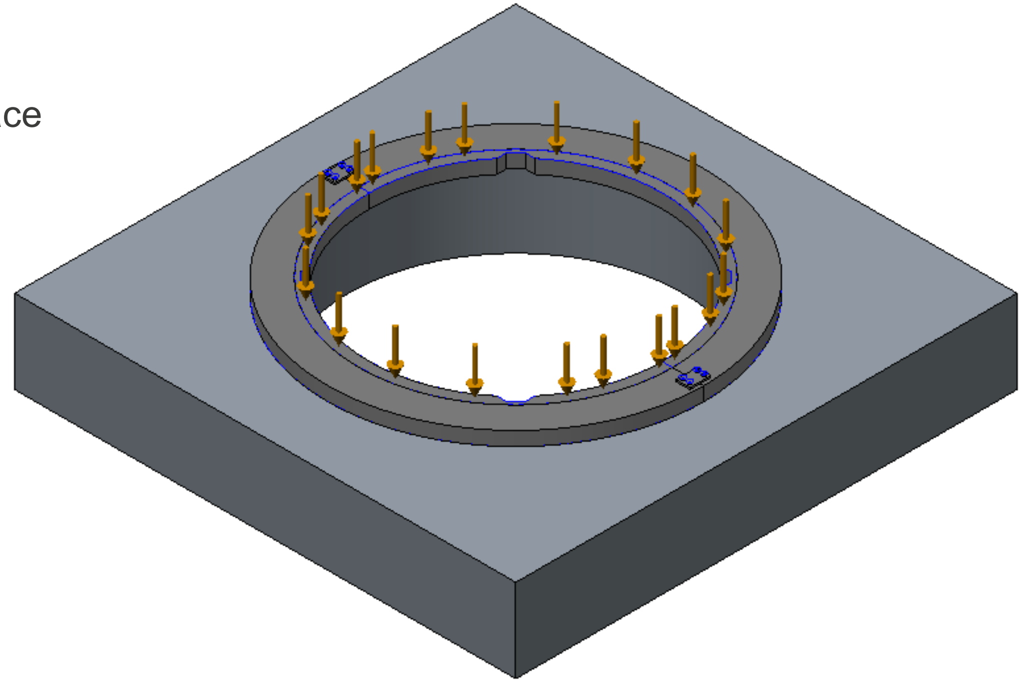
Analysis, in work – Landing Beam



DISPLACEMENT (in)

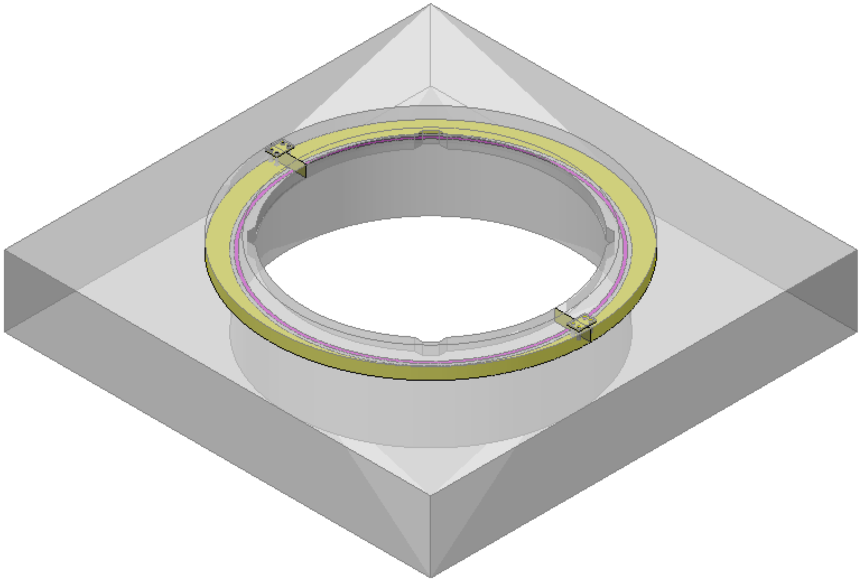
Analysis, in work – Support Rings LT

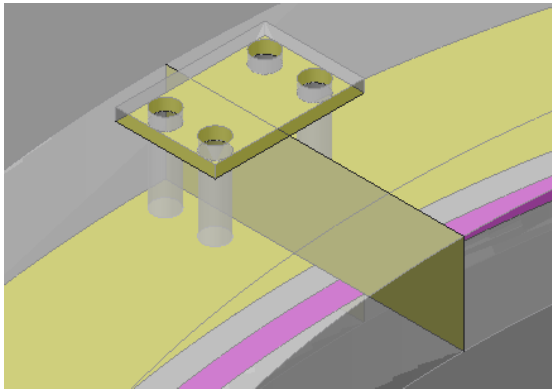
- **Constraints**
  - Fix lower surface of 'ground'
- **Loads**
  - 150,000 lbs applied to 3" wide surface area



Analysis, in work – Support Rings LT

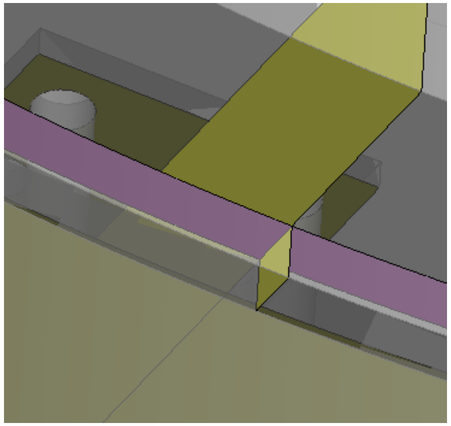
- **Interfaces**
  - Contact
    - Ring Connections
    - Ring to Ground
    - Connecting Plate
  - Bonded
    - Guide ring attachment



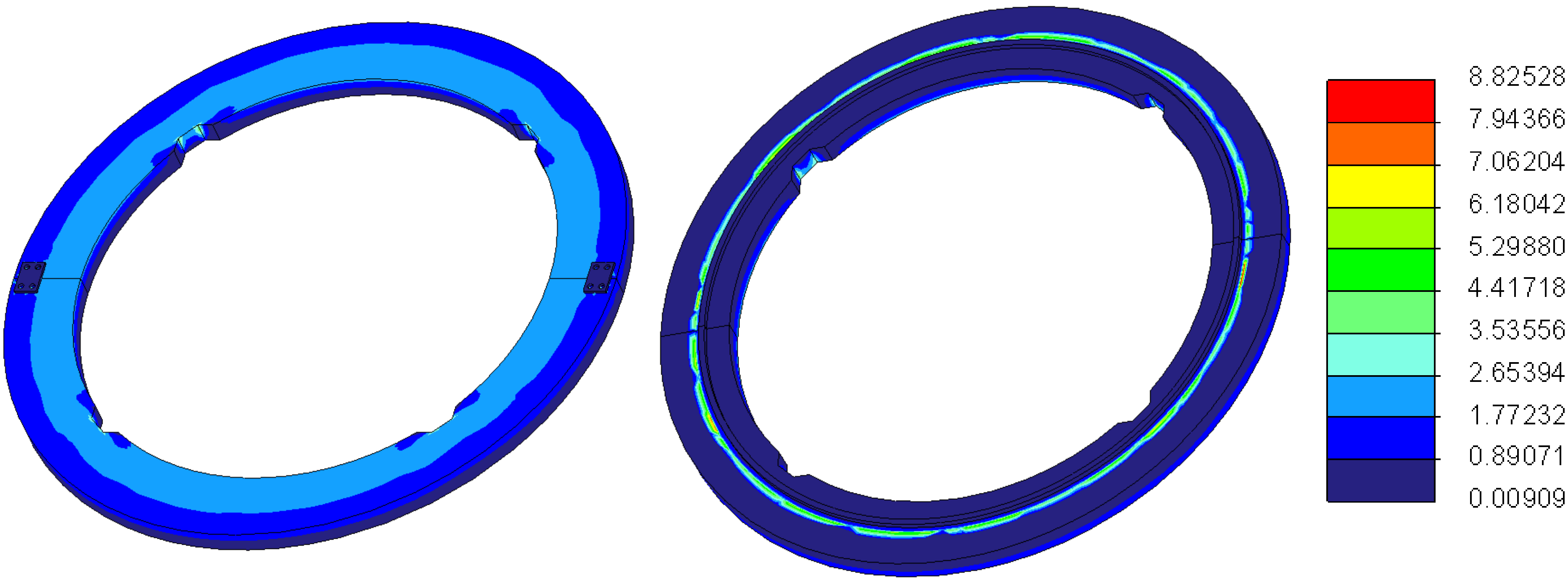


CONTACT

BONDED



Analysis, in work – Support Rings LT

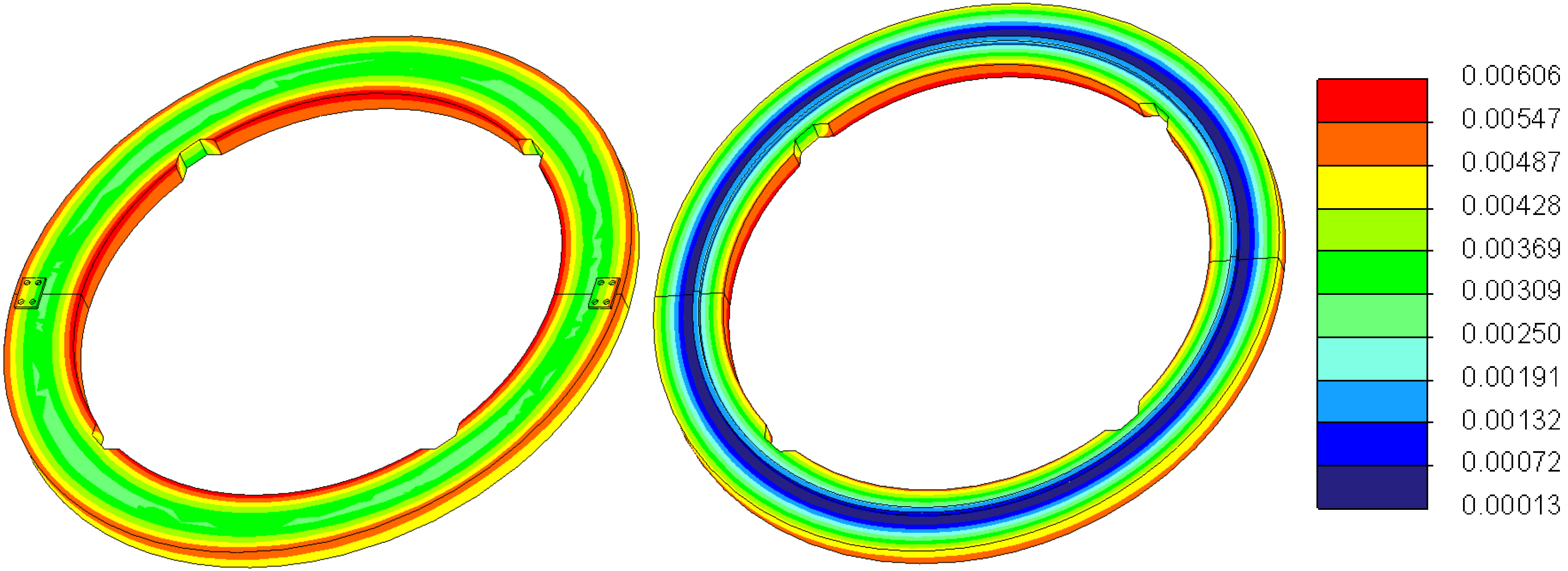


Top View

Bottom View

STRESS (ksi)

Analysis, in work – Support Rings LT



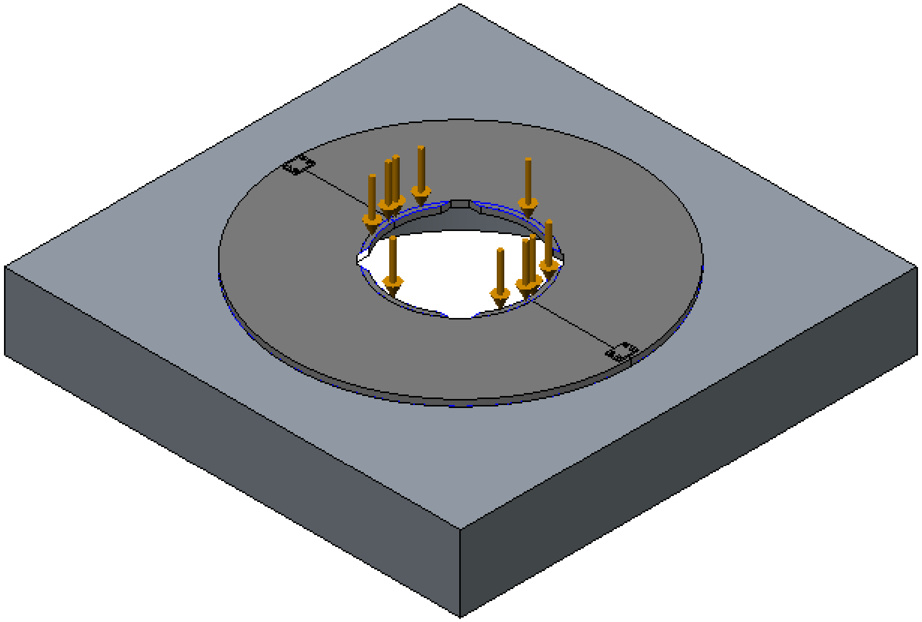
Top View

Bottom View

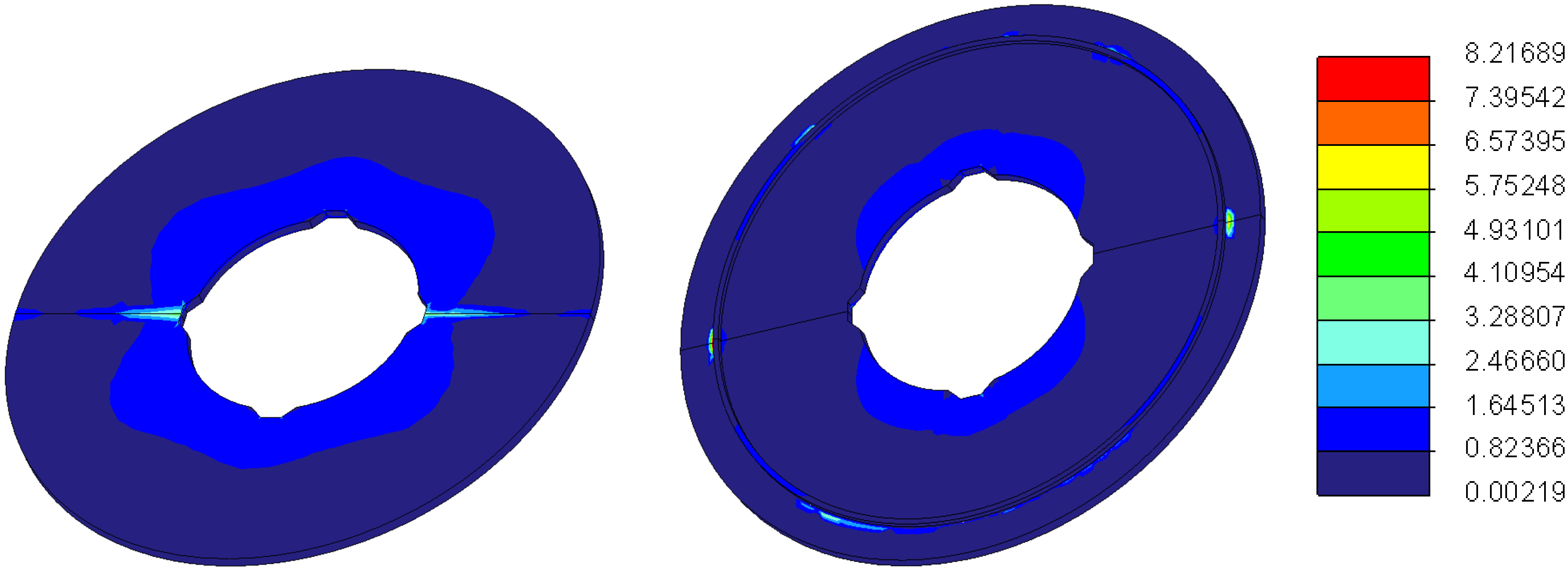
DISPLACEMENT (in)

Analysis, in work – Support Rings ST

- **Constraints**
  - Fix lower surface of 'ground'
- **Loads**
  - 5,000 lbs applied to 1.5" wide surface area
- **Interfaces**
  - Same as large tank plates



Analysis, in work – Support Rings ST

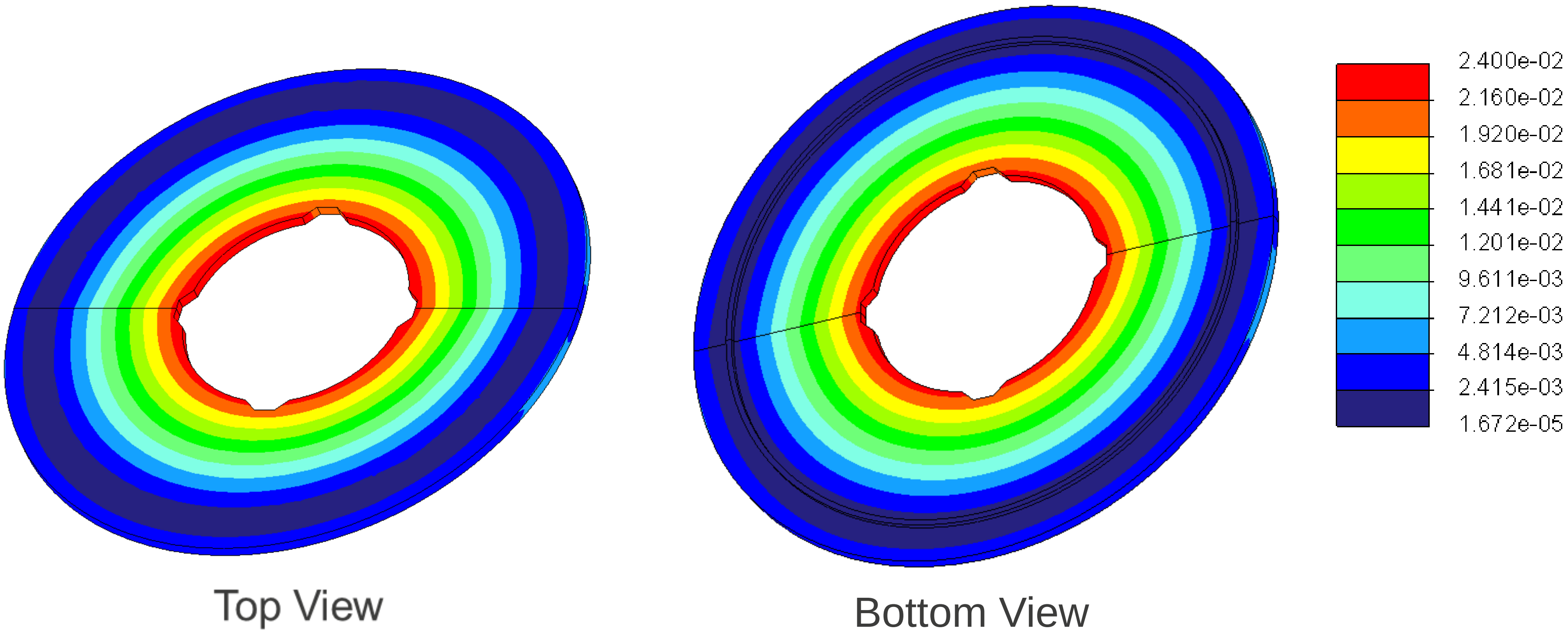


Top View

Bottom View

STRESS (ksi)

Analysis, in work – Support Rings ST



DISPLACEMENT (in)

Design Items In Progress

- **Support Rings**
  - Bolted connection
  - Welds
  - Lifting hardware
  - Interface with concrete pad
  - Removal of rings before lowering tank

- **Landing Beam**
  - Final design
  - Additional plate design
  - Forklift interface
  - Weld design