APA shipping frame use cases, specifications, and prototyping plan

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APA Engineering Design Review

July 28-30, 2020

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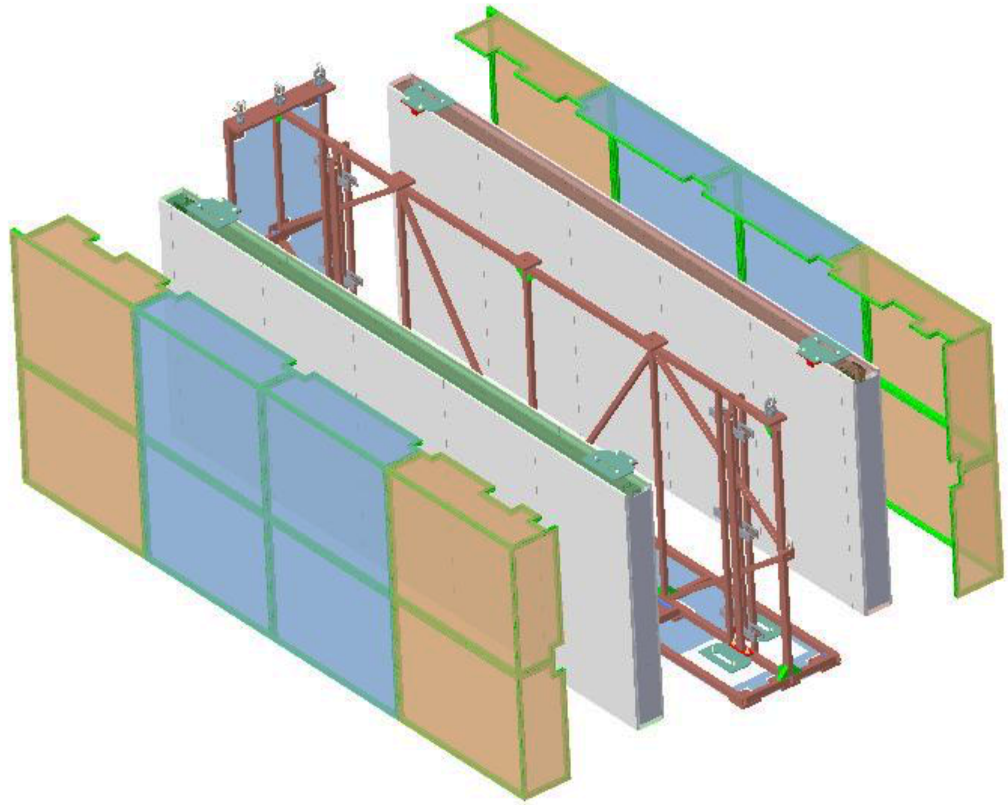
Outline

- Overview of the shipping packaging and shipping frame carts
  - Many more details in Peter's talk
- Shipping frame use cases → load cases
- Applicable standards and specifications
  - Many more details on the implications in Ang's and Peter's talks
- Prototyping/production plans
- Outline of documentation

Overview of APA shipping packaging

- Each APA shipping frame will be used to move the 2 APAs from the factory sites until they are integrated inside the clean room in the detector cavern in SURF
- The key to the shipping packaging is the central welded steel frame
- The APAs are loaded end-for-end swapped for balance and eventual top-bottom mating
- The APAs are attached through an array of wire-rope isolators to dampen shock and vibration during shipping and handling
- The shipping frame is surrounded by removable sectioned side panels
- Lifting ring mounts and attachment points are integrated into the central frame's design

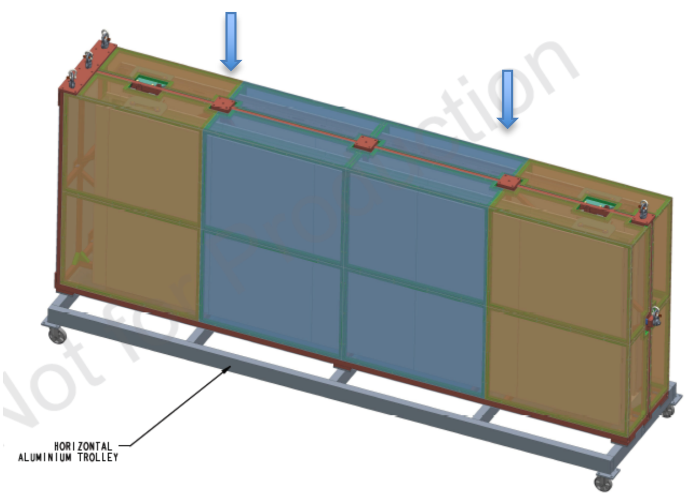


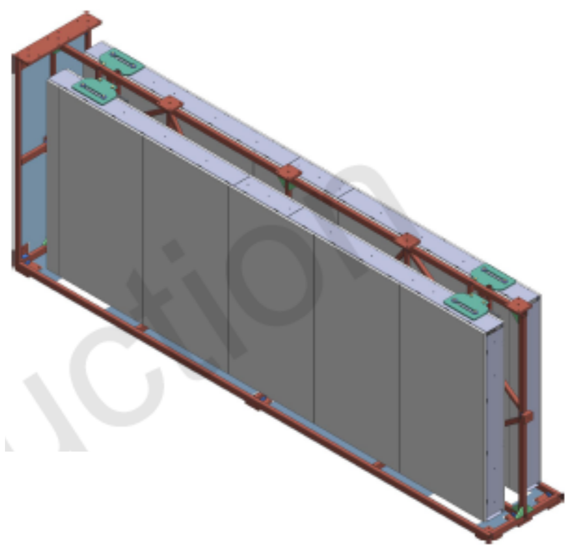
Presentations

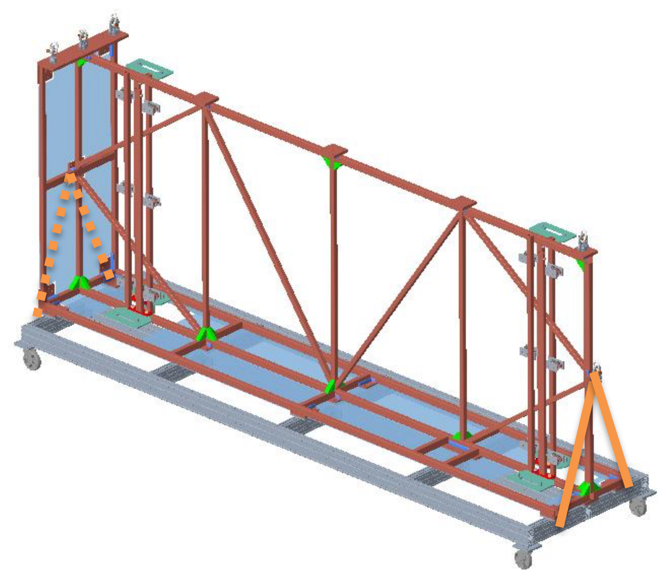
Tuesday	Wednesday	Thursday
Transport packaging requirements (this talk)	Modal analysis, vibration, and shocks (Ang Lee)	Stability analysis and carts (Peter Sutcliffe)
Transport packaging design (Peter Sutcliffe)	Considerations on the APA frame (Dan Wenman)	APA Installation (Dan Wenman)
Transport frame FEA (Ang Lee)		

Use case 1 - loading & moving at factory sites

- The shipping frame is strapped onto a horizontal cart during this operation (right)
- At the APA production sites the completed APAs are loaded onto the shipping frame with an overhead crane and a spreader bar; they are bolted to mounts (green) top and bottom (middle)
- We consider stability/load cases for both 1 and 2 APAs loaded on the cart
- Side covers are added and wrapped with sheeting (except lifting/bearing points)
- The carts are pulled and pushed with a transporter to the loading area
- The frame (side panels in place, left) will be lifted with a spreader bar to be further packaged







Use case 2 – transport from production sites to SDWF

In the US
- Shipping frames are loaded (with overhead crane or forklift) onto a pallet & tarped
- The palletized load is loaded onto a trailer
- The shipping frame is shipped (on an air-ride flatbed trailer) to a local warehouse
- They will be trucked to the SDWF (a TBD warehouse regional to SURF) when it has availability for APA occupancy
- The shipping frames are then trucked in the same way to the SDWF when needed underground

In the UK
- Two shipping frames are loaded onto a pallet
- They are surrounded with wooden panels and cross bracing to form a shipping crate with exposed sling/fork pockets
- The crate is then covered with a tarp
- The crated frames are shipped to a local warehouse
- When space is available in the SDWF, they will be trucked to the port of Liverpool, loaded onto a roll-on-roll-off (RORO) ship and delivered to Baltimore
- The crates are then covered (on an air-ride flatbed trailer) and trucked to the SDWF

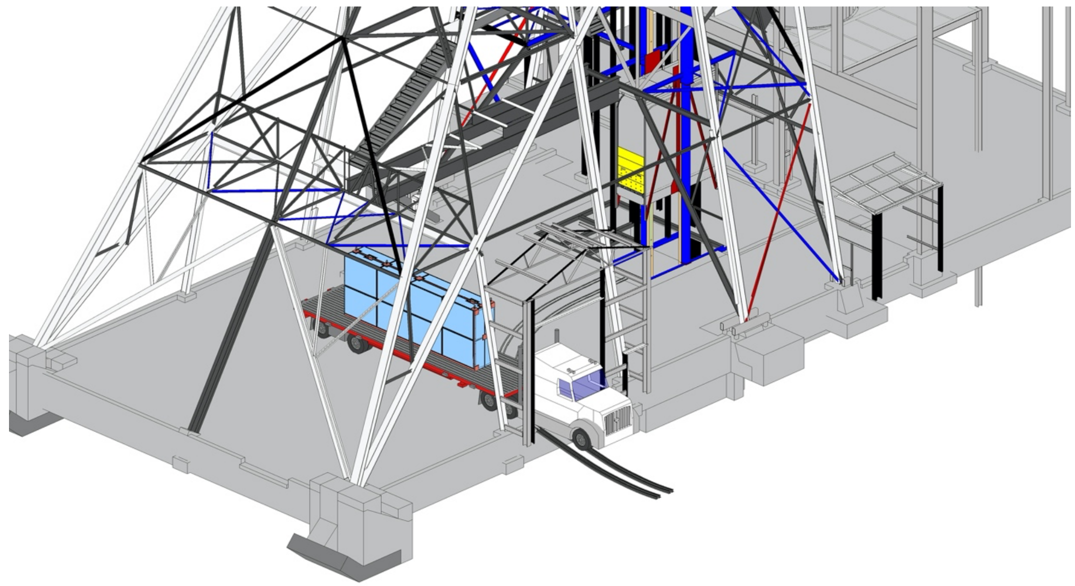
Shipping frames will incorporate multi-dimensional monitoring instrumentation to verify the they and APAs have not undergone excessive acceleration during transport

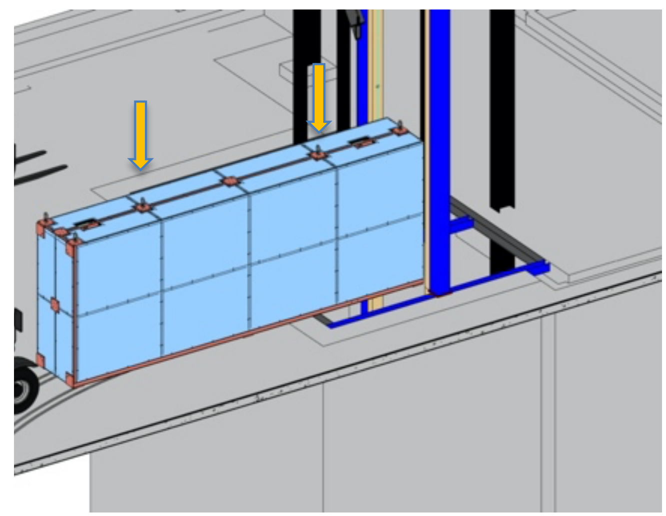
Use case 3 - Storage and testing in the warehouse

- We anticipate four forms of possible testing prior to that in the underground clean room (in an external clean room)
  - Visual inspection of the shipping frames exterior
  - Checking the datalogger
  - Electrical tests for wire continuity and isolation
    - This requires unsealing the frame and access to the headboards on each APA to attach a testing board
  - Wire tension testing using electrical pulses to generate vibrations
    - This requires unsealing the frame and access to the headboards on each APA to attach stimulation and measurement boards
- For the last two to be possible…
  - The protective panels installed on the APAs and the shipping frame's outer side panels must be designed to allow access to these locations without the possibility of parts contacting the wires
- This use case does not imply unique load cases

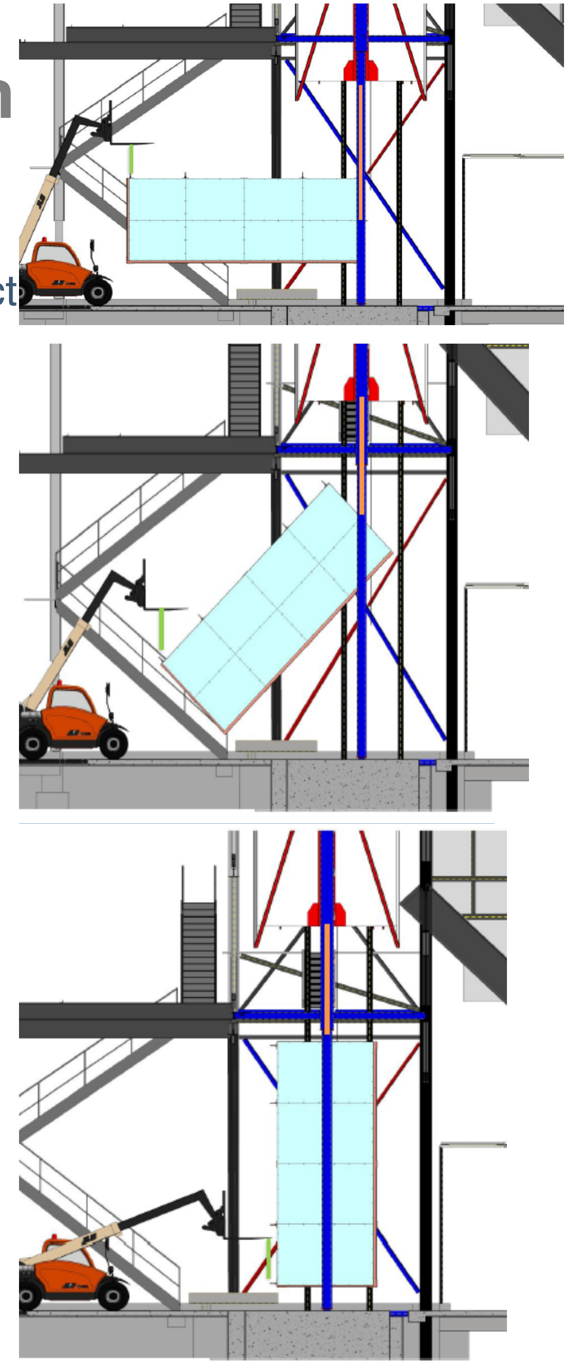
Use case 4 - Transport to the Ross Shaft

- The exterior wooden shipping box for the UK shipping frames are removed and discarded
- The shipping frames are placed singly onto US-style pallets
- Frames are loaded onto a trailer by forklift or craned onto a flatbed trailer, covered, and driven for a couple-hour drive to the Ross Headframe
- The trailer is backed into the lift door at the headframe
- The APAs packages are uncovered, a spreader from a hoist on the overhead monorail is attached. They are freed from their pallets, lifted, rotated, and placed at the shaft
- The lift points for this operation are the same as those used at the factories

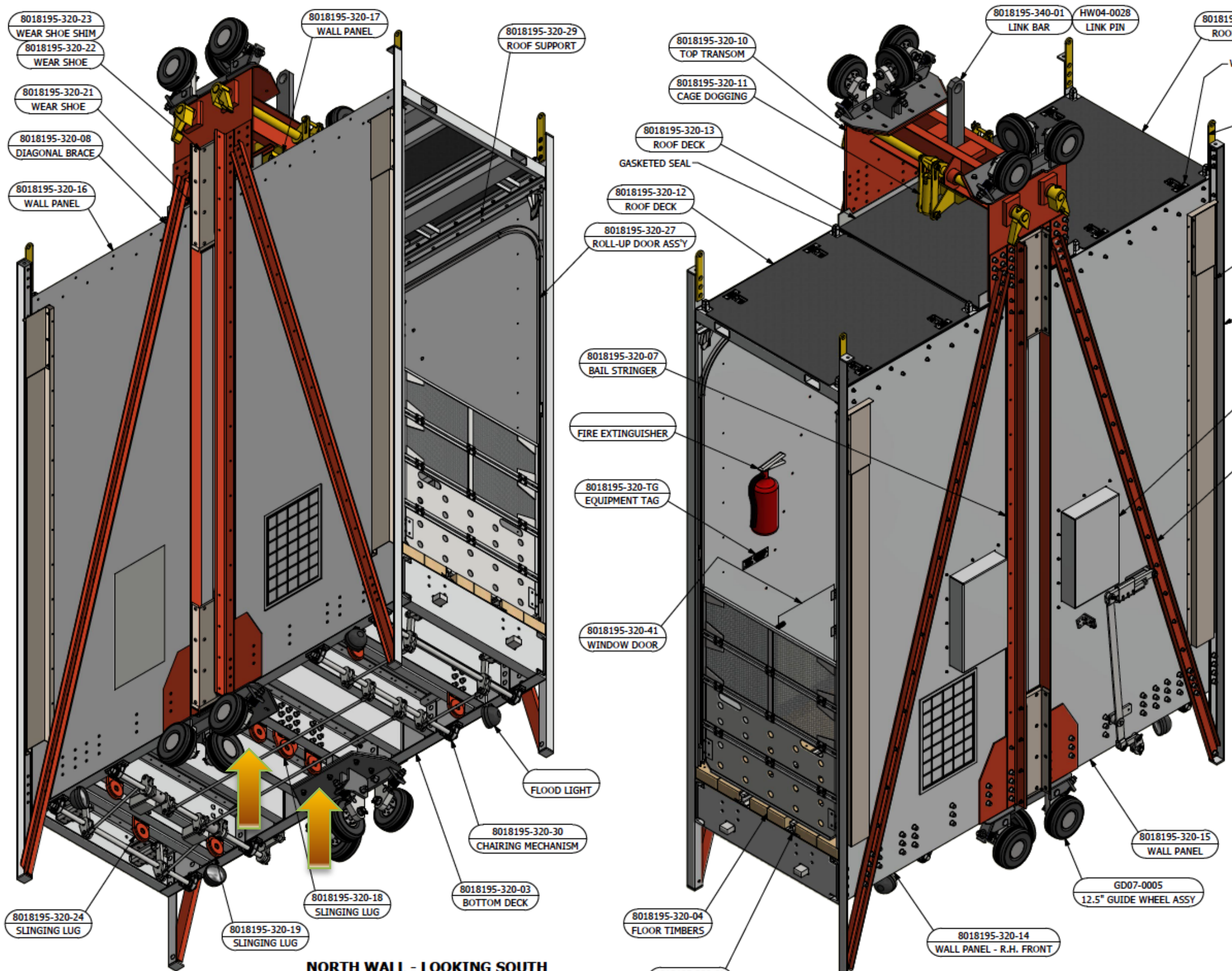




Use case 5 - Loading into, transport down and unloading out of the Ross Shaft

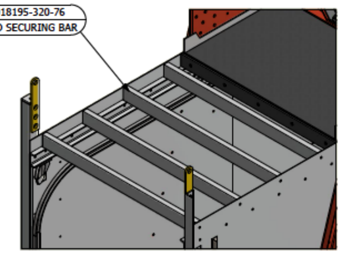


- The details for the materials handling equipment loading/unloading the shipping frame from the cage are still be negotiated between the project and SURF
  - The general plan is well defined to well specify the required structural analysis cases for shipping frame
  - The end of the shipping frame under the cage (upper) will be attached to the hooks underneath the cage [slide]
  - The cage/hoist will be used to lift the shipping frame from horizontal until vertically slung below the cage
- The shipping frame design clears the headframe during this operation.
- The lower end will be hung from from a telehandler to control the shipping frame as it is rotated to vertical over the shaft
  - Throughout this operation the forces on the shipping frame (and cage) are almost completely vertical with only small horizontal deviations to control the rotation near the later stages
  - This is a very similar process the at CERN for ProtoDUNE [slide]
- This operation implies a variety of unique load cases
- Vertical shaft-timber guides (provided by the SD team) will be added to the sides of the frame and deployed



NORTH WALL - LOOKING SOUTH

SOUTH WALL - LOOKING NORTH



CAGE LOAD SECURING

FOR APPROVAL

DATE:____________

APP. BY:____________

NOTE:
1. TOTAL WEIGHT DOES NOT INCLUDE INSPECTION CANOPY/HANDRAIL, MAINTENANCE PLATFORM/CANOPY/HANDRAIL.
2. ALL FASTENERS TO BE STAINLESS STEEL

TOTAL WEIGHT (LB)
8457

ITEM	QTY	PART NO.	NOMENCLATURE	DESCRIPTION	MATERIAL	COMMENTS	WT. (LB)
41	4		FLOOD LIGHT	FLOOD LIGHT			4
40	1		FIRE EXTINGUISHER	20 LB. CLASS ABC			31
39	2	1142A330	SEAL	3/8" X 5/8" RUBBER SEAL			0
38	8	94748A426	PIN	QUICK RELEASE PIN			2
37	1	HW04-0028	LINK PIN	SEE ASSEMBLY DRAWING			6
36	4	GD07-0005	12.5" GUIDE WHEEL ASSY	SEE ASSEMBLY DRAWING			1148
35	1	CS6721	SOCKET	M26 SOCKET W/ PIN			36
34	1	8018195-340-01	LINK BAR	SEE DETAIL DRAWING			92
33	1	8018195-320-TG	EQUIPMENT TAG	SEE DETAIL DRAWING			0
32	4	8018195-320-76	LOAD SECURING BAR	SEE ASSEMBLY DRAWING			38
31	2	8018195-320-41	WINDOW DOOR	SEE ASSEMBLY DRAWING			21
30	1	8018195-320-40	ESCAPE DOOR	SEE ASSEMBLY DRAWING			39
29	2	8018195-320-36	INSPECTION CANOPY	SEE ASSEMBLY DRAWING			728
28	2	8018195-320-35	ELECT. ENCL. BOX	SEE ASSEMBLY DRAWING			32
27	4	8018195-320-32	COUNTER WT. GUARD	SEE ASSEMBLY DRAWING			143
26	1	8018195-320-30	CHAIRING MECHANISM	SEE ASSEMBLY DRAWING			574
25	2	8018195-320-29	ROOF SUPPORT	SEE ASSEMBLY DRAWING			48
24	1	8018195-320-27	ROLL-UP DOOR ASS'Y	SEE ASSEMBLY DRAWING			503
23	1	8018195-320-26	FLOOR - KICK PL.	SEE ASSEMBLY DRAWING			9
22	1	8018195-320-24	SLINGING LUG	SEE ASSEMBLY DRAWING			24
21	4	8018195-320-23	WEAR SHOE SHIM	SEE ASSEMBLY DRAWING			89
20	4	8018195-320-22	WEAR SHOE	SEE ASSEMBLY DRAWING			130
19	8	8018195-320-21	WEAR SHOE	SEE ASSEMBLY DRAWING			81
18	4	8018195-320-20	LIFTING LUG	SEE ASSEMBLY DRAWING			21
17	6	8018195-320-19	SLINGING LUG	SEE ASSEMBLY DRAWING			143
16	1	8018195-320-18	SLINGING LUG	SEE ASSEMBLY DRAWING			32
15	1	8018195-320-17	WALL PANEL	SEE ASSEMBLY DRAWING			158
14	1	8018195-320-16	WALL PANEL	SEE ASSEMBLY DRAWING			153
13	1	8018195-320-15	WALL PANEL	SEE ASSEMBLY DRAWING			155
12	1	8018195-320-14	WALL PANEL - R.H. FRONT	SEE ASSEMBLY DRAWING			151
11	1	8018195-320-13	ROOF DECK	SEE ASSEMBLY DRAWING			120
10	2	8018195-320-12	ROOF DECK	SEE ASSEMBLY DRAWING			353
9	1	8018195-320-11	CAGE DOGGING	SEE ASSEMBLY DRAWING			506
8	1	8018195-320-10	TOP TRANSOM	SEE ASSEMBLY DRAWING			737
7	2	8018195-320-09	DIAGONAL BRACE	SEE ASSEMBLY DRAWING			144
6	2	8018195-320-08	DIAGONAL BRACE	SEE ASSEMBLY DRAWING			144
5	2	8018195-320-07	BAIL STRINGER	SEE ASSEMBLY DRAWING			318
4	4	8018195-320-06	CORNER STRINGER	SEE ASSEMBLY DRAWING			150
3	2	8018195-320-05	FLOOR RAIL	SEE ASSEMBLY DRAWING			453
2	1	8018195-320-04	FLOOR TIMBERS	SEE ASSEMBLY DRAWING			475
1	1	8018195-320-03	BOTTOM DECK	SEE ASSEMBLY DRAWING			1131

PARTS LIST - REQUIRED FOR ONE ASSEMBLY

PART #8018195-320-02
MAN / MATERIAL CAGE
ISO VIEWS
SCALE 3/4" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ±1/16" ACCUMULATIVE
ANGULAR MACHINE = ±0.5°
ANGULAR BEND = ±1°
X.XX = ±0.01
X.XXX = ±0.005
X.XXXX = ±0.0005

INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED IN ASME Y14.100M

REV.	DATE	BY	DESCRIPTION	APP.	REV.	DATE	BY	DESCRIPTION	APP.		
P1	10/15/18	JAD	GENERAL UPDATE FOR PROGRESS	CLL	P4	11/13/18	JAD	ISSUED FOR 75% DESIGN REVIEW	CLL	DWG DATE:	9/4/2018
P2	10/25/18	JAD	UPDATES FOR DESIGN CHANGE REQUEST	CLL	P5	6/5/19	JAD	ISSUED FOR 90% DESIGN REVIEW	CLL	DESIGN BY:	FKC - LS
P3	11/5/18	JAD	UPDATES FOR DESIGN CHANGE REQUEST	CLL	P6	8/30/2019	MAK	ISSUED FOR 100% APPROVAL	CLL	DRAWN BY:	JAD
										CHECKED BY:	CLL

FK LAKE SHORE
A DIVISION OF FRONTIER-KEMPER CONSTRUCTORS, INC.

CLIENT: FKC - LAKESHORE
EVANSVILLE, IN
MAN / MATERIAL CAGE

DRAWING STATUS: PRELIMINARY | ORIGINAL SIZE: 22 x 34

TITLE: ROSS
MAN / MATERIAL CAGE
ISO VIEWS & PART LIST

FILE: 8018195-320-01.idw
DRAWING NO. 8018195-320-01 | REV. P6
DO NOT SCALE DRAWING | SHEET: 1 OF 4

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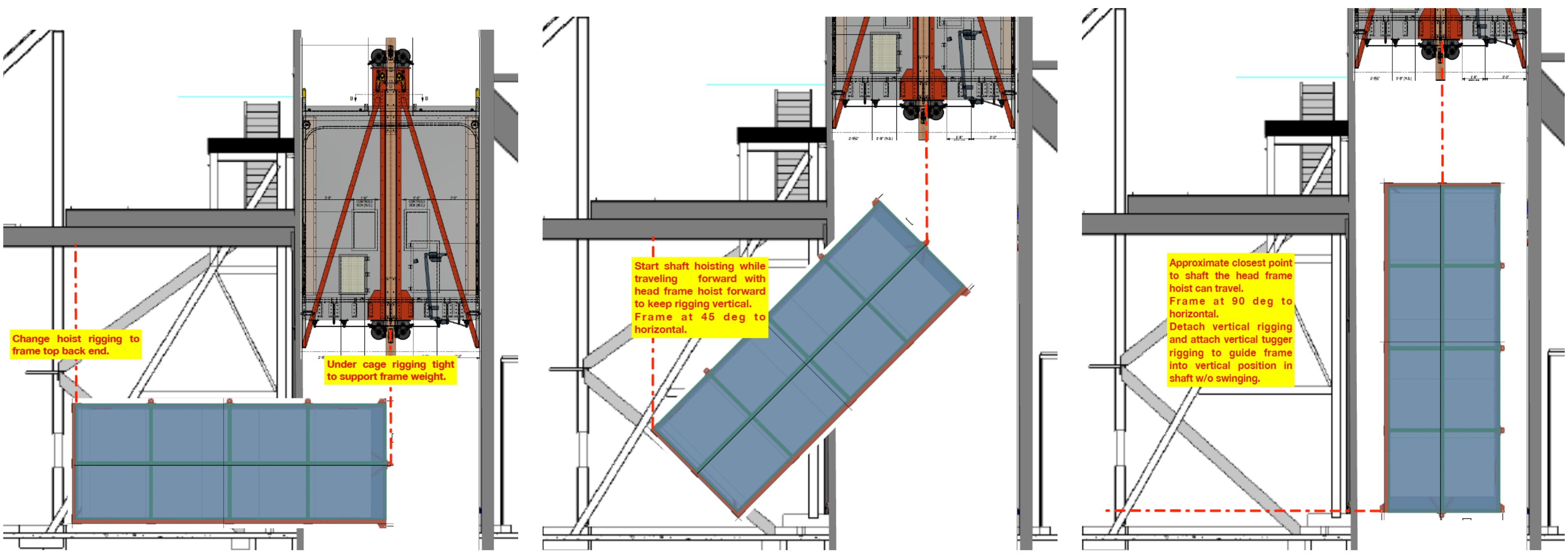
MERLO

Use case 5 - Loading into, transport down and unloading out of the Ross Shaft

- SURF has proposed alternative equipment for the operation
  - Overhead free-moving monorail and horizontal tugger
- If the hook points and angles of the forces are consistent with our analysis/specifications, then they can pick their equipment for the job



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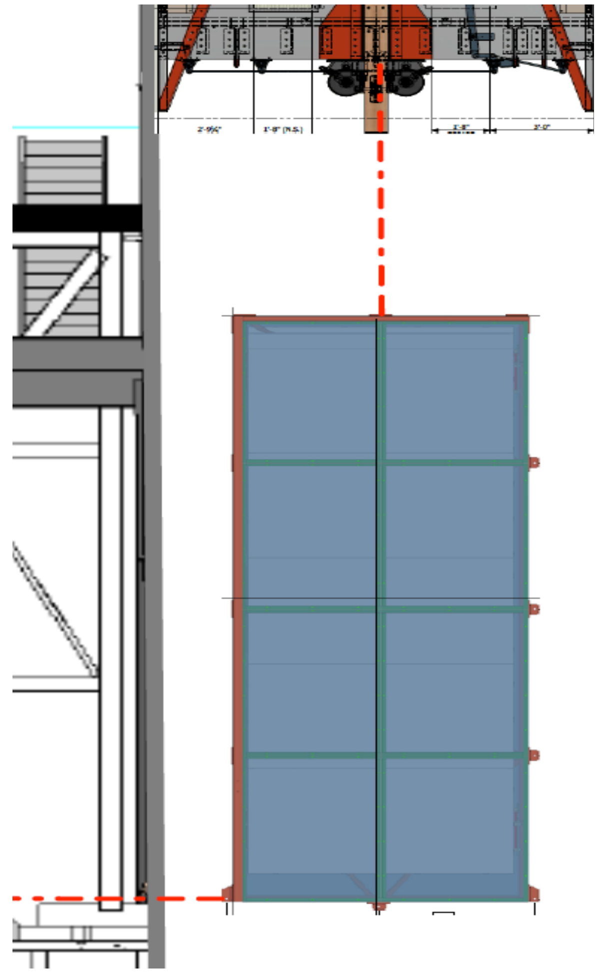
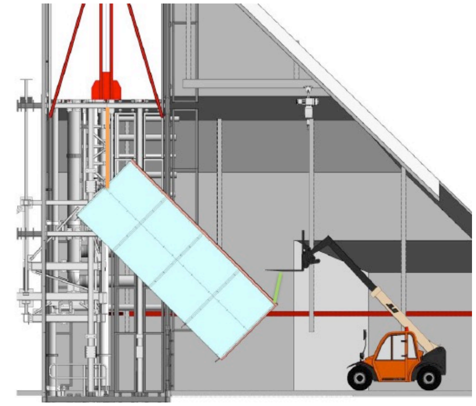
Use case 5 - Loading into, transport down, and unloading out of, the Ross Shaft

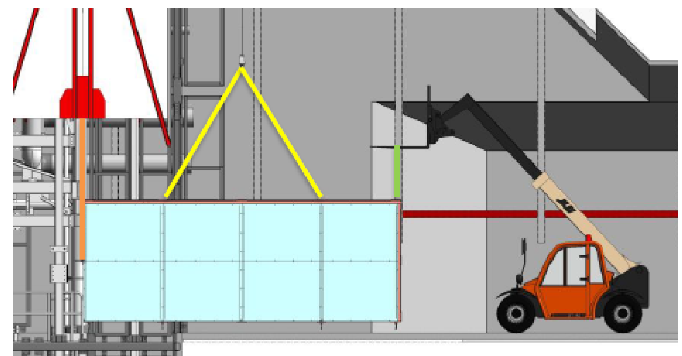
- The APA shipping frame will be slung load below the main cage
- These loads are moved down the shaft slowly to reduce movement of the load
  - Dynamic loads specific to the facility
- In an accident a dogging system that will stop the cage
  - We consider this an accident condition
  - We want to ensure the facility and workers are protected in such an incident
  - Analysis of this condition is focused on failure of materials – none expected

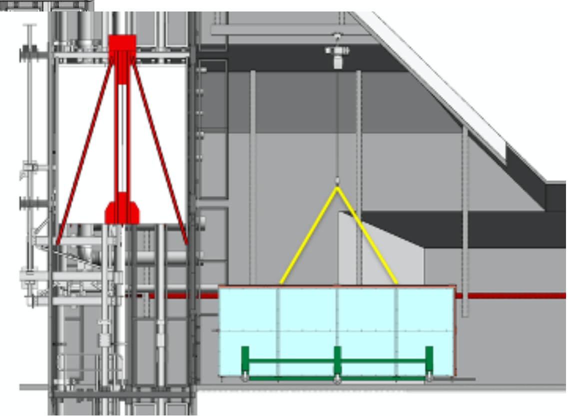


Use case 5 - Loading into, transport down, and unloading out of, the Ross Shaft

- The details for the materials handling equipment loading/unloading the shipping frame from the cage are still be negotiated between the TC and SURF
  - The general plan is well enough defined to specify the required structural analysis cases for shipping frame
- The surface rigging operation will be reversed
  - The shipping frame will be pulled out of the shaft and landed on the opposite long edge of the shipping frame than was used on the surface (upside down)
  - A suggest method is shown here; SURF has alternative proposals
  - If the hook points and the angles of the forces are consistent with our analysis and specifications, then they can pick their equipment for the job
- The shipping frame will be placed on a horizontal transport cart and rolled down the drift to the cavern
  - This cart is currently understood to be a multi-purpose device not provided by the APA consortium
  - The actual conditions may require this to be a custom cart specific for this operation, possibly with suspension depending on as-built surface conditions
- Throughout this operation the forces on the shipping frame (and cage) are almost completely vertical with only small horizontal deviations to control the rotation
- As this is the inverted version of that on the surface, the orientation implies a variety of unique load cases, but they are similar to those on the surface

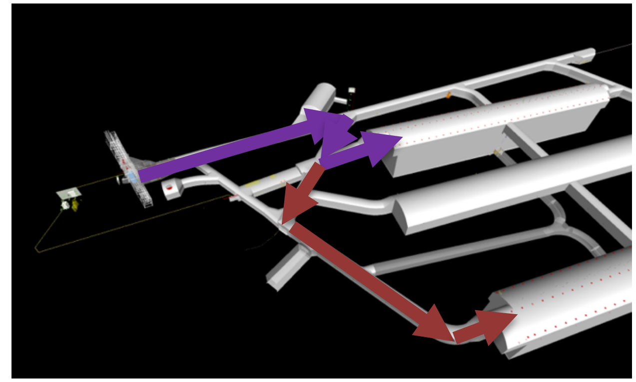


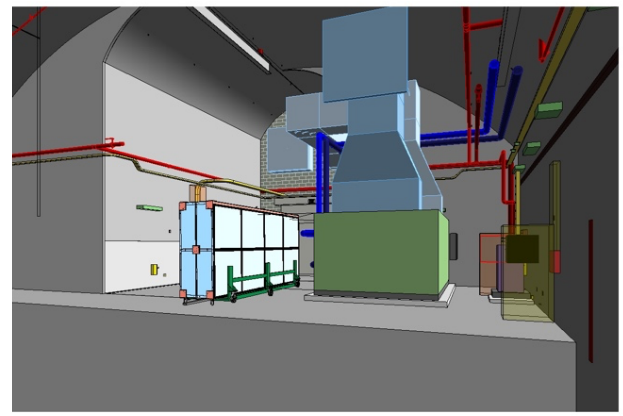




Use case 6 - transport to & inside the cavern

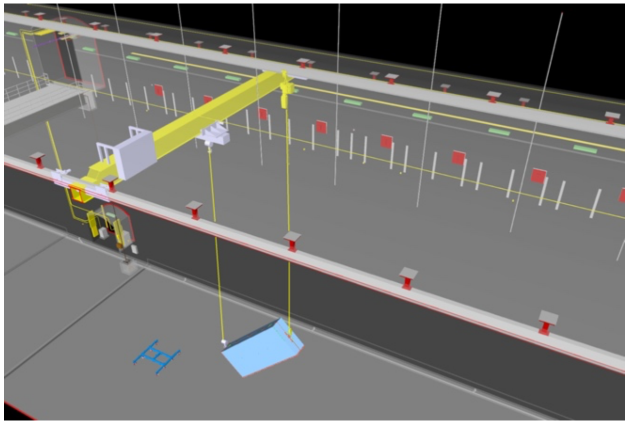
- The loaded shipping frame and cart must be stable when moved down the drift, on modestly inclined surfaces (<2^0)
  - The APA shipping frames are hauled along the drift to the cavern at SURF using a general – purpose horizontal cart still to be specified powered by a vehicle still to be specified – current model is SDSS provides both
  - These systems will be supplied by SDSS and will need to meet similar stability requirements to the carts used in the APA assembly sites
  - It may be that we need build an APA-specific cart to control vibration or for stability
- Surface quality of the drifts should be sufficient, and the speed of the transporter sufficiently slow, to ensure that they do not imposed dynamic conditions larger than expected during over-land shipping

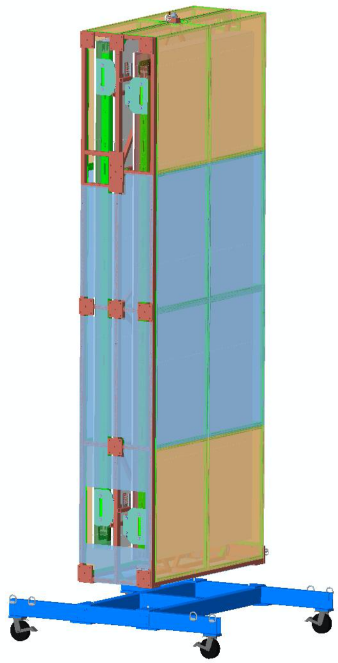




Use case 6 - transport to & inside the cavern

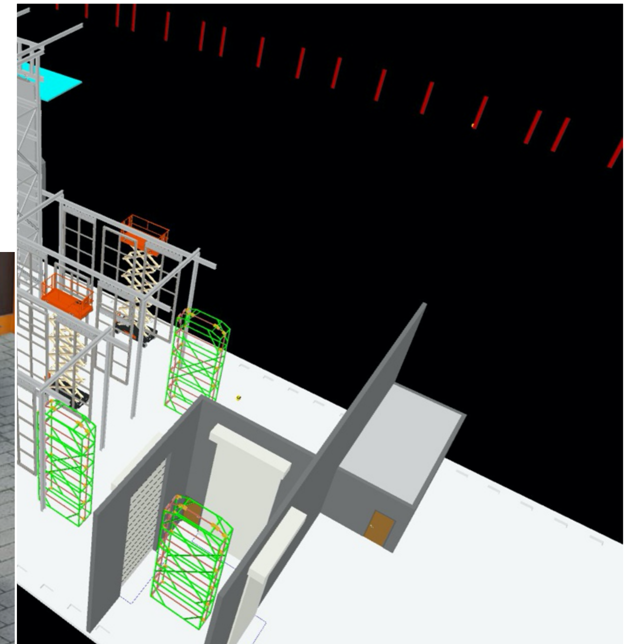
- The frame is connected to the cavern bridge crane and monorail, the cart is released, and the frame is lowered toward the hall floor
- They are rotated to the vertical position,
  - Rotation to vertical will use two cranes
    - Similar to ProtoDUNE operation [shown earlier]
  - Same mounting locations as used during cage loading and unloaded operations
- They are secured on a vertical APA carts
  - APA Consortium provides these carts (Peter’s talk)
- APA shipping frames are then moved by transporter into a storage area in the cavern
  - 1 month of APAs will be stored as a buffer (12 shipping frames)
  - Floor space for storage will be determined by the size of the vertical APA cart

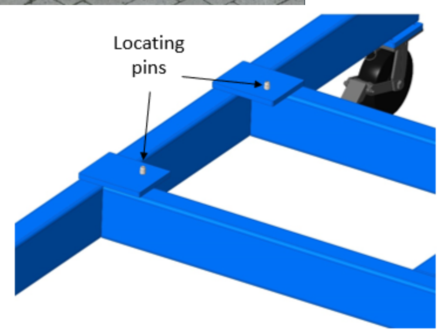


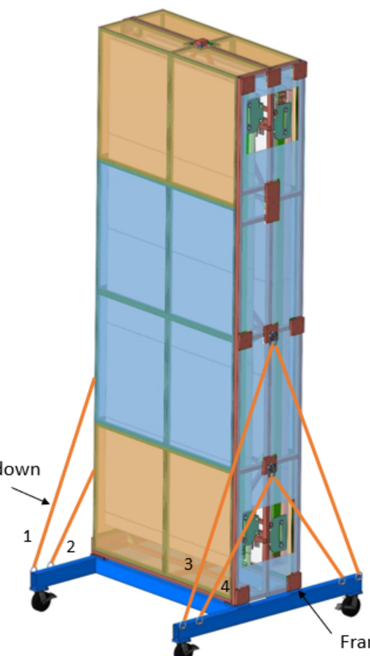


Use case 7 - transport to the SAS, APA integration, APA mating, and testing

- They are rolled through a door into the SAS
  - Outer packaging (side frames and wrap) is removed and the carts (esp. wheels) are cleaned
  - They will be connected to a transport via an A-frame towing bar to allow for both pull & push
  - A separate “clean” transporter will be used inside
- The door will be sized to fit this object (expected to be largest)

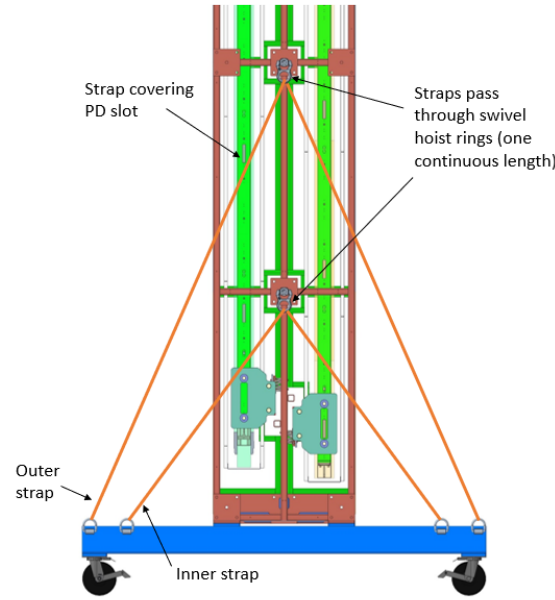


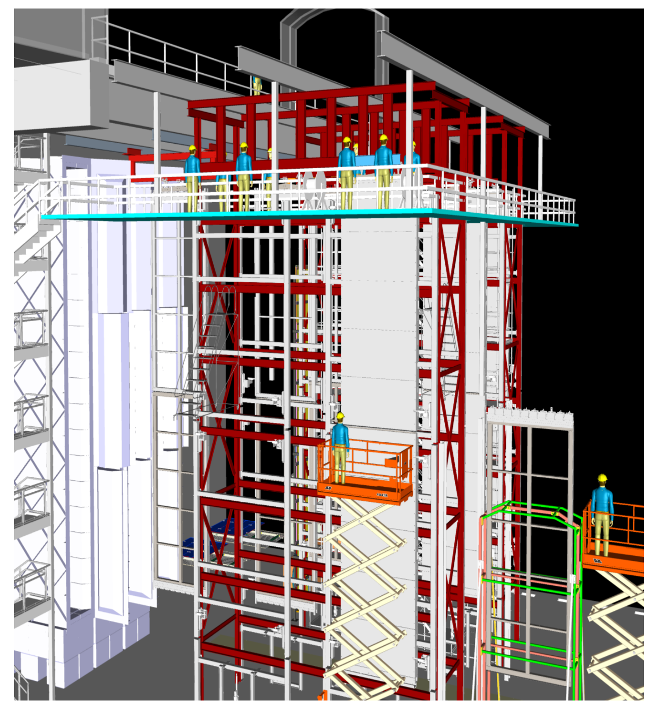




Use case 7 - transport to the SAS, APA integration, APA mating, and testing

- APA shipping frame is moved to the cleanroom
  - PDs are installed and cable management is completed
  - Frames+carts allow access to all photodetector slots (more in Peter's talk)
- APAs are unloaded from the shipping frame and loaded onto the assembly tower using the cleanroom crane
  - 1st APA is lifted from the shipping frame using a fixture on a monorail-mounted hoist & placed on a lower rail
  - The cart is moved a short distance
  - 2nd APA is lifted from the shipping frame using a fixture on a monorail-mounted hoist & placed on an upper rail
  - This completes APA operations with the shipping frame
  - More details on this in Dan's talk
- APAs will be tested for continuity, isolation, and wire tension in the clean room after the APAs are mated





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Use case 8 - transport to the surface

- Up to 25% of the pallets, shipping frames, and protective covers may be shipped back to the US APA factories
  - For use on the second module production
  - For these the removable side frames are reattached to the shipping frames
  - The shipping frames will be returned to the surface (in the reverse of the operation that brought them underground), and trucked back to the warehouse
- More typically…
  - Empty frames/pallets will be cut up and treated as waste or salvage
  - Protective covers from a number of APAs will be packed (e.g. in wire cages or bins) and periodically shipped to the surface in bulk
  - Wrapping materials will be bailed and shipped to the surface with other waste packaging
- If an APA failed quality tests and needed repair at PSL, a counterweight would be added to the frame (or we wait for a 2nd APA) and it would be brought to the surface and shipped to PSL
- No unique load cases are implied

Use case 9 - Sampled above-ground cold testing at PSL

- We will fully test the first 5 APA pairs from each factory at PSL including cold tests and wire tension tests
- PSL modules they will be double shipped to/from SURF prior to these initial tests
- During steady-state operations, 1 in every 10 APA pairs maybe sample tested at PSL
- The APAs will be unloaded and completely stripped of packaging material for the cold tests
- They must be repackaged and reloaded onto the shipping frames for eventual shipping to SURF
- No unique load cases are implied

Requirements derived from factories & shipping

- The shipping frame should hold 2 APAs positioned end for end (top & bottom APA)
- The shipping frame, in horizontal orientation, should allow transfer of a completed APA to the shipping frame at the factories
- Be stable while secured to a horizontal cart when only one APA is installed
- Must be cleaned after fabrication and transportation prior to entry to the APA factory
- Steel should be painted to facilitate cleaning
- The side frames that wrap around the APAs (currently designed as Al T-channel hardware), must be able captured by pockets to help mate to the frames while protecting the APA panels, and must be relatively efficient to secure in place
- Frame must be designed with lifting points for swivel rings for slings or hooks
- The carts should have mount points for A-frames to allow a material transporter to engage and move the shipping frames while on carts
- APA must not undergo more acceleration that they can sustain (quasi-static 6g for vertical portrait or 4g for landscape orientations)
  - Documented in the APA engineering analysis
  - See Dan's talk and EDMS #2100877
- The shipping frame should isolate the APAs from shock and vibration due to transportation and handling to not damage the APAs and meet applicable standards
- All the engineering design, fabrication, QC and documentation process will follow the documented expectations as summarized in
  - *Validation of the DUNE/LBNF structures and mechanical components for equipment and detectors*
  - EDMS #2172998

Below the Hook (BTH) Lifting device

- The operational requirements lead to the specification that the APA shipping frames are considered, in their entirety, to be a *Below the Hook Lifting device*
  - *Below the Hook Lifting device - Design Category A lifting equipment, Service Class 0 as defined in ASME BTH-1 Chapter 2, Table 2-3-1 and Appendix B.2.1 Table B-3-1 and ASME B30.20.2013 section 20-0.4*
  - The shipping frame a minimum design factors (per ASME BTH-1 2017)
    - SF ≥ 2.0 for the members (based on yield strength)
    - SF ≥ 2.4 for the connections (based on yield strength)
  - *To comply with ASME B30.20 and the European Machine Directive, **the load factor of 1.5** will be applied*
- Each of the 75 shipping frames for each module will need its welds individually inspected and individually be subjected to load testing
  - Load tests of each shipping frame shall follow the ASME B30.20 requirements except to use a **load factor of 1.5** on the work load limit so as to also be compliant with the European Machine Directive

Additional applicable standards

- ANSI/AISC 360 (Specification for Structural Steel Buildings – American Institute of Steel Construction)
- Structural Welds consistent with ANSI/AWS D14.1 and ASME BTH-1
- EN1090, Class 2 (all applicable parts or US equivalent) - execution of steel and aluminium structures
- DOE 10 CFR851 – Work Safety and Health Program
- OSHA – CFR-2005-title29-vol8 PART 1926 – SAFETY AND HEALTH REGULATIONS FOR CONSTRUCTION, especially
  - *§1926.451(general requirements*) requires a safety factor of 4 for stability
  - This is applied for the requirements of the cart tipping analysis

Analysis overview

- Stresses within the shipping frame should be assessed such that they are within acceptable limits considering the maximum reaction forces applied by the isolation system for each load condition
  - It is likely these will be the highest forces in overland shipping
- Requirements for assessing road transportation loads of APA and transport frame were determined within the APA consortium aided by a helpful literature review complied by the DUNE Compliance Office
  - EDMS #2366873
- Ocean shipping standards within the IMO/ILO/UNECE *Code of Practice for Packing of Cargo Transport Units (CTU code)* determined that quasi-static load cases during transport as acceleration coefficients 0.8 g horizontally and -1 g vertically
  - This applies to cases where up to 1/3rd of waves being >12m !
  - This analysis is being treated a preliminary and it will need to be updated when data from the specific shipper is made available

Analysis overview

- Standards test scenarios defined in the "transportation shock test sequence" from MIL-STD-810H
  - 21 shocks consisting of a half sine wave of 6.4 G over 11 ms over common roads for a distance of 1000km
  - We will investigate the feasibility of such a test on a vibration table
  - For now, results from an FEA analysis under those conditions are documented in the engineering analysis note (Ang's talk)
- The isolators should be specified to stay within their max displacement under the scenarios considered
  - Internal clearances should accommodate the full stroke of the isolators in all 3 directions to avoid collision between the APAs and the shipping frame for each load case including expected deformations and tolerances
- The shipping frames should have datalogging instrumentation to indicate if the APAs were subjected to more than 4g/6g during shipping

Analysis overview

- As a starting point for dynamic analysis, shipping data from the literature were used in a set of analytical calculations
  - They indicated air suspension have significantly lower strength of vibrations at higher frequencies (above ~10Hz) while having comparable peak strengths at lower frequencies (peaking around 2Hz) when compared to leaf-spring suspensions
  - Initial analytical calculations used measured **power spectral density** (PSD) data from literature, and it gave guidance on the specifications of the vibration damping elements (wire-rope isolator)
    - This analysis is included in an appendix to the engineering analysis note
  - Subsequently dynamic analysis of the APA frame and shipping frame using FEA methods have confirmed that we should specify air suspensions for shipping the APAs to reduce higher frequency vibrations during over-land transport
- The first modes of vibration of the shipping frame should be computed and compared to the lowest modes of the APA frames and expected PSD in shipping
  - The design should incorporate as much separation between shipping frame natural modes as practical, expected vibrations frequencies during transport, and APA natural modes to ensure effective isolation
  - The photodetector rails should be incorporated into this analysis (but have not yet been considered at this time)

Analysis overview

- For resilience to handling conditions the isolation system, the acceleration experienced by the APAs when exposed to a drop should be evaluated
  - MIL-STD-810H overs a guidance height, but it also notes that is may not be practicable, and the limit should be analysed to determine to the highest drop allowable drop
  - The drop condition should be assessed for all configurations of the lift sequence, i.e. drops on the long and short faces and the corner between them (this is a work in progress)
  - An analysis indicates that a 11.4cm drop produces 4.3g (quasi-static) on the APA within the shipping frame in the horizontal orientation
    - We consider this to meet 4g at 10cm; this will become part of the shipping contract specifications

Requirements for packaging

- The removable side frames and the APA protection panels must be designed to allow one section to be removed
  - This will provide access to the head boards for testing and they must be able to be reinstalled while the APA is mounted on the shipping frame while oriented either horizontally or vertically
  - It must not be possible for hardware released in this process to accidentally fall inside the APA volume
- The loaded shipping frames must be able to be installed in wooden shipping crates (UK) or wrapped on pallets (US)
- The UK crates need to be less than 2.5m (98”) in width to allow shipping without wide-load permitting in the US
- The shipping frames will be stored long-term in the SDWF and their shipping packaging should allow them to be stable while stored in the warehouse

Specifications from handling at SURF

- At the headframe, the shipping frame must be able to be unloaded from trailer by a spreader beam or slings from an overhead crane (as in the factories)
- The shaft is controlled by SDSTA; they approve all loads transferred into the shaft
  - DocDB 4781, “Drawings and Analysis of Vertical Slung Loads in the Ross Cage Shaft for SURF,” Matt Sawtell (drawing F10071028).
  - Docdb-328, “Far Site Shaft Hoisting Assumptions and Parameters”

  - Maximum slug load weight not to exceed 13,000 lbs. (5,896 Kg)
  - Maximum length is 22’-11 7/16” (6996) *
  - Maximum width is 4’-8” (1422)
  - Maximum depth is 11’-0”
  - Load must maintain center of gravity
  - Suspension points will be from the two midline hooks underneath the cage

  * NOTE: The specifications have a round corner cutout which the shipping frame design overlaps. The specifications also allow an alternative envelop to be used if approved by SDSTA. The current design has been shown to their engineering team, and they are working with Fermilab engineering staff and materials handling experts at CERN to jointly specify the required materials handling equipment.

- The shipping frame must be able to withstand rotation from landscape (up-side up) to vertical in the shaft, be able to be pulled out to landscape (up-side down), and be able to be loaded onto transport carts at the underground shaft station
  - Throughout this set of operations the center of gravity should be safely below the plane created by the array of points used for rigging to ensure stability

DOE considerations

- The APA shaft operations meet the DOE category "Critical lift" conditions for the initial tests and also for the initial production lifts in 2025 as defined in DOE STD-1090-2011 based on § 2.1
  - "The load item is unique and, if damaged, would be irreplaceable or not repairable and is vital to a system, facility or project operation."
  - "The cost to replace or repair the load item, or the delay in operations of having the load item or facility damaged would have a negative impact on facility, organizational, or DOE budgets to the extent that it would affect program commitment."
- Assuming successes in the initial production lifts and an after-action review, we expect to propose that the transport activities be reclassified as either as a DOE "Critical Lift – multi-use plan" or as a DOE "Pre-Engineered Production Lift"

Requirements derived from transport underground

- The shaft's emergency braking system can give 2g in the vertical orientation, which should be considered an exceptional case (i.e. engineering analysis at 2g should be with respect to failure instead of yield)
  - Under normal circumstances the analysis should be done with the assumption of 1g vertical acceleration/deceleration
  - Ang will show that there is no yielding at 2g in the vertical orientation

- The produced underground cart must have mount points to the shipping frame and a wheel based to provide for stability (consistent with OSHA standards) while moving down the drift to the cavern

Requirements derived from testing and installation

- Outside side protection panels must be removable
  - A seal (plastic wrapping) over the side frames with protect the APA outside the cleanroom/SAS
  - We must be able to remove individual protection panels over the head boards during testing, and integration of PDs and cold electronics
  - The shipping frames must be designed to allow access to all of photodetector (PD) slots on the APAs while in the vertical orientation
- The frame sides must be able to be removed while the shipping frame is in the vertical orientation
- The APA shipping frame must be able to be rotated from horizontal to vertical the using two independent cranes in the cavern
- The frame will be stored in the main cavern in a vertical orientation attached to carts
  - It must be able to stable when stood on end and mounted to the “vertical” cart that brings the APA shipping frame into SAS and Cleanroom
- Must be able to remove a single APA while the shipping frame is vertical in the cart and have the remaining APA + cart remain stable

Prototyping plans

- A prototype shipping frame will be produced at W&M (east coast US)
- It will be shipped to Ash River
  - Crew will perform mock lift/rotation operations from the factories, SURF, and the cleanroom
  - The tests will use blank APA structural frames
  - Access for PD installation will be verified
  - Depending on approval schedule, this is planned for Fall
  - Masses and CofGs of the frames will be measured and compared to the models
- It will be shipped to SURF
  - The rotation operation at the headframe will be tested
  - Will test as a slung load and measure PSD spectrum
  - Lower shaft station not ready at that time
- We will log data during each shipping stage on US roads and collect PSD spectra
  - Will need to dummy the rest of the load (since they are not for this shipment test for it to be valid
- The first production frames will be in the UK (Liverpool) and used for ProtoDUNE2.0 APAs next year and then for initial FD production
  - Initial US shipments will be shipped to PSL to be tested in detail to ensure that it still meets specs

Production plans

- In the UK Liverpool will coordinate the procurement and testing of the shipping packaging for UK APA production (76 units)
  - They have been consulting with an experienced fabricator they have used previously on the manufacturability of the structure
  - UK crating will likely be from a company they use for other shipments (e.g. SBND APAs)
- If there is US production, William & Mary coordinate the procurement and testing of the shipping packaging for US APA production (76 units)
  - We are working to identify suitable vendors with verified testing/certification capabilities
  - US crating will likely be from a company near the port of Norfolk, VA that we have used before (ProtoDUNE HV fixtures)
- We are planning a QC/QA plan consistent with the identified standards
  - These specifications are a work in progress
  - EN1090 Execution Class 2 metal fabrications standards are applicable (determine equivalent US standards or write equivalent specifications)

Review documentation guide (link to this page on EDMS)

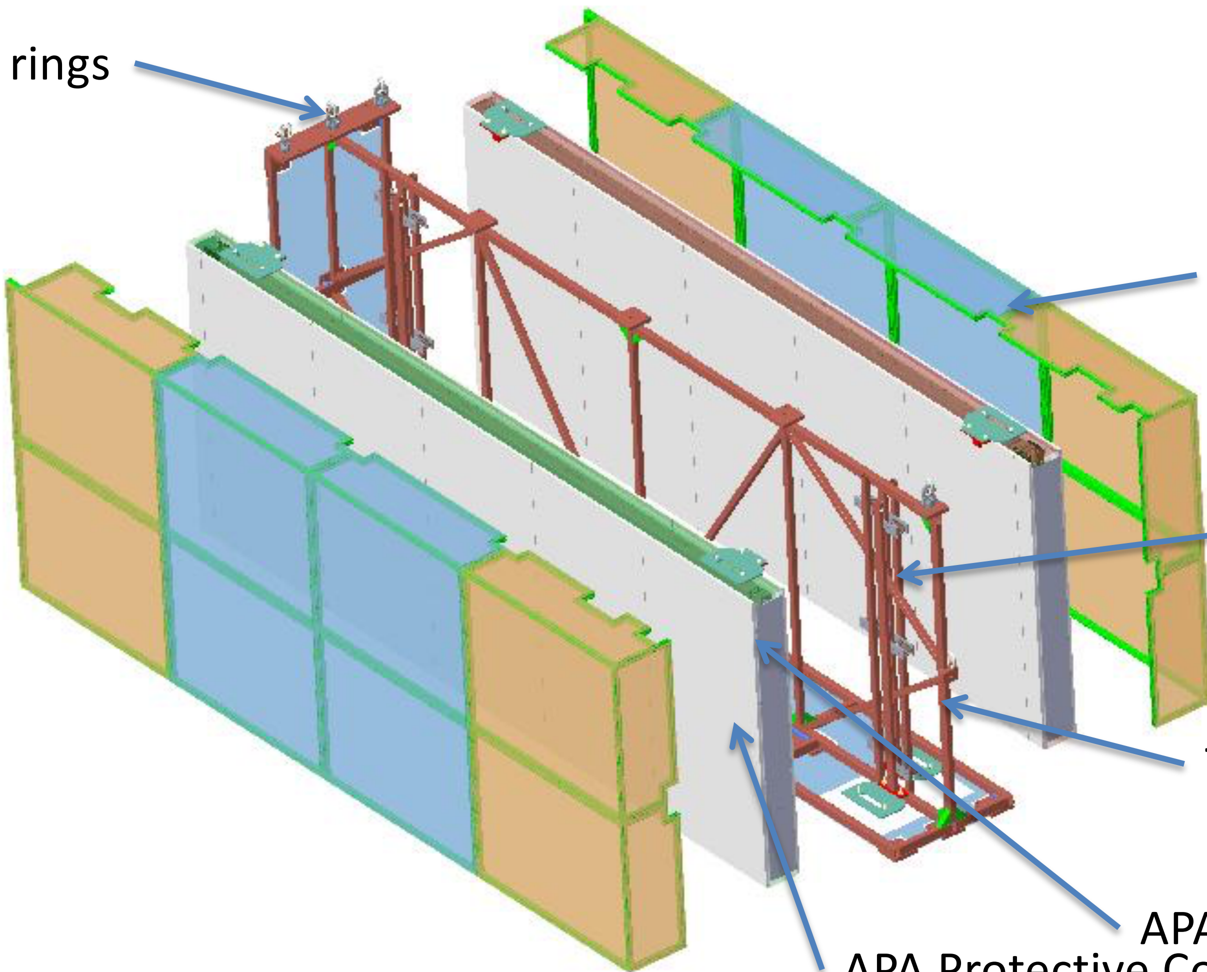
Category	EDMS	File Name	Description
Design Documents	2370041	VerticalCartDrawings.pdf	Mechanical drawings of the vertical cart
	2378982	NP79_Shipping_Frame.stp	Mechanical drawings of assemblies and parts for the shipping frame and horizontal cart
	2116830	8760185_full_model_REV_WIP2.STEP	APA full CAD model
	2112698	APA frame assembly	APA detector structural frame drawings
	2370041	Centre_of_mass_v1	Drawings with the calculated center of mass of the APA frames in different stages of loading
	2370041	Technical_Drawings_v1.pdf	Mechanical drawings used for the FEA analysis
	2370041	Technical_Drawings_v2.pdf	Mechanical drawings for the shipping frame and the horizontal cart that will be used in the APA assembly sites
Requirement documents	2370041	APA_Shipping_Frame_Requirements_Document_v2.3_docx_cpdf.pdf	Requirements and usage description for the shipping frame
	2370041	Vertical_Cart_Specification_V1_docx_cpdf.pdf	Requirements and usage description for the vertical cart
Engineering Analysis documents	2370041	APA_Shipping_Frame_Analysis_Plan_docx_cpdf.pdf	This document defines the analysis cases
	2370041	Engineering_analysis_of_the_APA_shipping_frame_v3.4_docx_cpdf.pdf	The quasi-static and dynamic analysis of the shipping frame and stability of the frame when mounted on the carts
	2370041	RT114 - DUNE_APA_Transport_Frame.pdf	An independent dynamic analysis performed by the AVMR/Vibrostop company.
	2370041	DUNE_APA_Considerations_docx_cpdf.pdf	The document addresses the implications of the shipping frame design on the APA frame
	2100877	DUNE_APA_Structural_Analysis_Master_2019v4_Dan_docx_cpdf.pdf	The structural analysis of the APAs

Presentations

Tuesday	Wednesday	Thursday
Transport packaging requirements (this talk)	Modal analysis, vibration, and shocks (Ang Lee)	Stability analysis and carts (Peter Sutcliffe)
Transport packaging design (Peter Sutcliffe)	Considerations on the APA frame (Dan Wenman)	APA Installation (Dan Wenman)
Transport frame FEA (Ang Lee)		

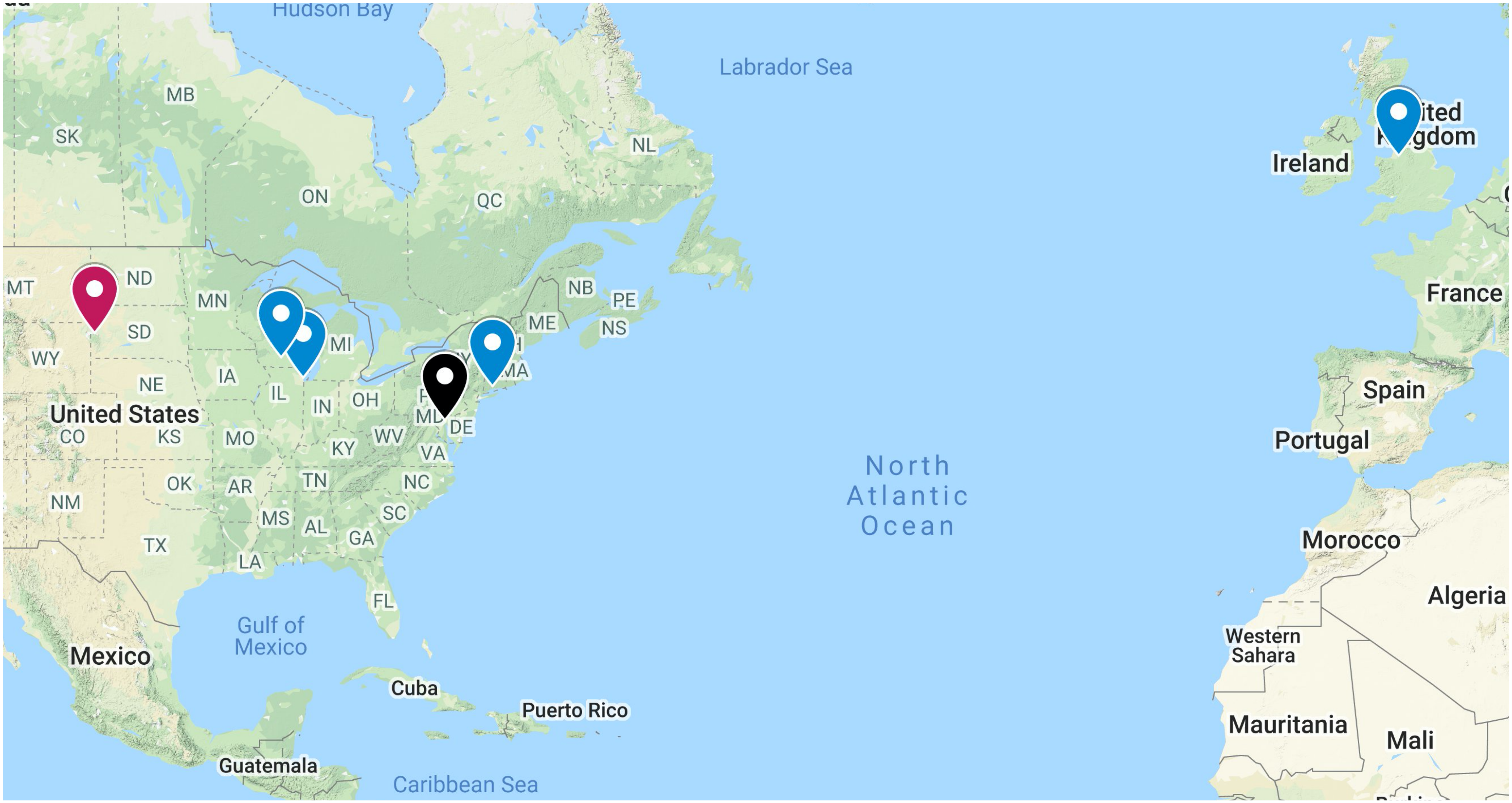
[redacted]

Overview of APA shipping packaging



Costing

- In Summer 2019 costings for an early design of the frame were developed in the US for the NSF proposal and in UK
  - These were before specification of the fabrication/testing standards
  - Adoption of those standards this winter and engineering analysis have resulted in several structural updates (cheek plates, gussets, member sizes…)
  - With defined specifications, we finalized a preliminary design over the spring/summer and we are starting to re-cost to shipping frames
- The UK costing is more advanced
  - Quotes are in hand from appropriate vendors for the revised central frame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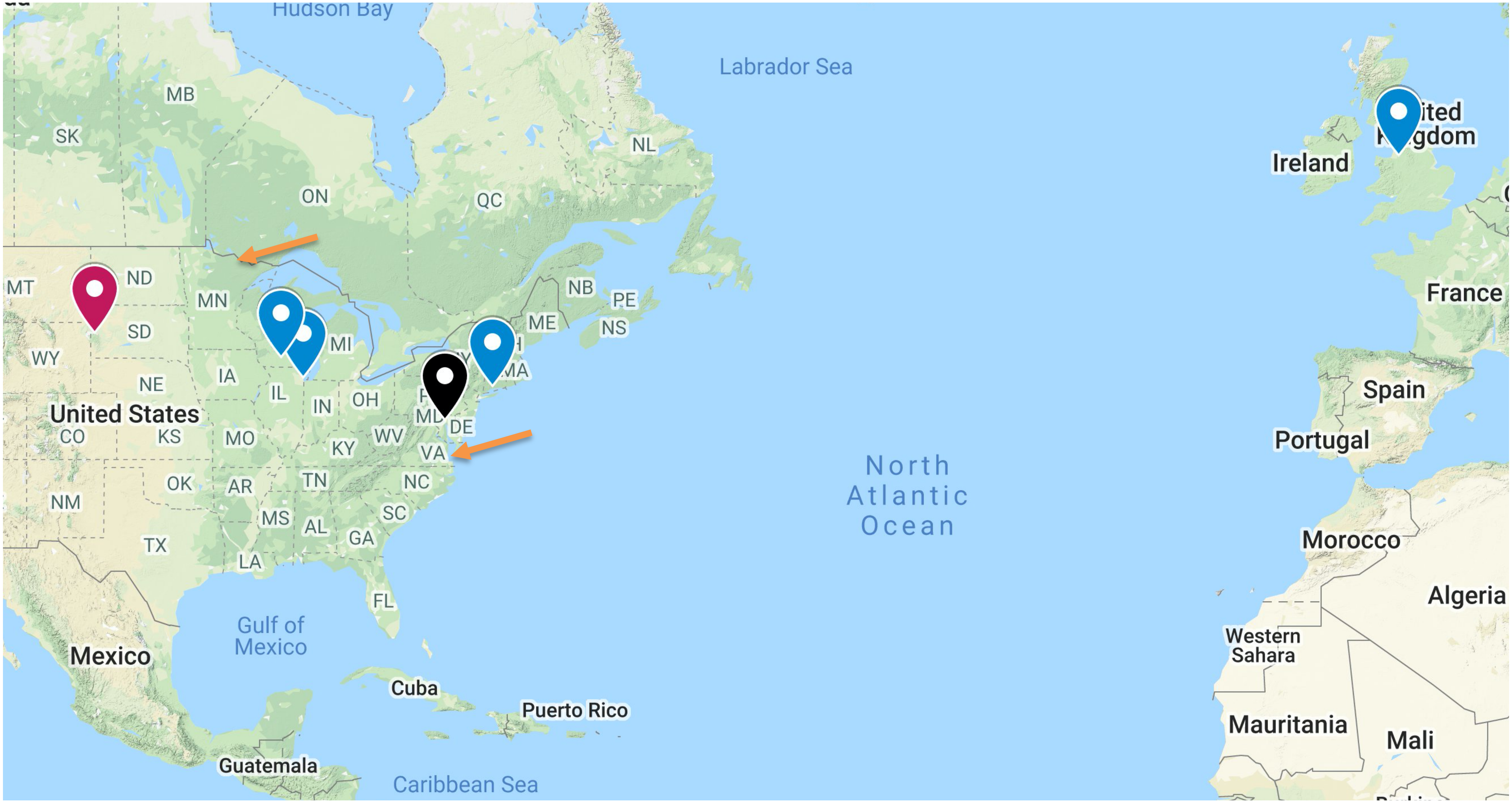
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