Installation sequence of the Type-A LCGT seismic attenuation chains

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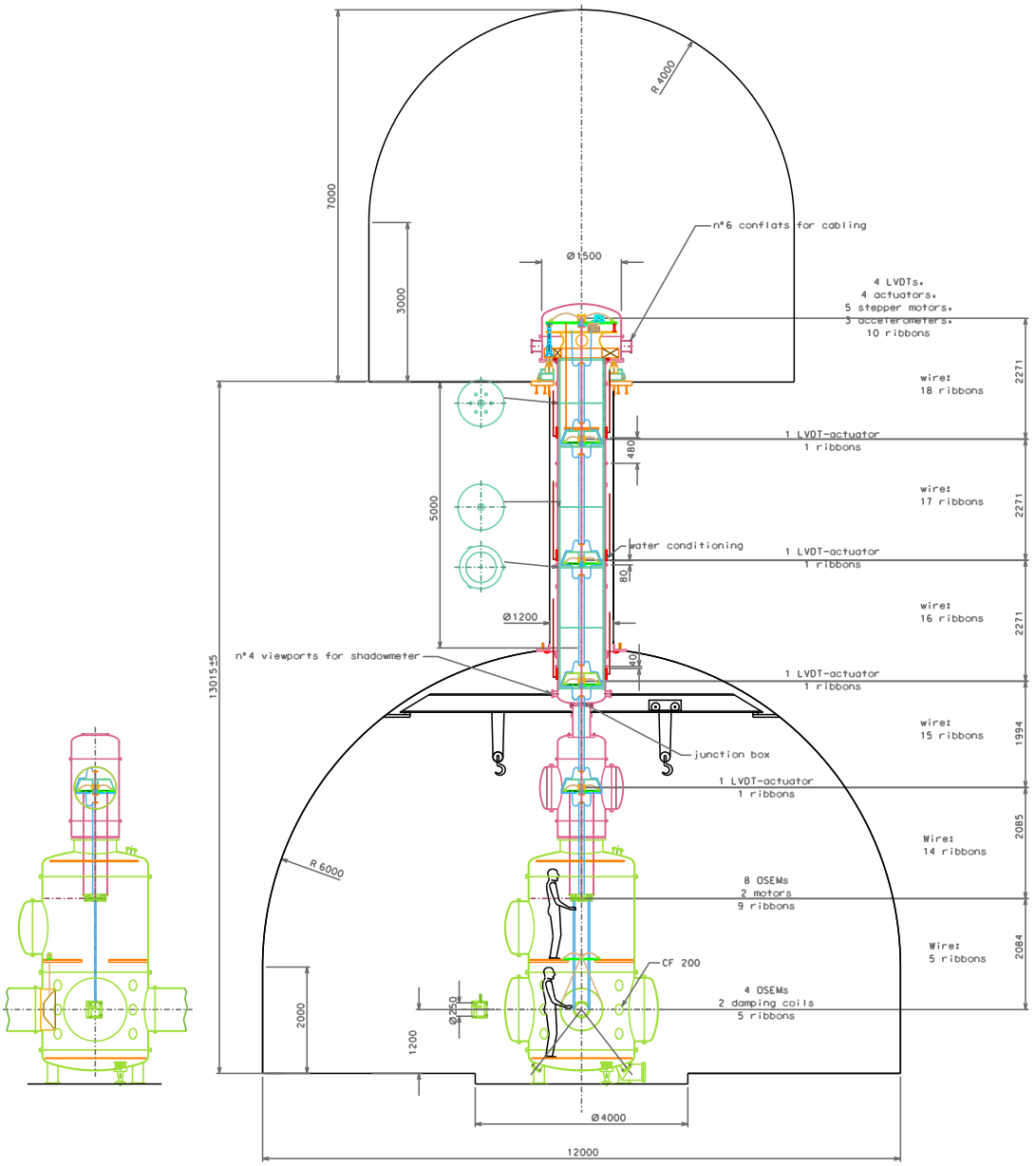
7th of July 2011

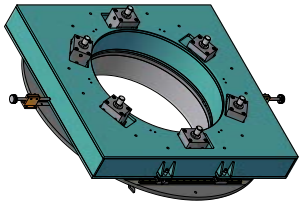
JGW-T1100410

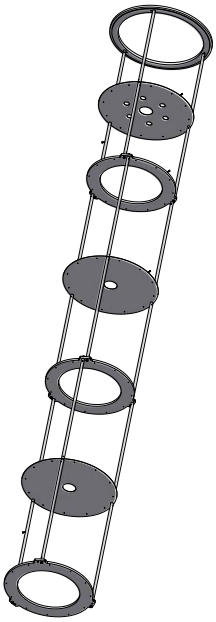
this report refers to the top filter and inverted pendulum design, its assembly sequence, the Standard filter design, and its assembly sequence.

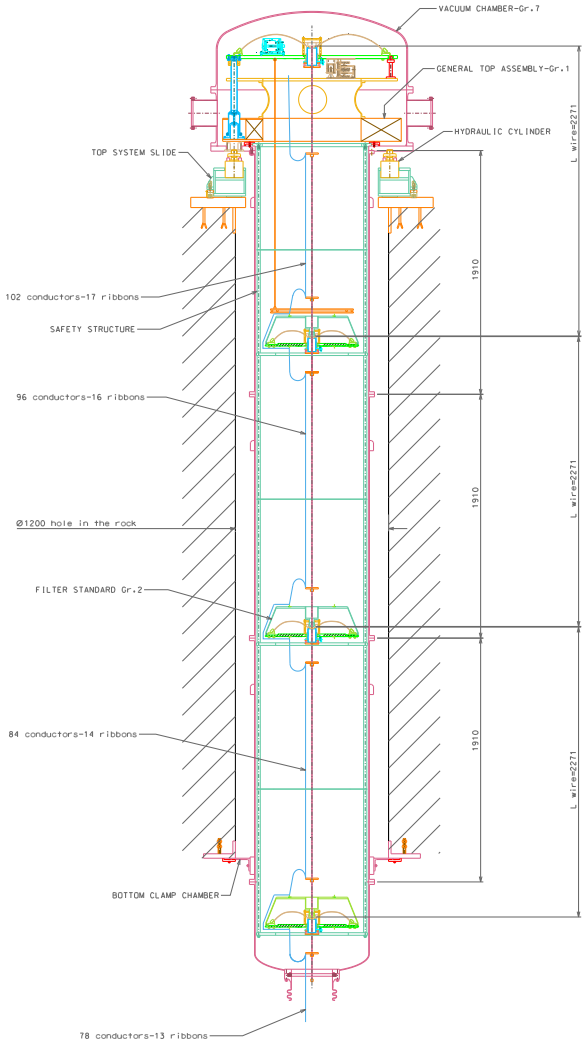
This documents illustrates the type-A SAS installation sequence down the well, how it and its payload can be effectively and safely implemented in the well between the two caverns. The aim is to assure that every step is easily and safely feasible. The aim is to make all of the installation at man heoght, without the use of scaffoldings or ladders. Of course a cherry picker cart, or suitable scaffolding will be necessary to reach the ceiling of the cavern.
Particular care is spent to assure clean, reliable, soft and low-mechanical-noise electrical cabling, which is probably the biggest challenge in the SAS scheme.
This first image (Drawing 0001) shows the final configuration. It also gives the wire count, the ribbon count and the listing of each instrument at every step of the attenuation chain.



This (on the right, drawing 0000) is a zoom into the hardware down the well section. For convenience, to avoid obstructing the view, in this and the following figures the struts of the safety structure, actually spread at 120°, have been placed at 180° from each other.
The structure shown top left is the sled that position and levels the vacuum chamber and the Inverted Pendulum structure.
The structure on the bottom left is the safety structure that catches the filters in case of catastrophic failure (e.g. earthquake) and guides the chain during installation.
It is made out of stainless steel rods connecting spacer rings that stiffen the structure transversally. The rings are positioned just below each standard filter, if the suspension wires are released the filters sit on these rings.





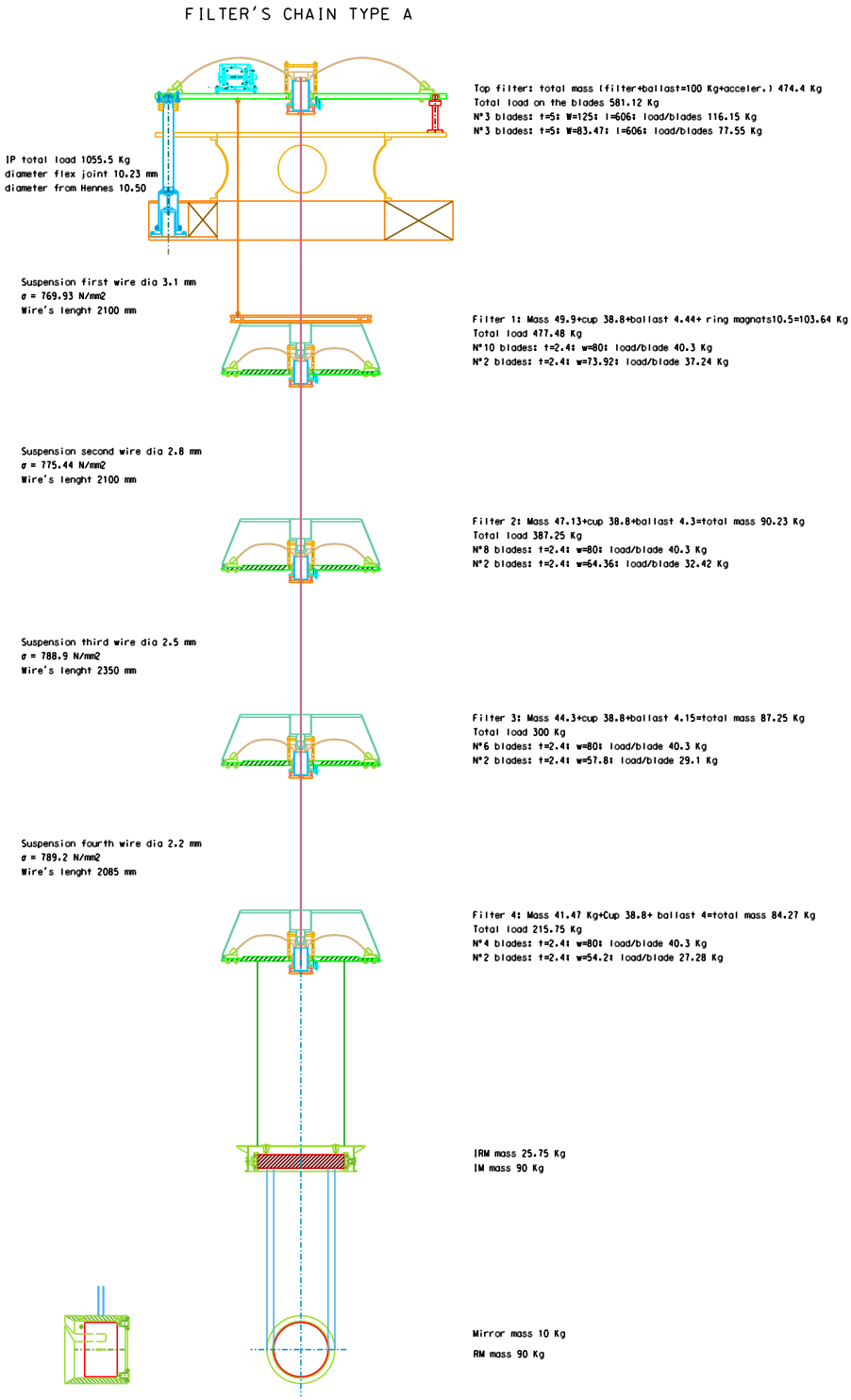


Half way between the filters, the structure incorporates disks acting as thermal baffles, which make that each filter is effectively in its own thermal bath.
In correspondence of the three filters, four or five turns of stainless steel 6 mm piping is tightly wrapped around the vacuum tank. The piping loops will have a pitch of ~30 mm. Thermostabilized water will flow in the piping for thermal tuning each individual filter's working temperature. This finely tunes each standard filter's working point (changing by 10 to 20 mm per ^{o}C) without recurring to its internal voice coil actuator.
The pipe loops are tensioned around the vacuum tank diameter by means of Breeze clamps, McMaster Carr 5426K3.

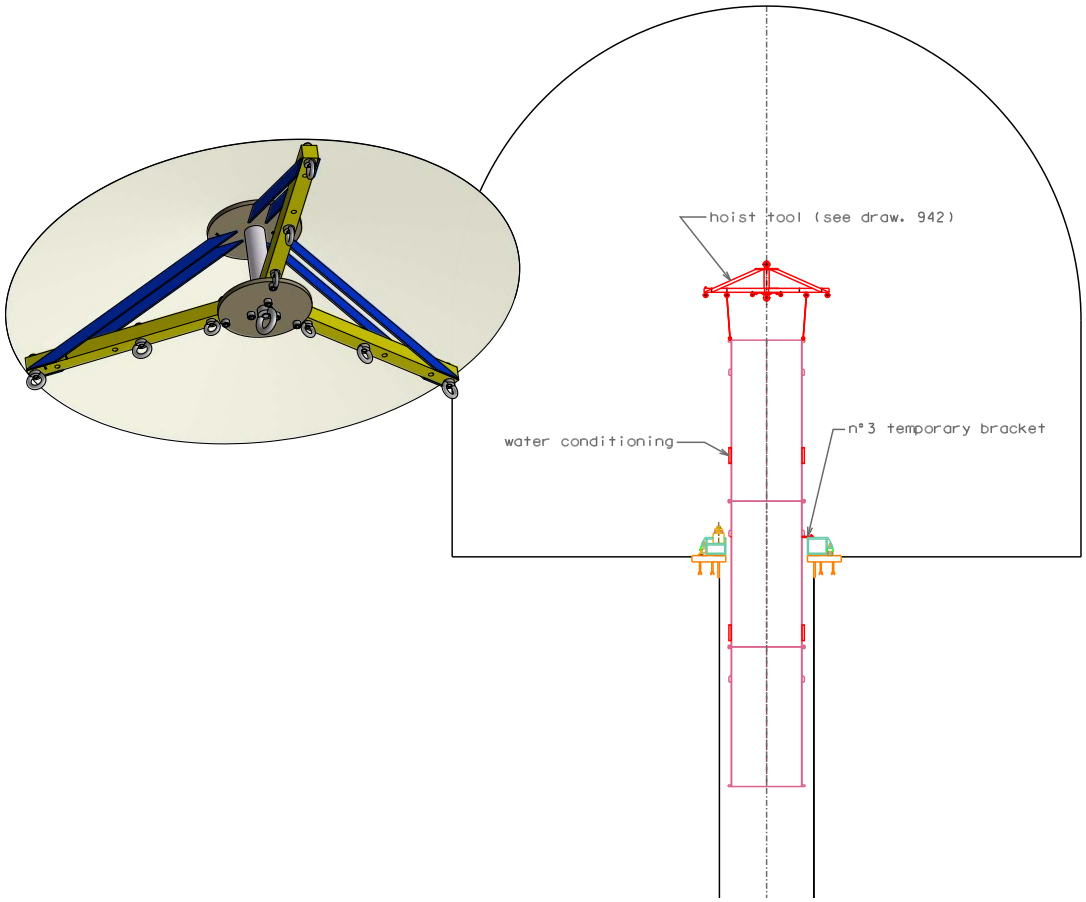
At each end of the pipe a loop of breeze clamp fastens a connection plate to the barrel. A second breeze screw attached to the connection plate pulls a section of Breeze band brazed near the end of the pipe.
The wrapped around pipe end is connected to pipes rising along the vacuum tank with compression fittings.

The rising pipes will be insulated with polyurethane foam tubes and run on the sides perpendicular to the beamline, to allow full longitudinal movement of the vacuum tank along the beam-line.
The turns of pipe wrapped around the tank will be insulated with polyurethane foam sheet, also clamped with Breeze band.
A suitable monitoring thermal probe should be tucked together with the pipe looping. Its leads should be routed together with the rising pipes.
The water feed piping is routed to the top chamber.

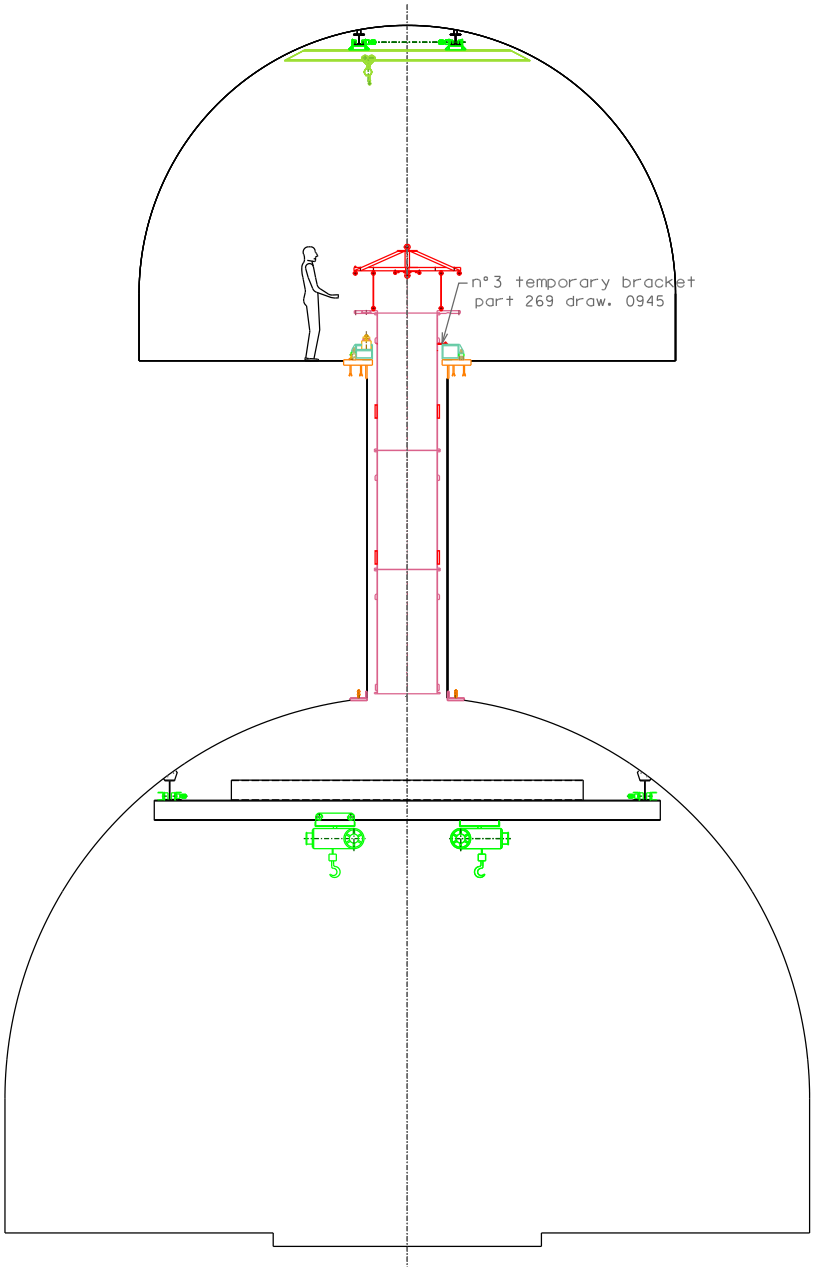
In this figure (Drawing 0013), load, stress, suspension wire length and electrical wiring data are listed.



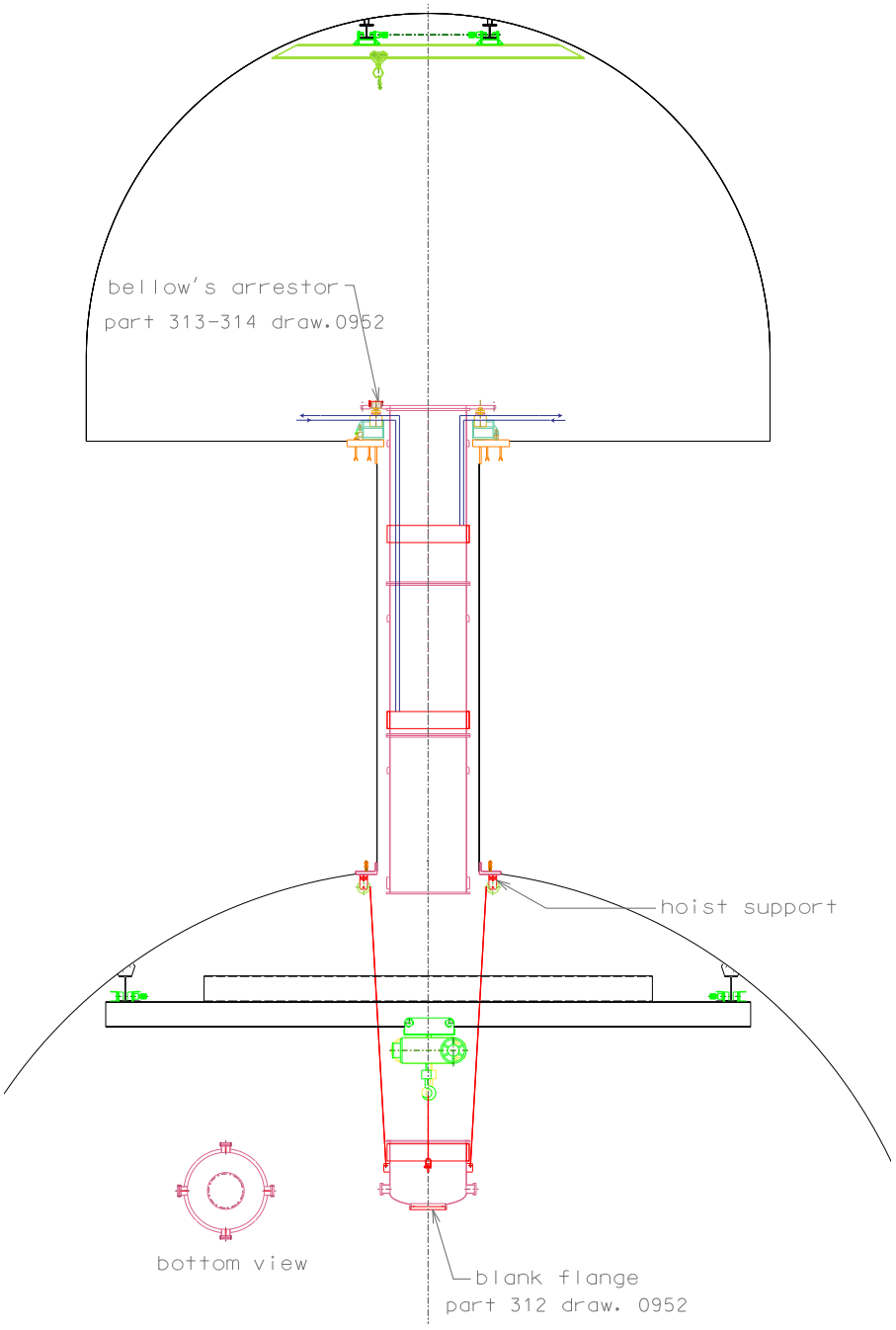
The installation procedure starts with empty caverns. Note that in all figures the top chamber has been rotated 90º for illustration only. Underground the top and bottom chambers would be built at 90º from each other, for rock stability reasons.
The green sled is mounted first on its rails on the floor of the top chamber.
Using the overhead crane, the individual vacuum chamber spools are lowered in the well, temporarily supported on brackets bolted on the sled while the next spool is brought in, sealed and bolted on. Then the spools are lowered one step deeper, and the operation is repeated until all three spools are assembled.
The crane spreader shown on the left is used over and over throughout the operation to handle all large components. It is provided with eyebolts at different diameters to match all components.



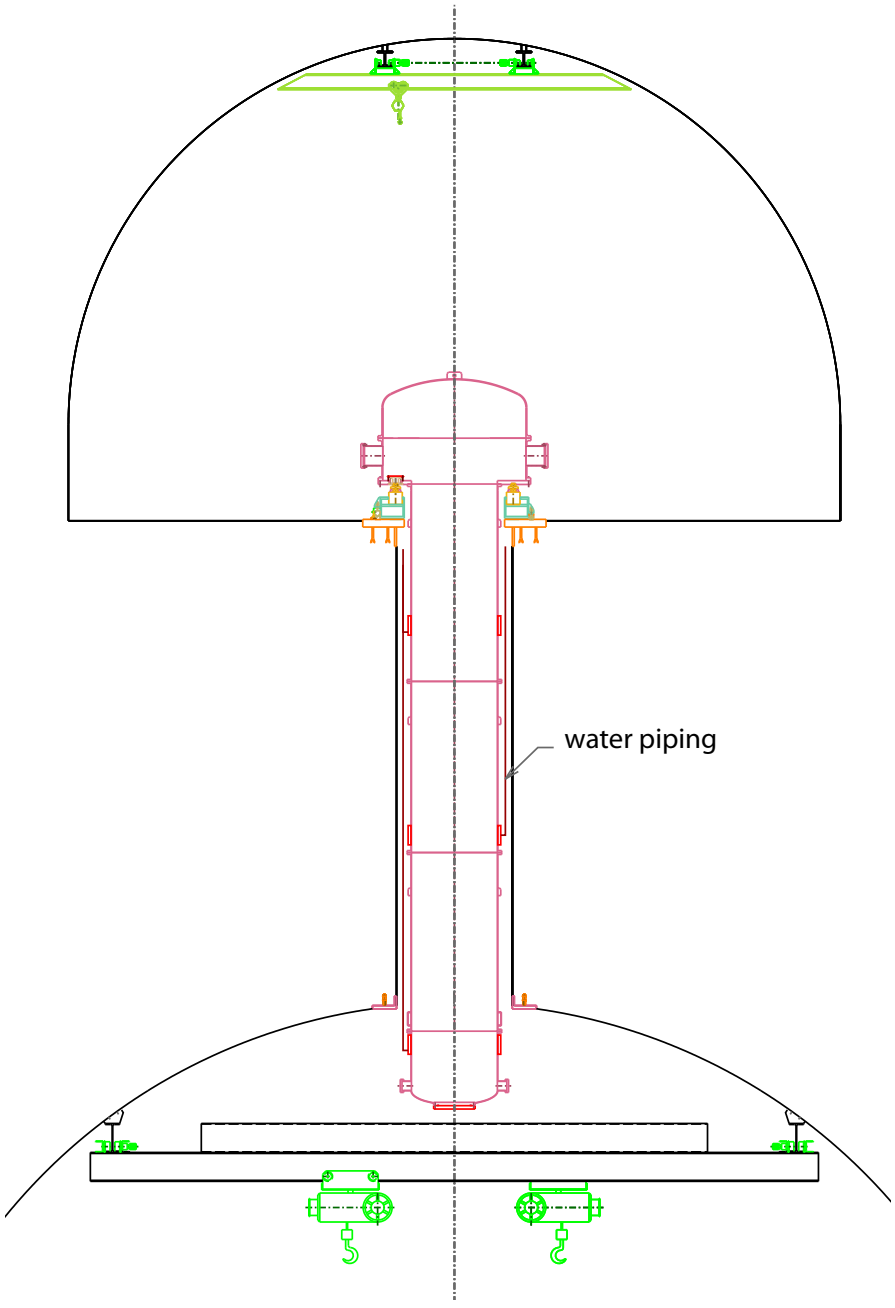
When all the spools are in place, the base vacuum flange of the inverted pendulum is installed over the top spool in the top chamber. The bellows of the Inverted pendulum are installed and sealed as well.
The vacuum assembly is lowered on the hydraulic jacks supporting the vacuum chamber and the Inverted pendulum. The three vacuum chamber jacks are used to achieve verticality of the vacuum chamber inside the well, and the bottom end of the vacuum chamber is fastened to the lower mouth of the well. Then the jacks are locked and disconnected to avoid accidental changes. Note that at this stage the water piping for the temperature stabilization belts must be properly installed and pressure and leak tested.



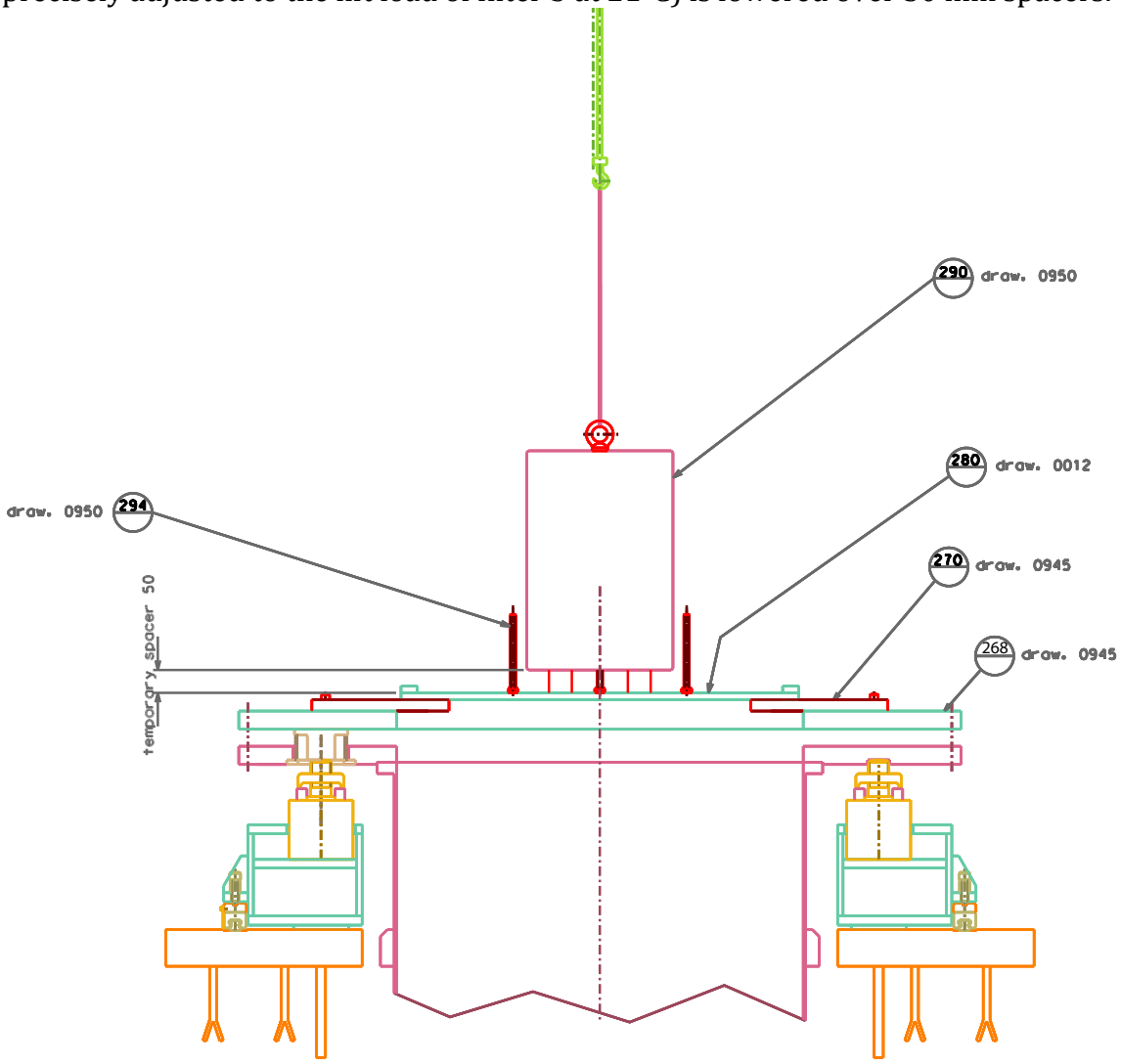
Bellow arrestors are mounted in preparation of vacuum tests.
The lower dome is raised by means of the two cranes of the lower chamber so that it can be hooked to manual chain hoists, and connected to the lower spool.
Note that in the lower chamber two independent cranes, one of each side of the vacuum chamber are needed, because of the suspension chimney impeding their movement.



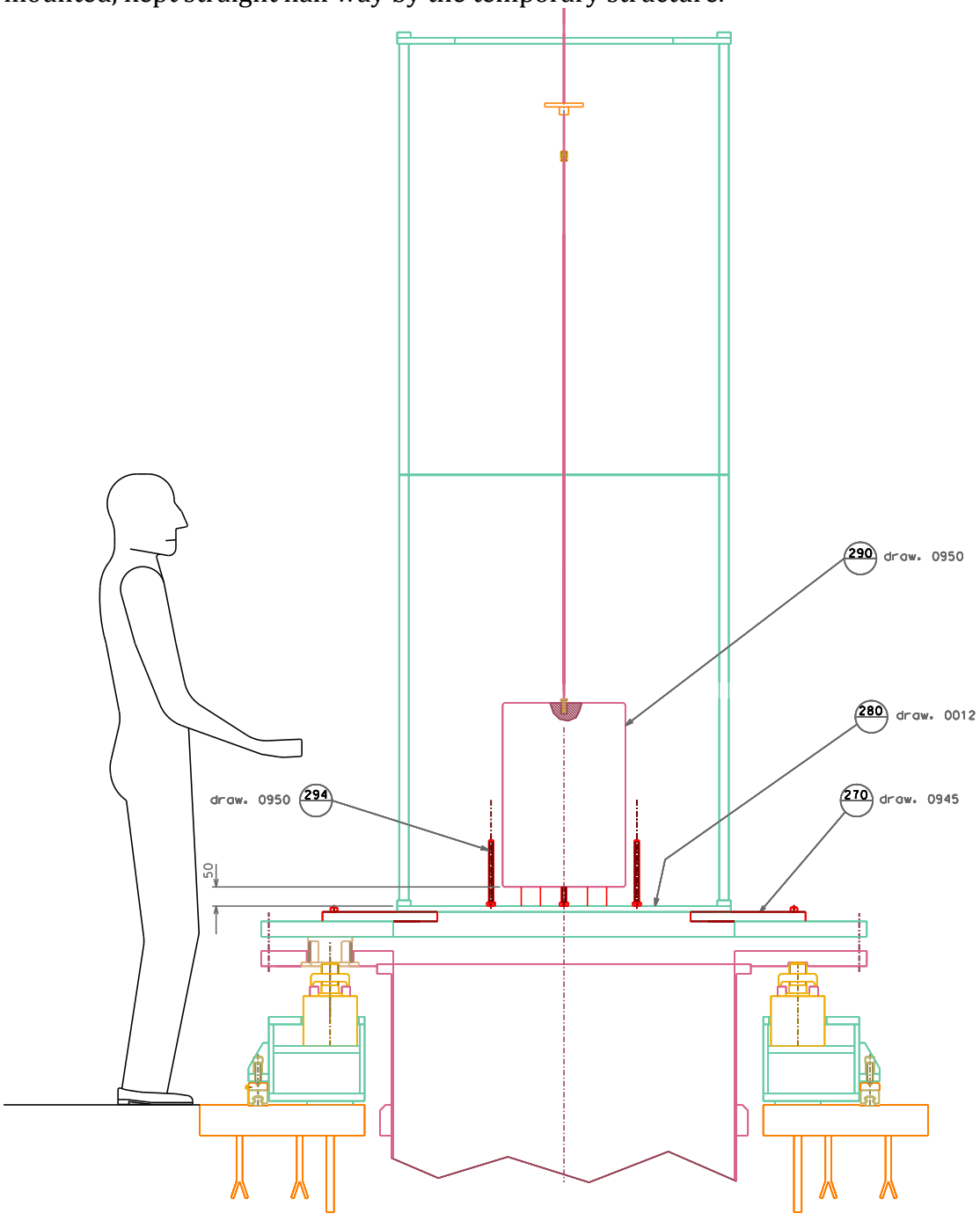
The top service spool and dome are mounted on the bottom flange. All viewports are sealed. The chamber is connected to a vacuum pumping unit.
When the vacuum assembly is closed it is UHV tested for leaks, to make sure that all unreachable flanges are perfectly sealed. Plastic foil lining taped to the cylindrical surface of the spools, and thin plastic tubes allow blowing Helium around each unreachable flange, to identify location of possible leaks.
After the vacuum tests are successfully completed, the top and bottom caps are removed to continue the installation of the seismic attenuation hardware.



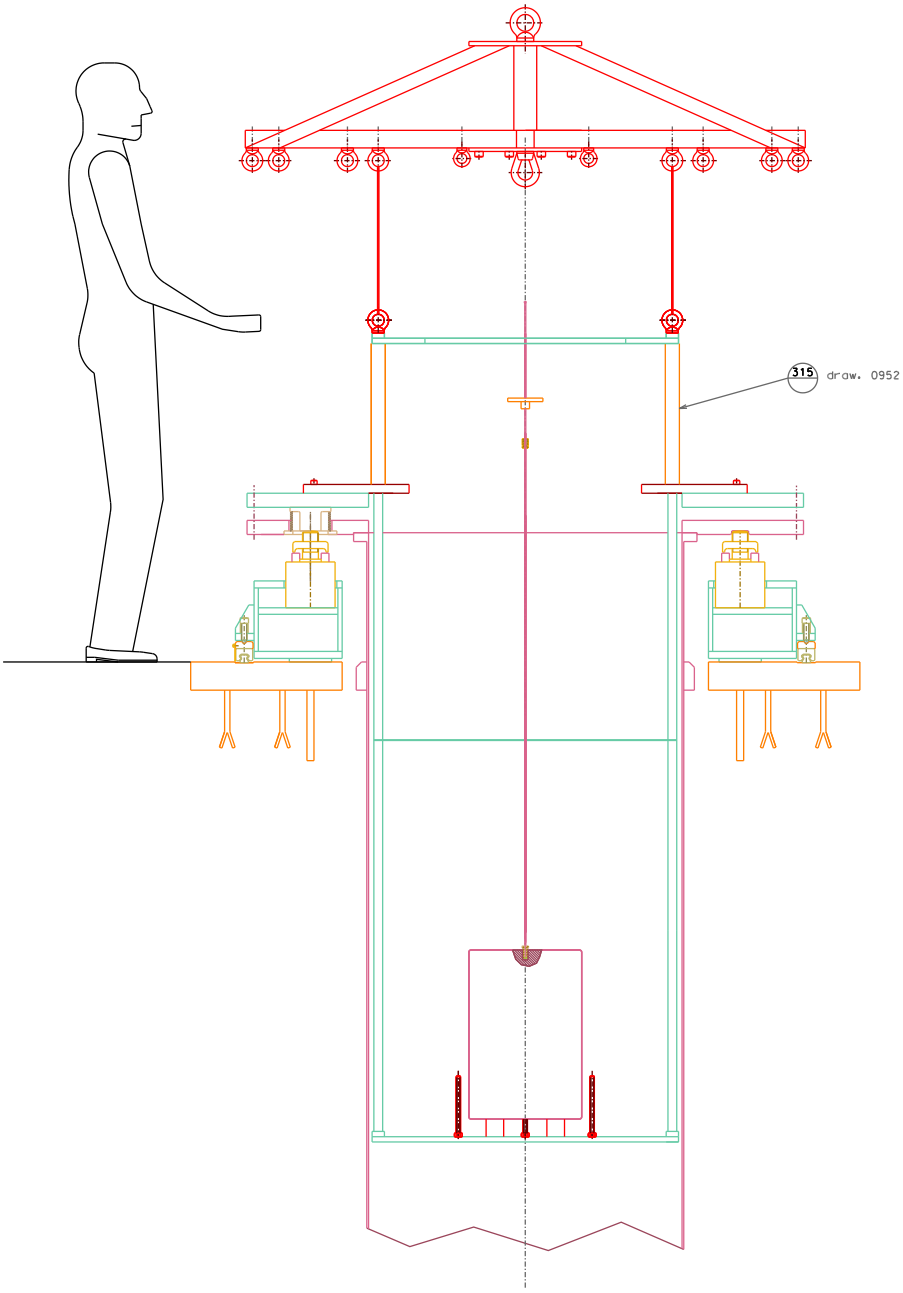
Step 1:
A temporary plate (268) is placed on the inverted pendulum bellows and temporarily bolted to the base flange. Temporary brackets (270) and a safety base plate (280) are positioned on the plate. The ballast mass (290, weighting~300 kg, precisely adjusted to the lift load of filter 3 at 21°C) is lowered over 50 mm spacers.



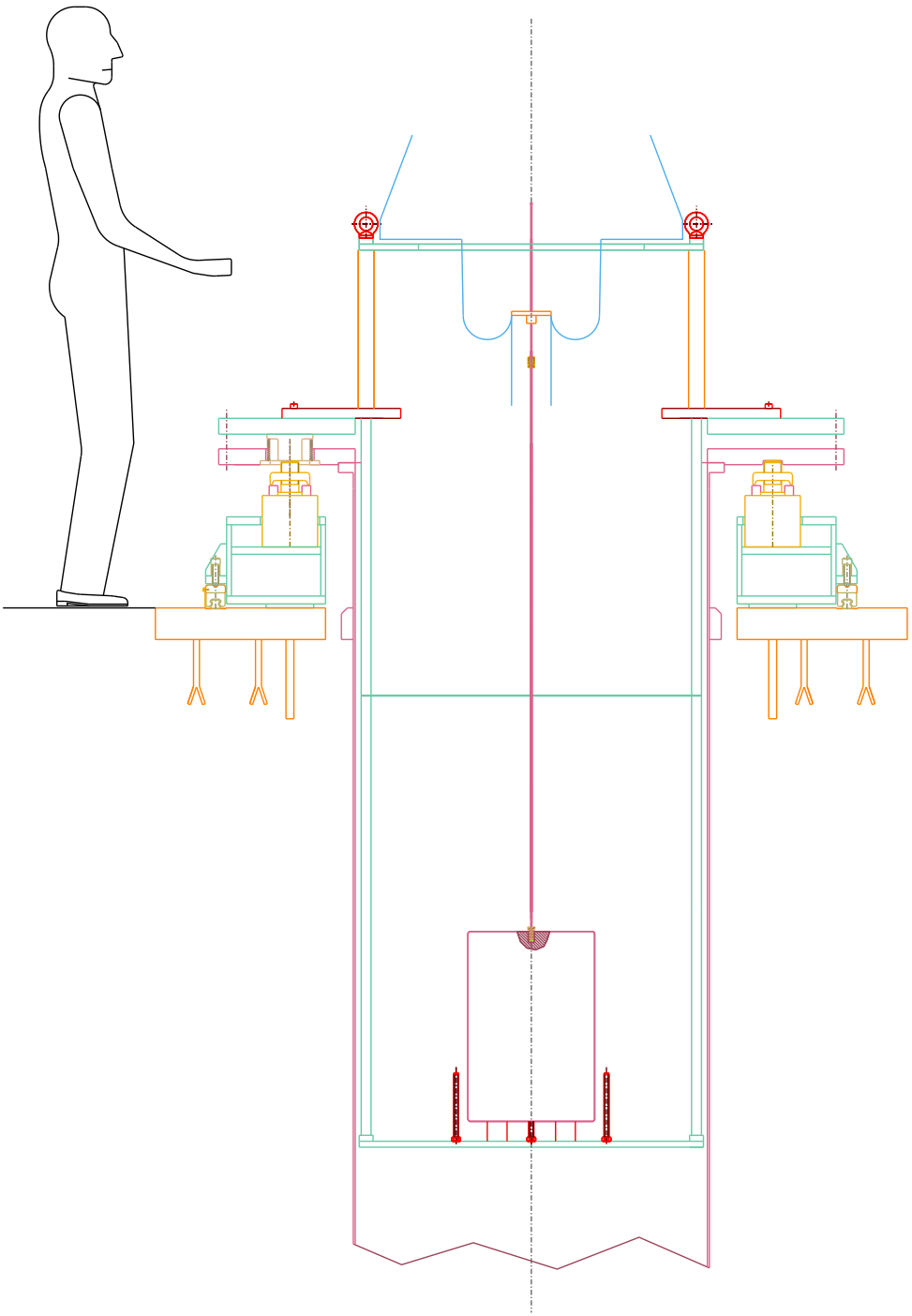
Step 2:
The temporary safety structure is built, the ballast suspension wire (279, 281) is mounted, kept straight half way by the temporary structure.



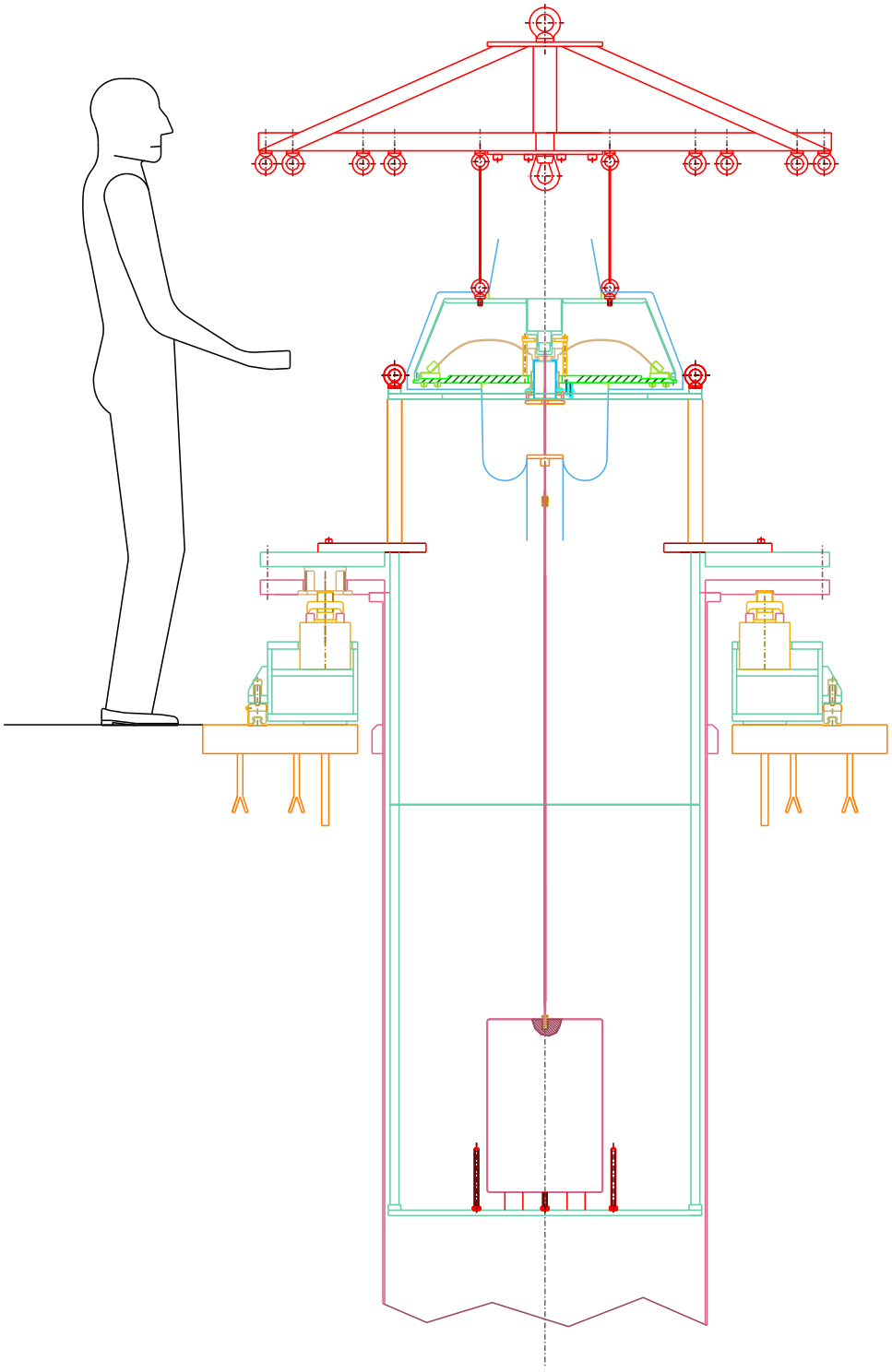
Step 3:
The temporary ballast safety structure is lowered in the well ¾ of the way, and fastened with three spacers supported by the shelves 270.



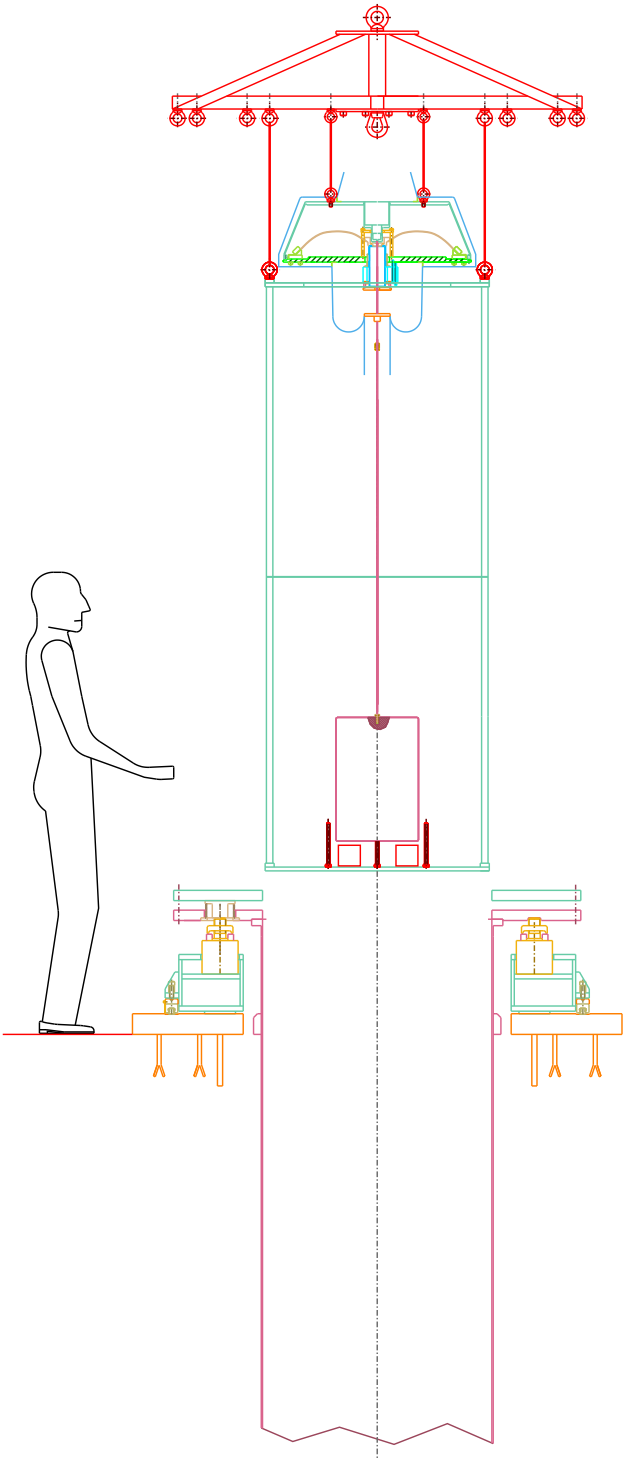
Step 4:
Electrical cabling is performed from the lowest spider to above the safety structure plate (rolled cables above and below are not shown).



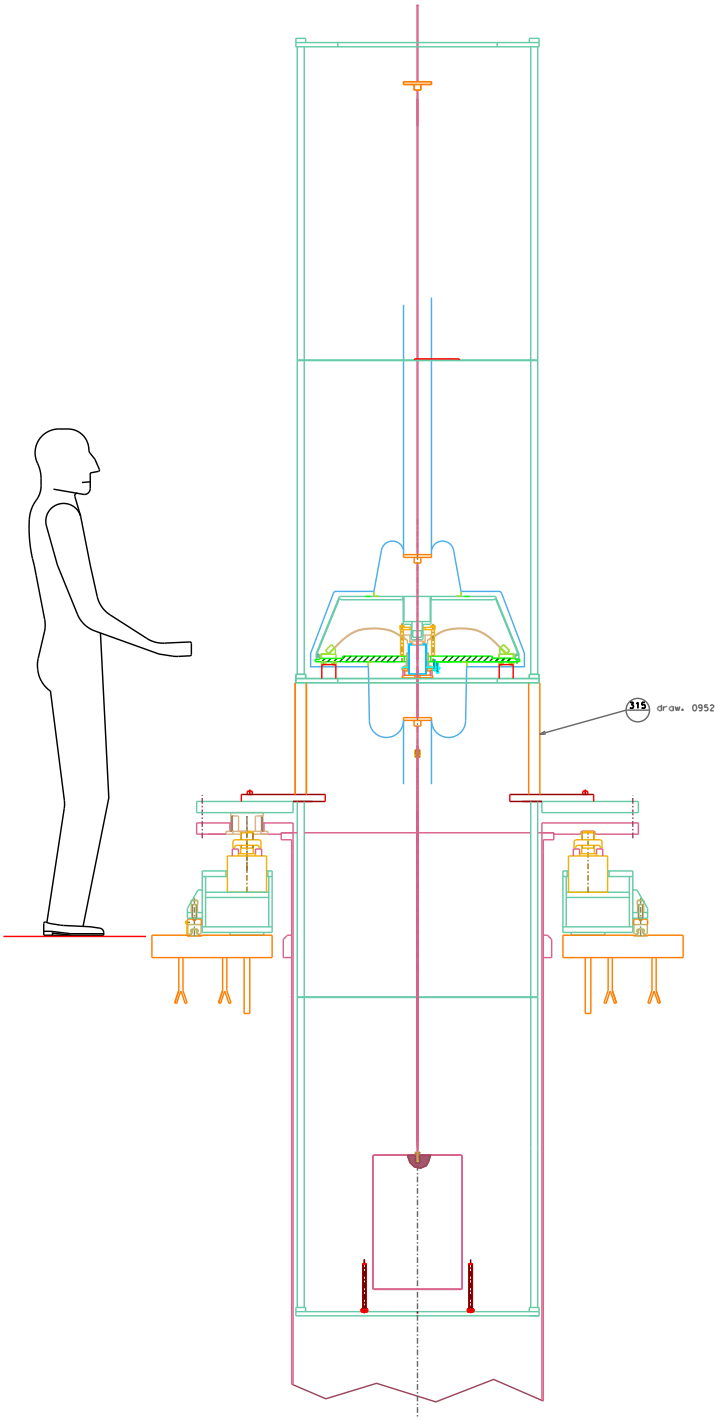
Step 5:
Filter 3 is craned in and connected to its suspension wire, then raised ~60 mm.



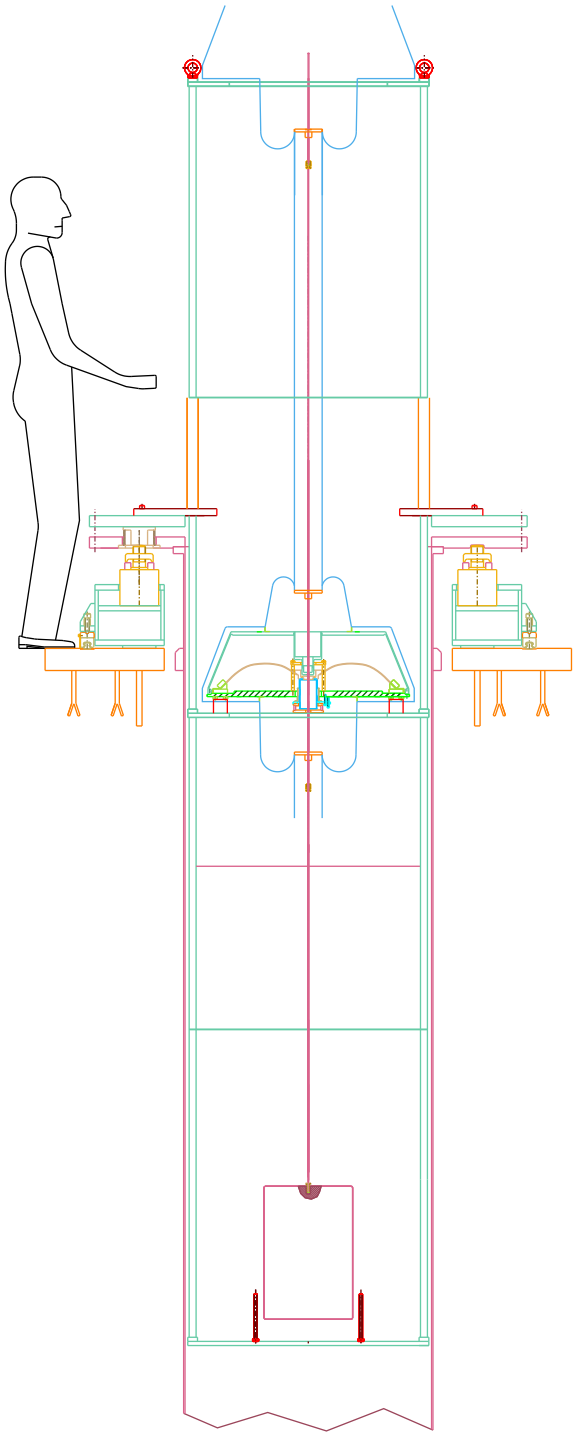
Step 6:
The safety structure is attached to the crane as well, and lifted, shelves and spacers removed. The chain is raised to allow for the extraction of the blocks below the ballast mass.



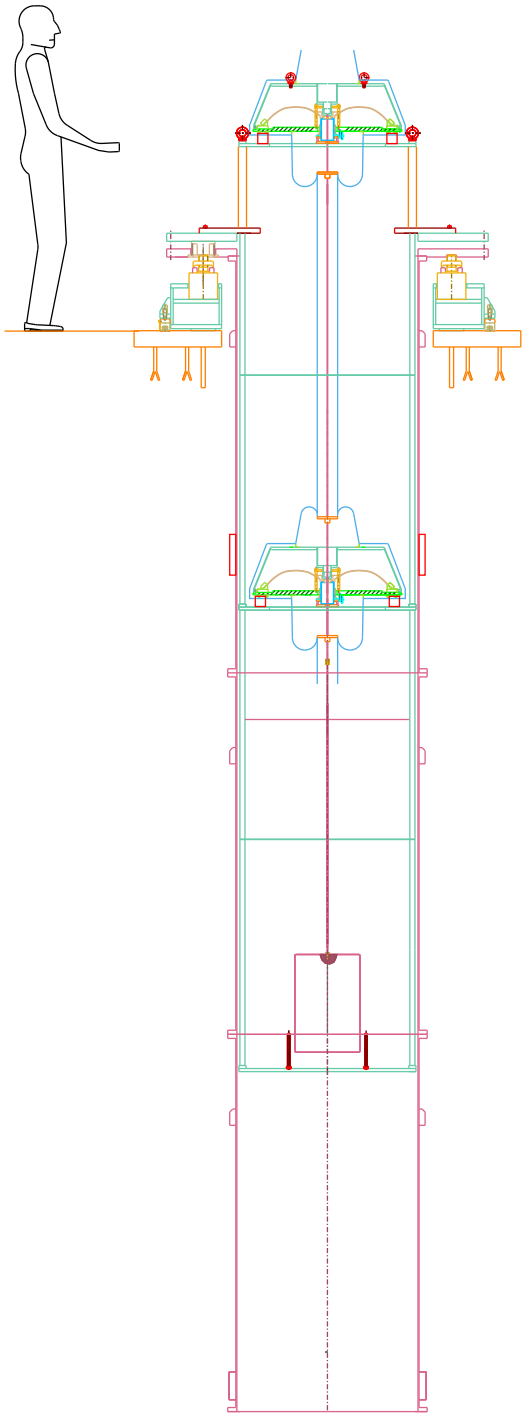
Step 7:
Then the system is lowered again in the well on its shelves and spacers.
Electrical cabling is completed until above the safety structure of filter 2.
At this point the functionalities of filter 3 are tested, using the LVDT and actuator.
Then the safety structure above filter 3 is built, its suspension wire is mounted, the electrical cabling is completed up to the separating plate above filter 3.



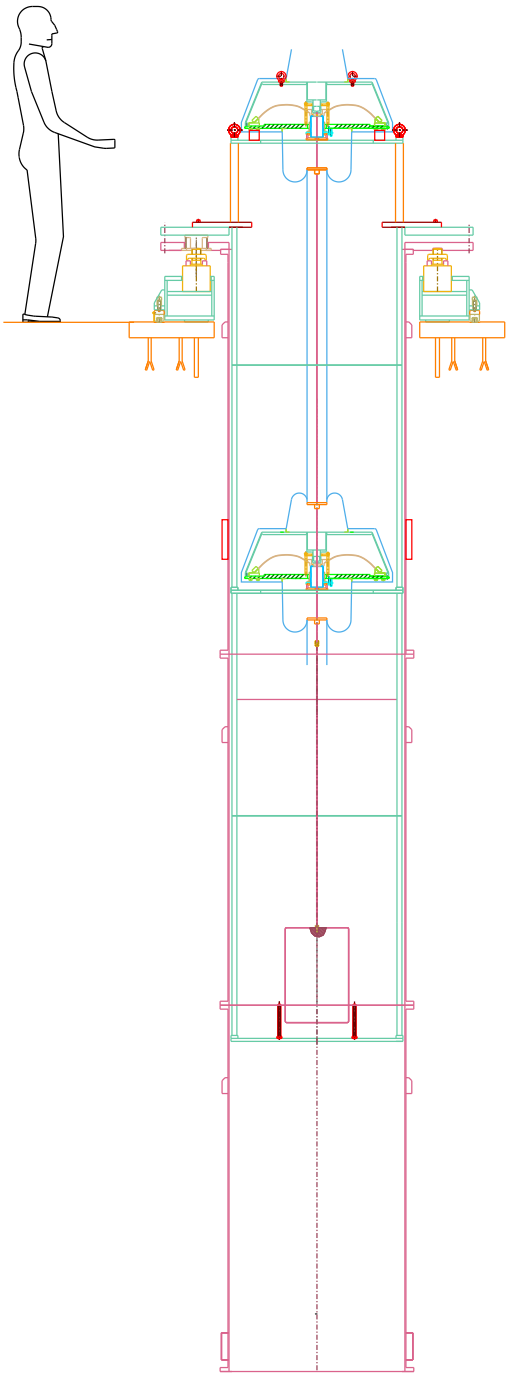
Step 8:
The structure is lowered another half step and the cabling up to filter 2 is completed.



Step 9:
The filter 2 is craned in, connected to its suspension wire, then mounted on spacers.

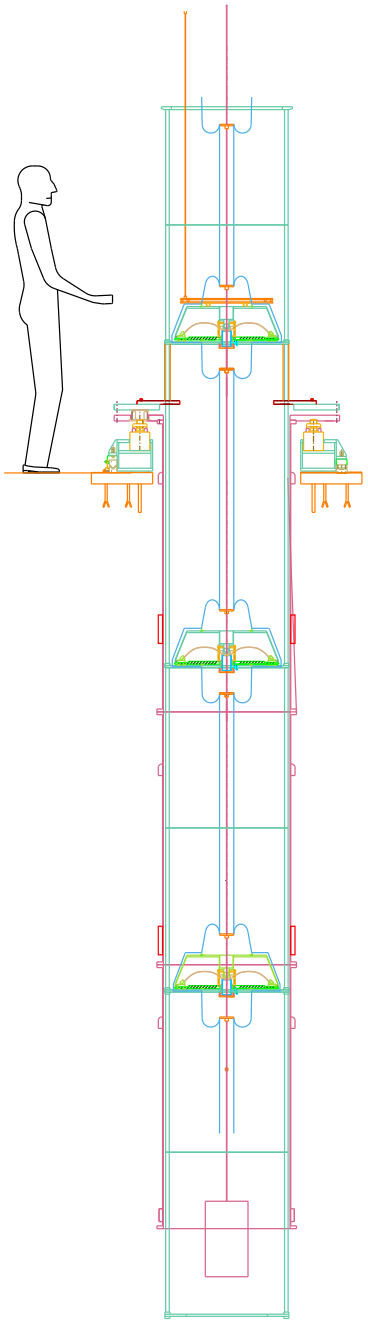


Step 10:
Then the safety structure is hooked, like in step 6 raised 2 m to allow removal of the blocks below filter 3, and the holder keeping the wire straight. The structure is lowered again on its shelves and spacers like in step 7.
At this point the functionalities of both filter 2 and 3 are tested.

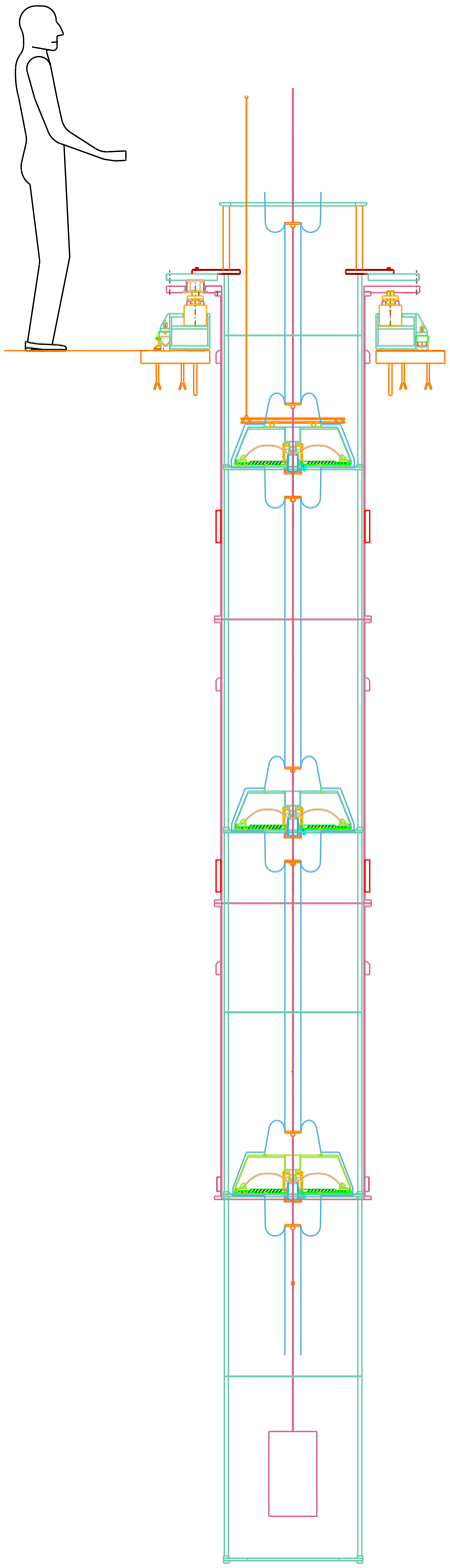


Step 11:
The procedure is repeated like in step 8, 9 and 10 for the installation of filter 1

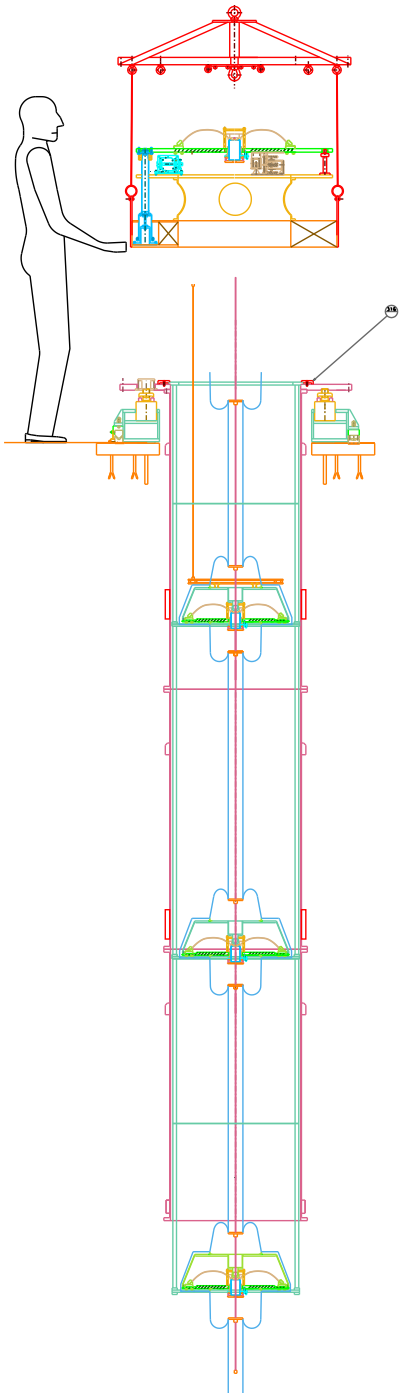
Step 12:
The assembly between filter 1 and the top filter is somewhat different because the magnetic damping ring and its suspension wires need to be implemented.
The safety structure between the Top filter and filter 1 is assembled, as well as the suspension wire of filter 1, electrical wiring, in a way similar to all preceding filters. The only difference is that the Eddy current damping ring and its suspension wires are mounted and sat on the corresponding copper ring on filter 1.



Step 13:
The structure is lowered another step in the well for wiring.

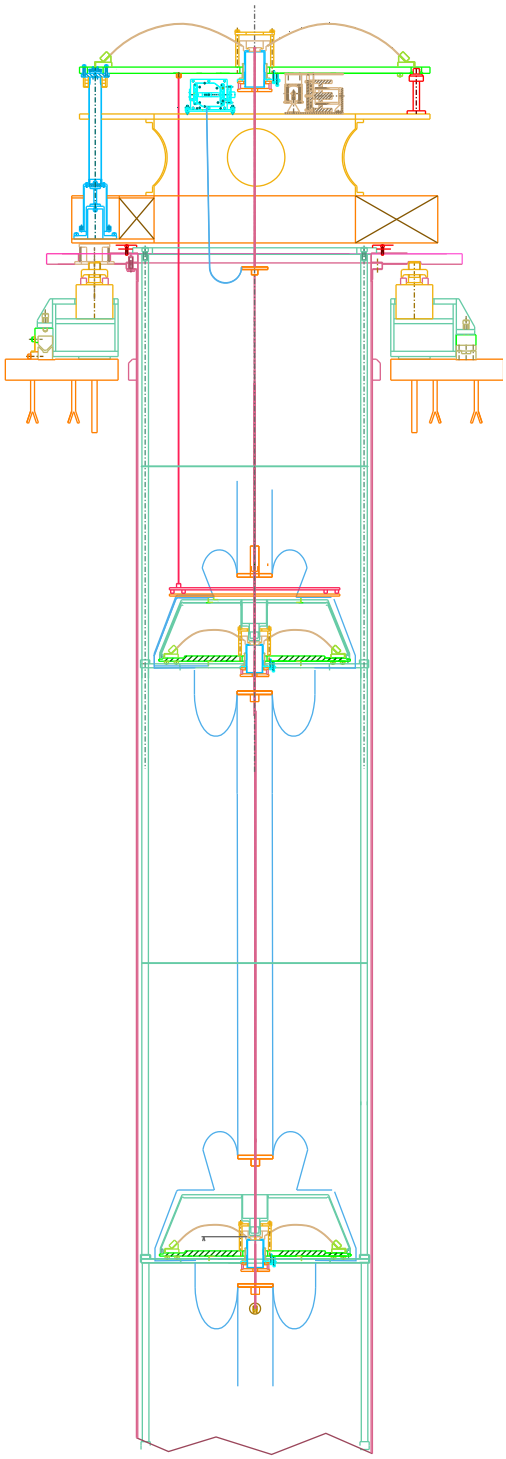


Step 14:
The structure is lowered in place and bolted down (316) with its proper orientation.
The temporary service ring used to support the safety structure is removed.
The top filter is brought in. Even when the top filter unit is sitting on its bellows, it cannot be attached to its payload because it sits on the safety structure, 10-20 mm too low.

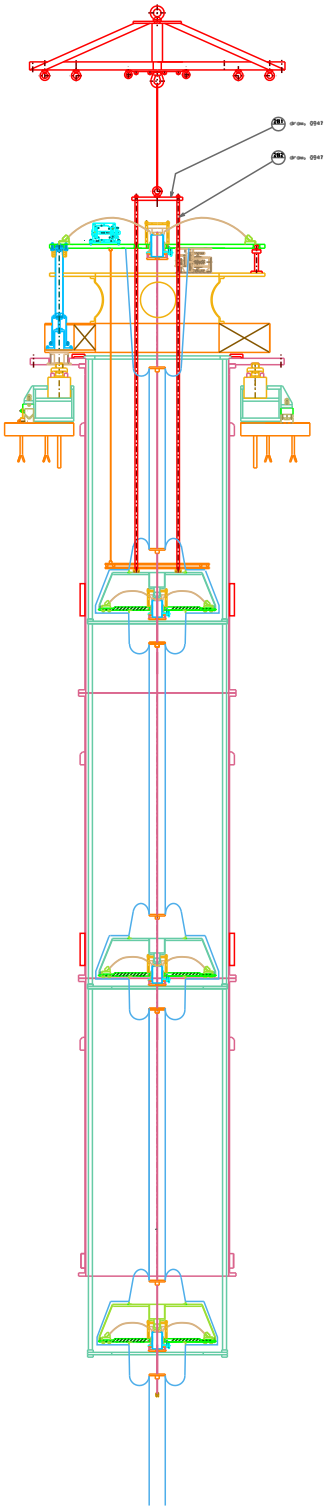


Step 15:

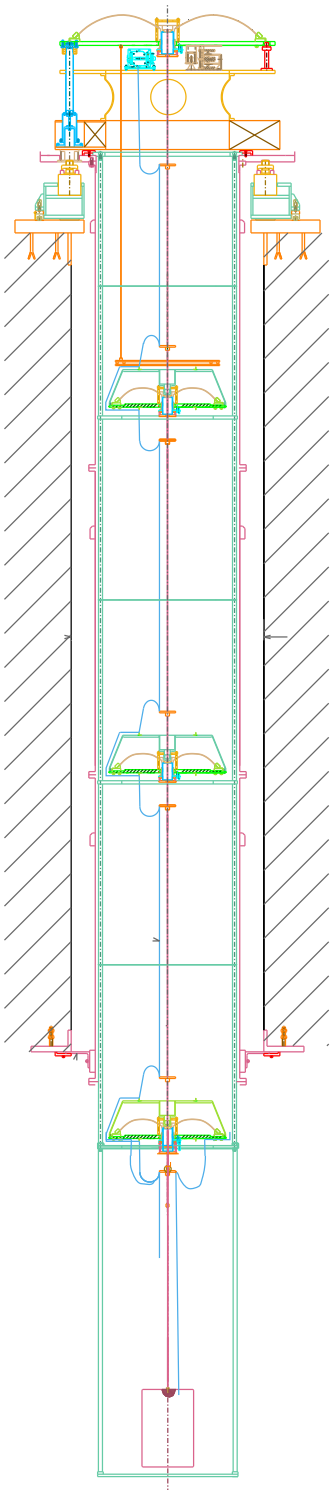
Even when the top filter unit is sitting on its bellows, it cannot be attached to its payload because it sits on the safety structure, 10-20 mm too low.



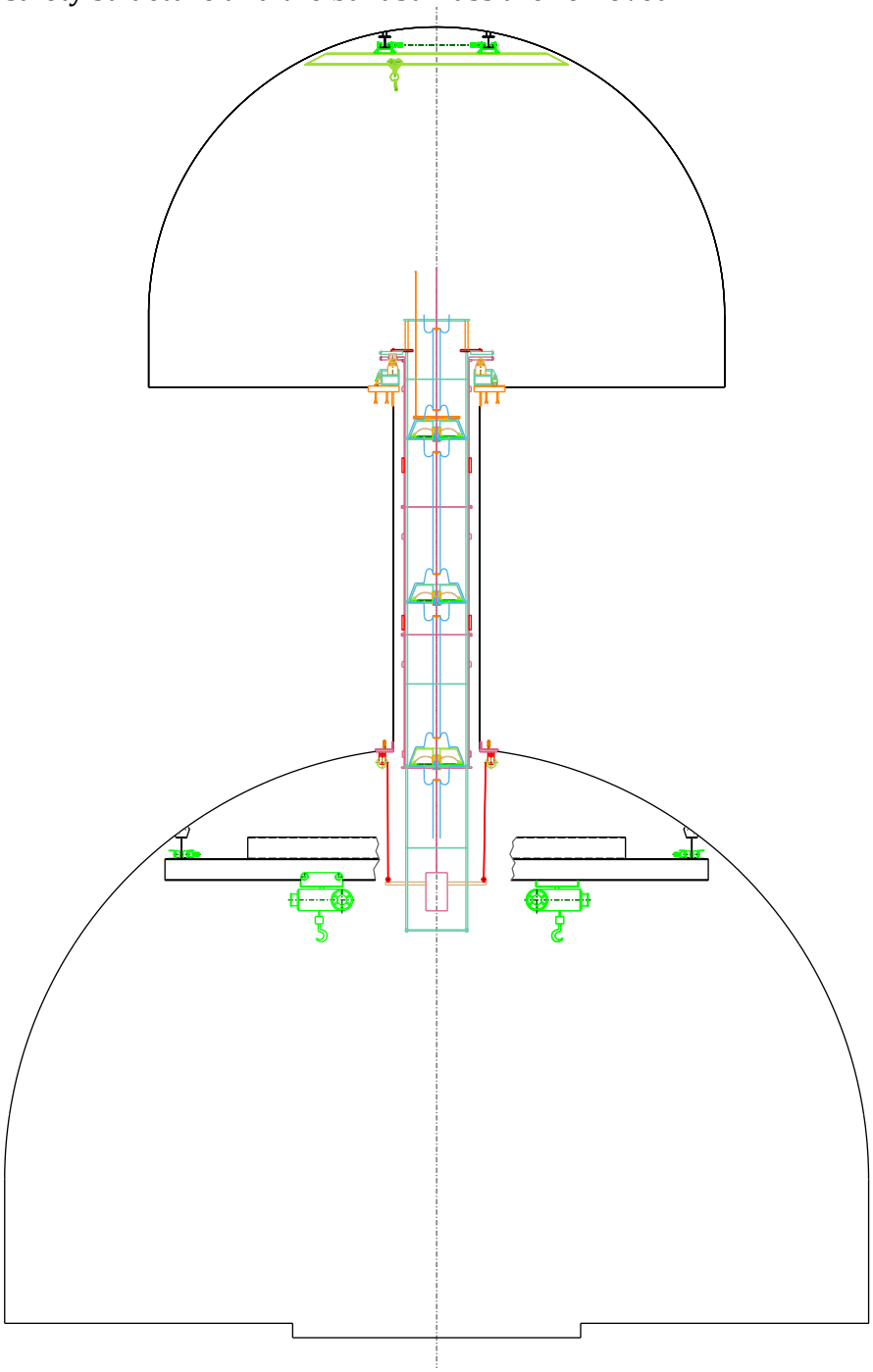
Step 17:
Special lifting rods (281 and 282) are inserted through holes into the top filter, are screwed into the roof of filter 1, and used to lift it, so that its wires can be attached to filter zero.



Step 18:
After lowering filter 0 in its final position and fastening it, the functionalities of all filters are re-checked.
Then the Inverted Pendulum table is leveled and the Inverted pendulum is tuned.
The entire chain functionalities are tested.



Step 19:
The 300 kg payload and its temporary safety structure extend in the lower chamber.
The ballast mass is lifted with the help of the small hoists already used to mount the lower dome. The suspension wire is disconnected at the wire junction box and the temporary safety structure and the ballast mass are removed.



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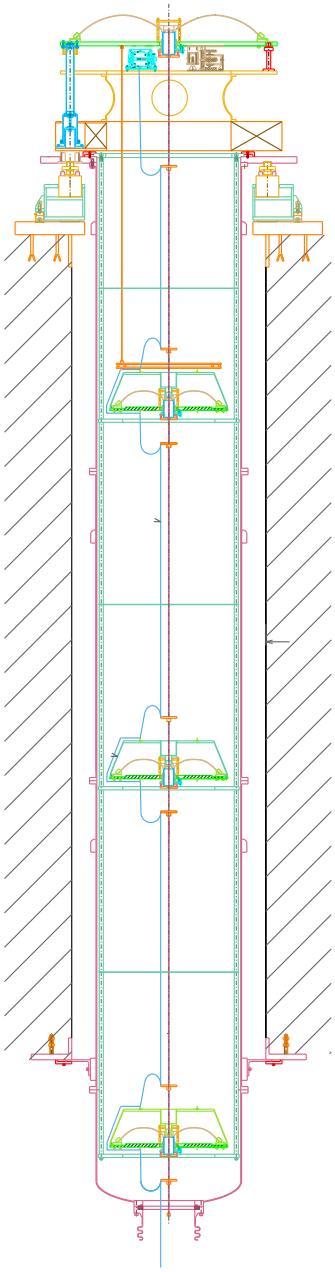
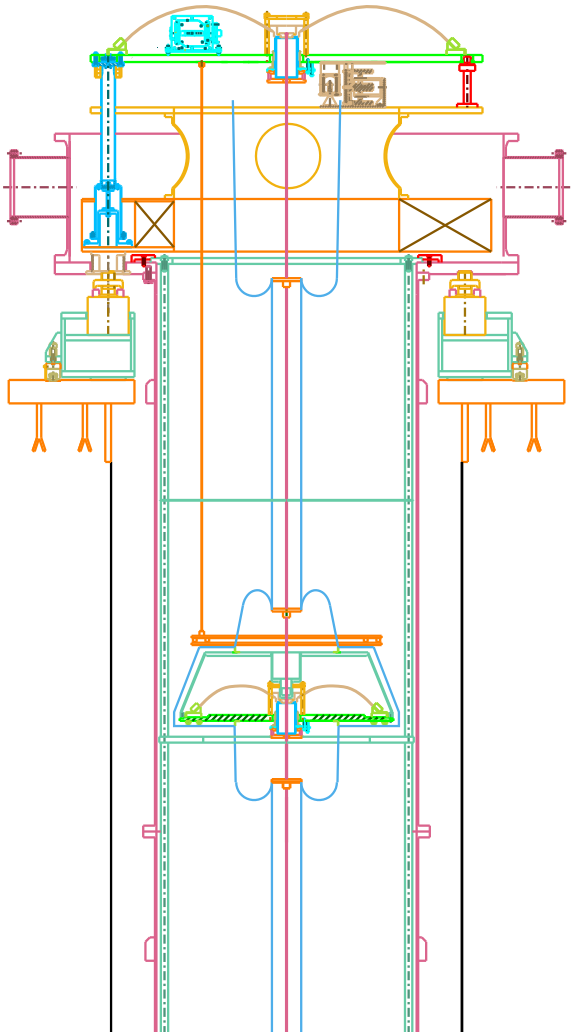
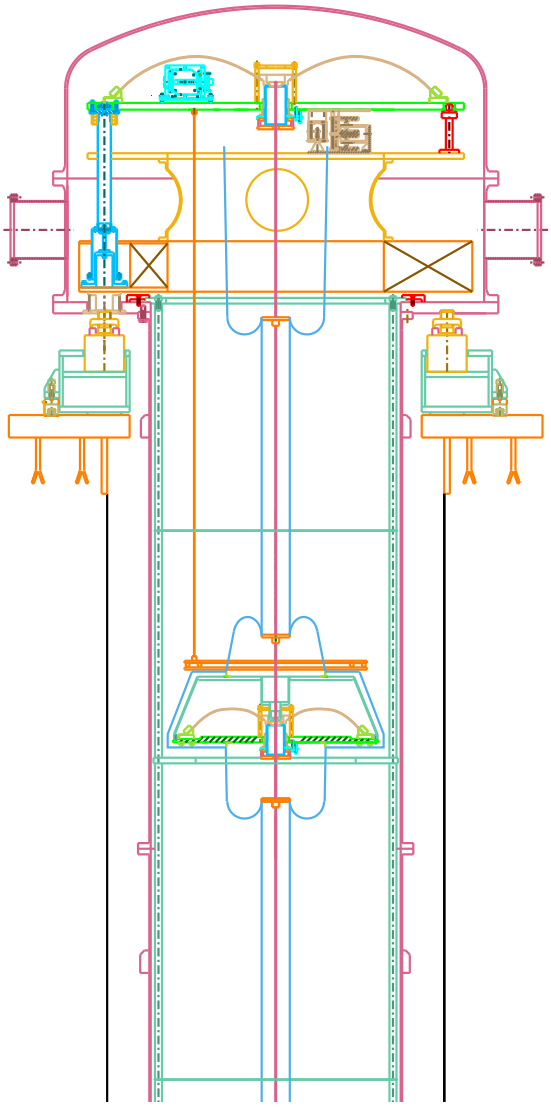
Step 20:
The lower dome is installed.



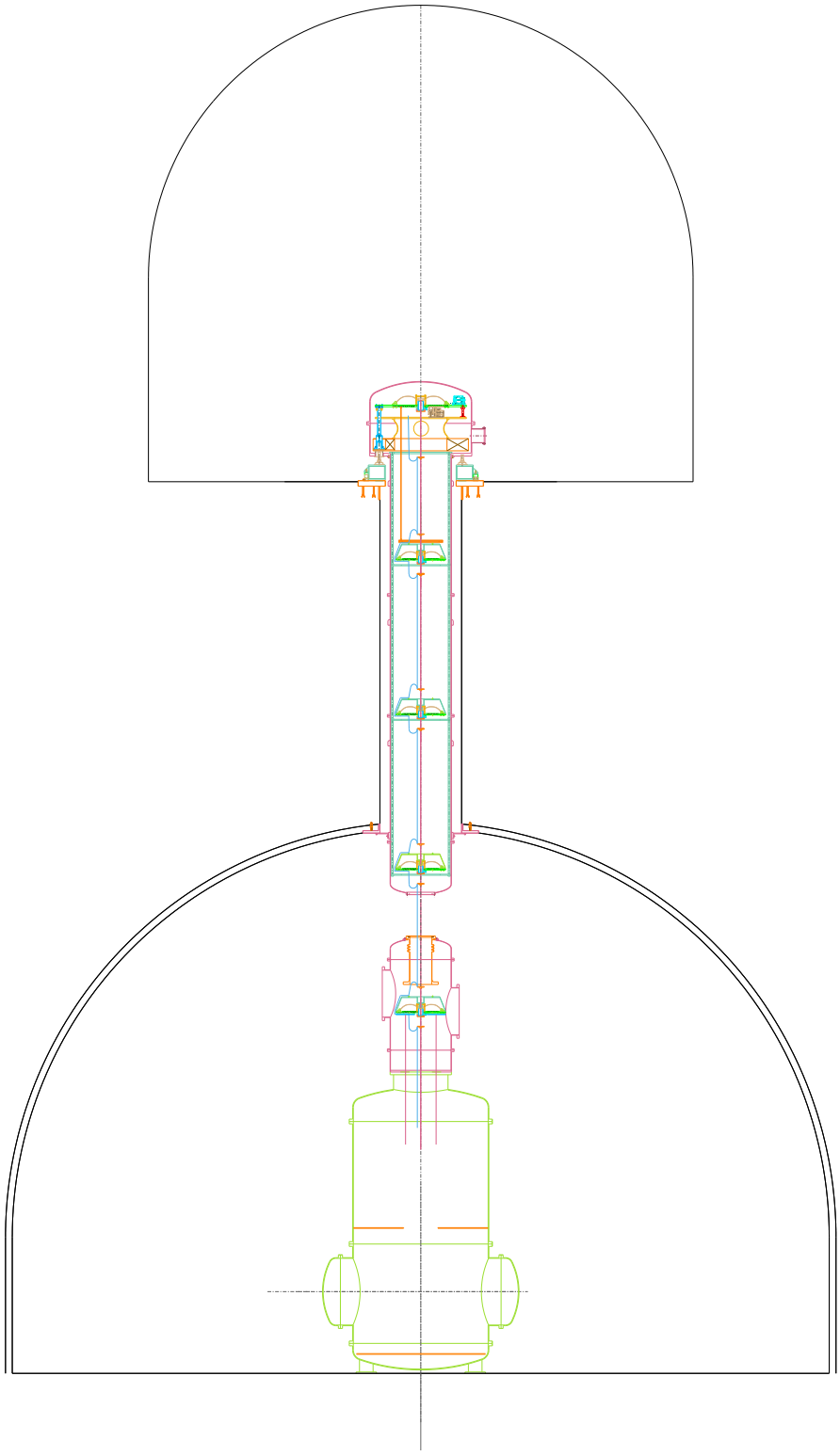
Step 21:
The flange spool is mounted on the top layer and the cabling is performed.



Step 22:
The top dome is installed and the system is ready for installation of the payload



The vacuum chambers are positioned (note only the top, pink, part needs to be removed to insert the SAS chain). Filter 4 is inserted on a stretcher, connected at the junction box and electrically wired. Then the vacuum neck above is closed.



Finally the intermediate mass and the mirror are inserted and suspended.