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CUORE EXPERIMENT: TOWERS' CONSTRUCTION SYSTEM

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Abstract

CUORE experiment, predicted to be installed at "Gran Sasso" National Lab, consists in a detector placed inside a large cryostat. This detector is composed by 1000 very pure crystals, organized in a 20 copper towers system. The main problem of this assembly, is to integrate these towers, keeping a radioactively pure environment around crystals and copper frames, in order to don't compromise the detector functionality. This job describes how has been decided to proceed, in the LNGS clean room, for the tower's assembly.

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1 INTRODUCTION

CUORE (Cryogenic Underground Observatory for Rare Events) is a neutrino physics experiment, that will be installed in LNGS. It consists in 1000 extremely pure TeO_2 *crystals* (50x50x50 mm), assembled inside 20 towers made by very pure copper frames. These towers will constitute the CUORE detector, once put inside the underground large cryostat at *Gran Sasso National Lab*. One of these tower is shown in picture 1:

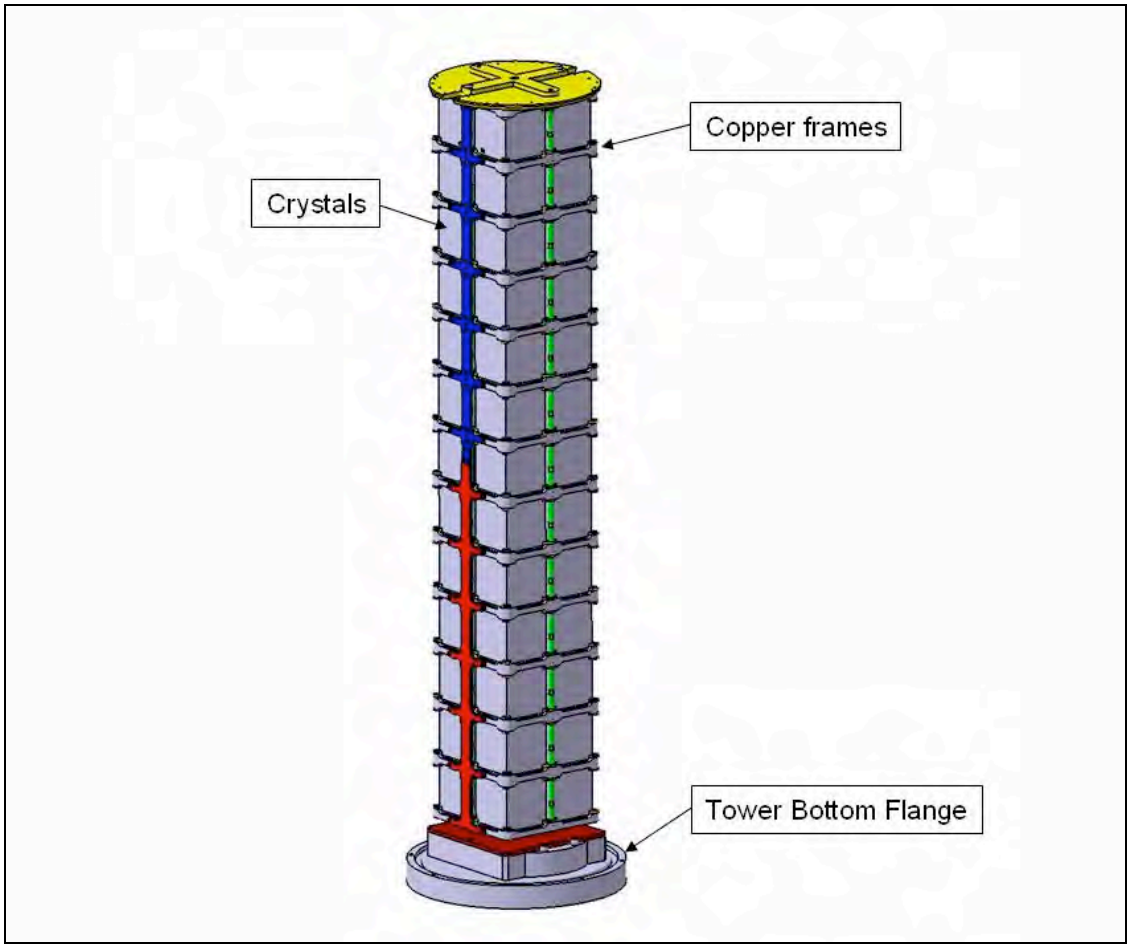

Fig. 1

Any material in nature have a bulk contamination of some long-live isotopes (Uranium, Thorium, Potassium among the others). This contamination is unavoidable and determines the main source of background for the CUORE experiment.

Of paramount importance for CUORE is to keep such activity at an extremely low level. To reach this goal particular care must be put first in the choice of the materials to be used (in CUORE copper, Te and Teflon) by looking for material that for composition, provenience etc. are already the most radio-pure on the market (those with the lowest natural bulk activity); by choosing the cleanest methods to machine and produce the components; foreseeing a cleaning procedure to strike down the residual surface contamination and last, but not least designing an assembly procedure and tools able to preserve such the extremely high level of radio-purity reached and protect the pieces from any recontamination.

Recontamination can be induced by touching the pieces with not as clean tools, by exposing the pieces to Air, by cosmic rays.
The last, the cosmic rays, provide a negligible contribution in an underground lab as LNGS. Handling procedures and exposition to the Air must be the main concern designing the assembly line.
The Air, in particular, contains Radon, a radioactive gas normally emitted by rocks and present almost everywhere. At LNGS the Radon activity have been measured and is of the order of 20-30 Bq/m^3.
Another constraint to keep in mind during assembly, it's to ***avoid any kind of mechanical shocks and accelerations***; it means that an extremely carefully handling is required, with very smooth movements. In fact the 20 towers will be put inside a cryostat and kept at T=10 mK; while the assembly will be realized at 300 K (normal environment temperature). It means that the structure is dimensioned in order to send in contact the several parts, with temperature's decreasing contraction's effect; only in cold the tower's structure will be rigid and stiff. Therefore, during the normal handling and assembly at T=300 K it won't be rigid but fleeting, and any sudden movement could make it crash or damage it.
Giving these parameters and operative constraints the whole assembly chain have been designed to be a "zero-contact" procedure where zero contact means: to avoid any contact of any pieces with the air (or not-controlled atmosphere) along the whole process, minimize their handling, minimize their lifetime out of LNGS, and have the pieces facing or touching low activity materials only. The whole ***tower's construction process*** will consist in 4 separate phase:

1. *The tower's mechanical assembly phase: copper frames and crystals, both cleaned will be assembled in order to form the tower structure.*
2. *The tower's cabling phase*
3. *The tower's bonding phase: a very thin gold wire (20 µm diameter) will be applied on each chip of each tower level*
4. *The tower's storage and transport phase, keeping a pure contact environment*

The principle chosen is a multi glove-boxes system with a common interface to a lift/storage tool called "*garage*", used to safely house the tower all over the assembly period and provide all the tower motions (rotation + vertical translation) needed by glove-boxes operators to manage any of the assembly actions. The garage, just below the common operative interface, allows to hide the tower in the underneath pure and close environment, during the instrument's changing on the table surface, making it ready for the following phase. This system will be described in details, in next paragraph. The space over operative table surface will be a close environment, using specific *Plexiglas Glove-Boxes*, one for each phase, in order to allow only operator's hands access, with particular gloves. Each glove box will have a particular shape and connection, able to host the instruments of that procedure's phase. The material is *Plexiglas*, preferred respect the normal glass, presenting a lower radio-activity.
This document describes the preliminary study and design about the towers construction system, strictly respecting all these requirements. Presently 2 elements are completely defined in this study: the *Working Plane*, and the *Removing Glove Box* (phase 4). That's why study began from the 4^{th} and 3^{rd} phase, since they are the most critical and the phases introducing the greatest number of limits and constraints. In fact the bonding procedure put strict constraints about the Working Plane geometry, and the removal operations determine the basis plate of tower's movement.

2 WORKING PLANE

The towers assembly will be realized, on a clean *Working Plane* and inside a radioactively-pure environment. The insulation is guaranteed by specific *glove-boxes*, installed using a flange-O-ring connection on the working plane border. The glove-boxes will be 4, one for each phase allowing all the handlings required, and they will be made in Plexiglas. It's important to explain that only the operator's hands will enter inside the glove box, using specific hand gloves. Presently only the glove box referred to the fourth phase is almost defined, and it will be described in details, inside a specific paragraph. The procedure chosen for the several construction phases, consists mainly in the possibility to move vertically and rotate the tower assembled on a specific lifting system, called *garage* as told before, already defined and realized. This system will move vertically the structure from a pure environment, able to keep uncontaminated the tower during the several handlings, to the upper surface of the working plane, keep uncontaminated by the glove boxes as explained before, and which represents the effective operative zone. As shown schematically in the picture 2, the working zone where the operators will work, is exactly the top surface of the working plane (A), upon the garage (B).

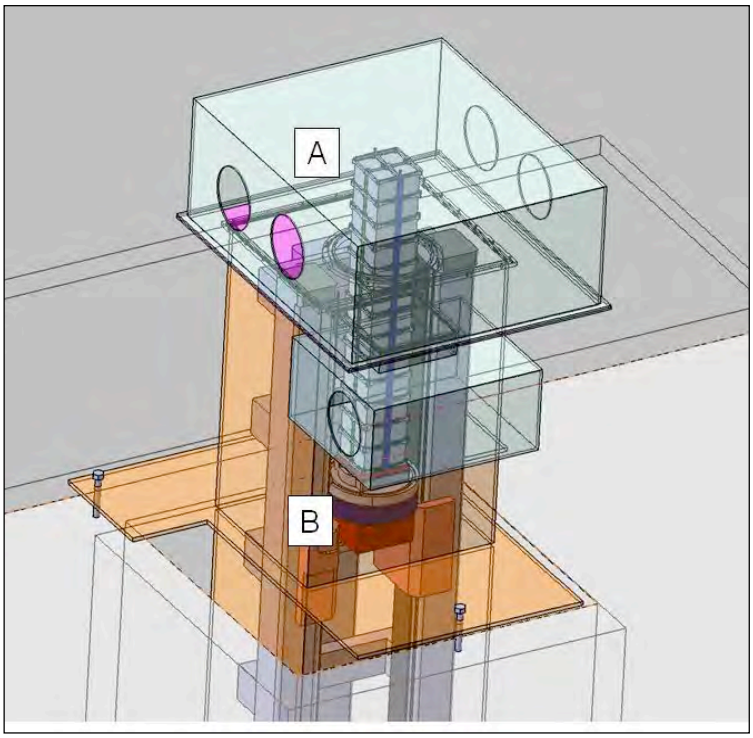

Fig. 2

In the picture, referred to mechanical assembly phase, it's represented the glove box that in future will keep insulated the working zone. It's clear that the tower will come out through a porthole of the working plane itself. It will be assembled level by level, stepping down at each level completed; after the construction finishing the hole will be closed and the tower will be kept in a pure closed environment (Nitrogen) inside the garage. Each glove box presents openings on the sides, due to necessity to apply the gloves for the operator's hands access. Working Plane presents a shape directly connected to the several demands of each moment of procedure; in particular the bonding phase has determined the hole's dimensions and the

threaded holes patterns. In fact there has been a very long dimensional study in order to place correctly the bonding machine, making it able to reach the chips on the tower's sides.
The Working Plane, (pink part in the previous and following images), must present a very specific pattern of machining operations, to guarantee a perfect functionality. In picture 3 it's shown the Working Plane drawing:

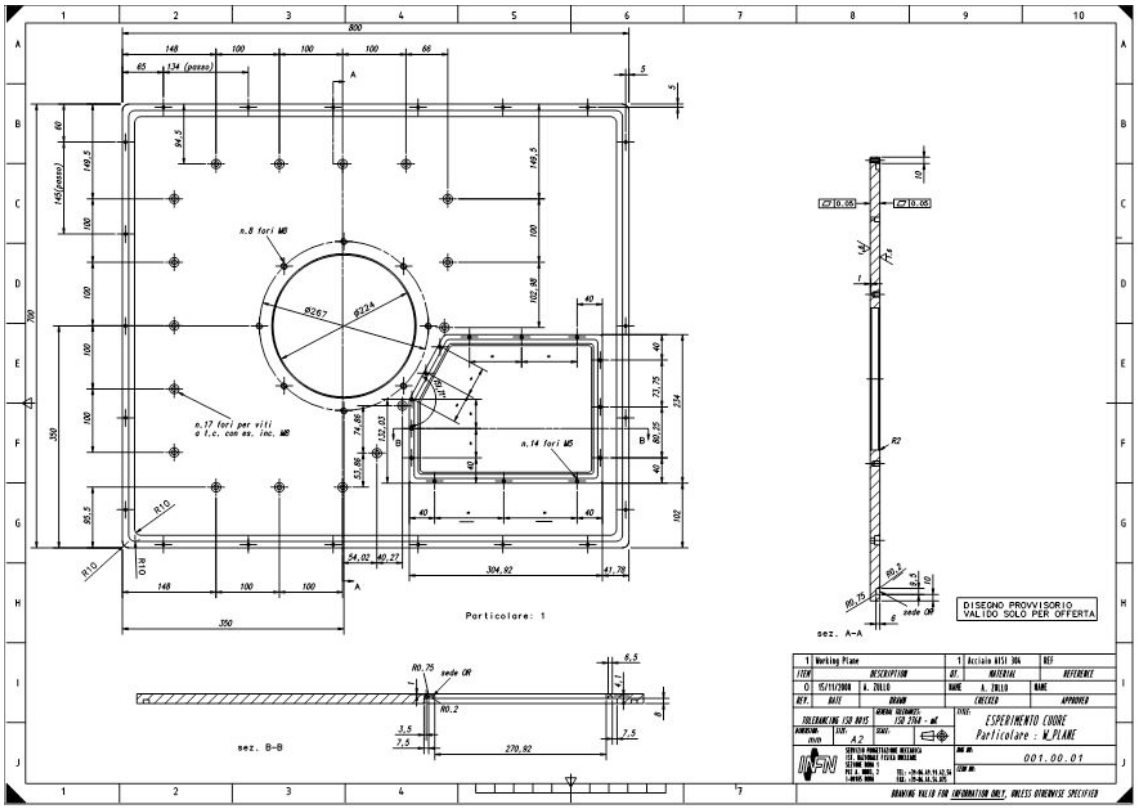

Fig. 3

The central hole is the tower vertical access point, on the plane surface, coming up from the garage cavity. The complex-shaped hole, just on the right side of the central hole, is the Bonding Machine operative zone, referred to phase 2 of the construction; its position, shape, and dimensions are due to Bonding Machine geometry. In fact the machine itself must be able to reach the tower side and realize gold-bonding (20 μm diameter gold wire) on micron-scale chips placed on towers side. The Bonding Machine is schematically reported (brown) in picture 4.

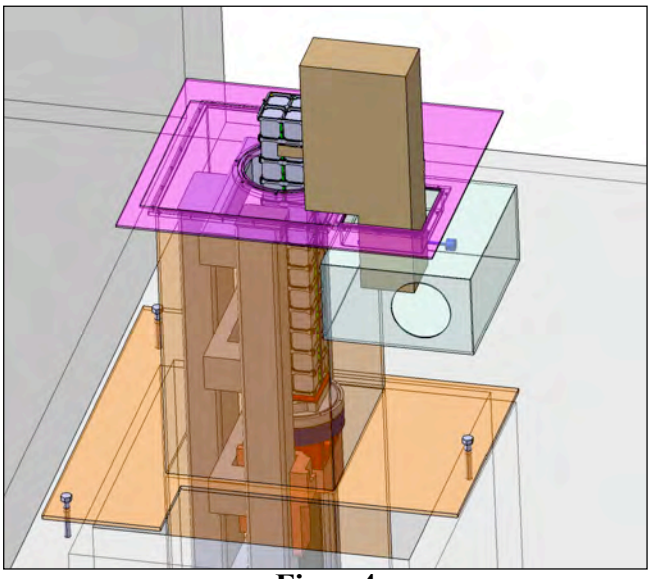

Fig. 4

It's important to consider that the Bonding Machine, applied only during the second phase, will have to reach 2 different positions on each opposite tower's side, like shown in picture 5, so it will be able to move horizontally in a range of **±40 mm** (the distance between them) to perform its function.

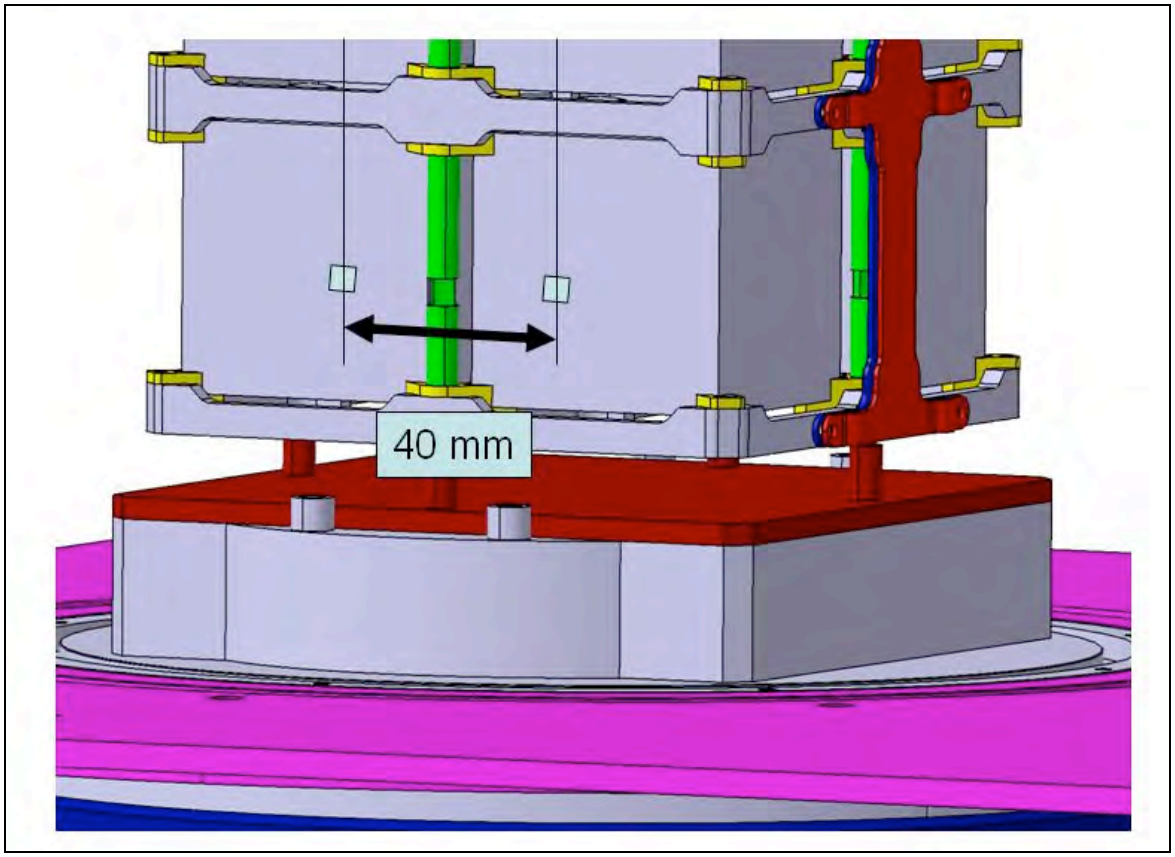

Fig. 5

For this reason there will be other threaded holes patterns able to fix all the linear bearings, necessary for this machine motion. The garage will rotate tower by 180° in order to present the other side's chips to machine's bonding tip. This combination of movements will allow job's execution.
The Working Plane, that's physically a stainless steel AISI 304 machined table, presents some threaded holes pattern, each one with a specific function.

- The border pattern is for the flange-O-Ring connection of the several glove boxes of each phase.
- The bigger complex shaped is for the insulating connection between the garage and the Working Plane bottom face.
- The circular central pattern is for the Removing Glove-Box application, that's the fourth phase of the process.
- The complex-shaped pattern on the right side is for the Bonding Machine insulation, as shown in the previous image.

3 REMOVING GLOVE BOX

As discussed before the second element already defined is the glove-box able to remove the tower, once completed each operation of assembly and electronic cabling: the *Removing Glove Box*. The main problem of this study, as discussed before, is to guarantee a "Recontamination-Free" handling; in order to respect this constraint a concentric system of O-rings has been studied. In the picture below it is represented the *Removing Glove Box (yellow)*, applied on the Working Plane with the tower inside:

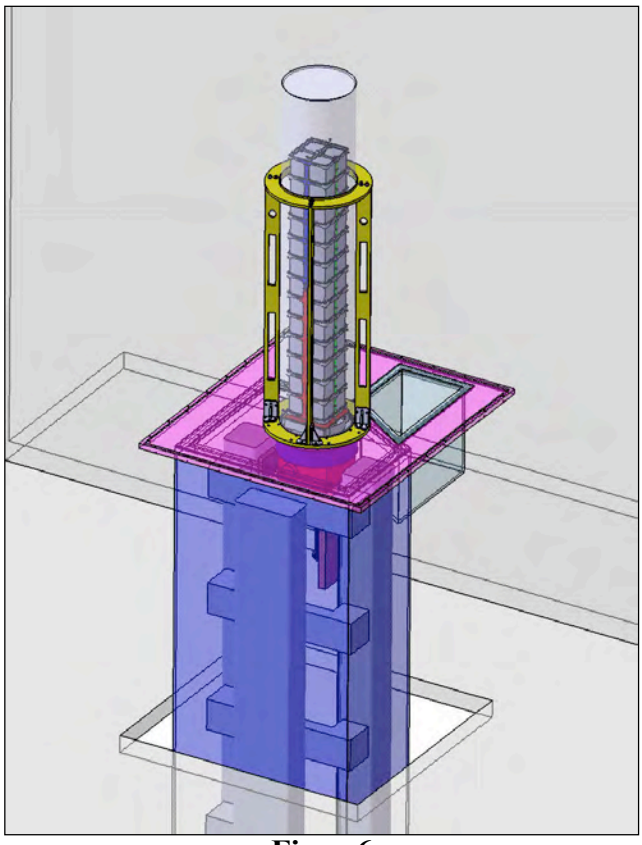

Fig. 6

In the picture below it's represented the Removing Glove Box drawing, where it's possible to see the dimensions of the structure (**1000 mm height; 290 mm diameter**), entirely made by stainless steel AISI 304, with overall mass 13 Kg.

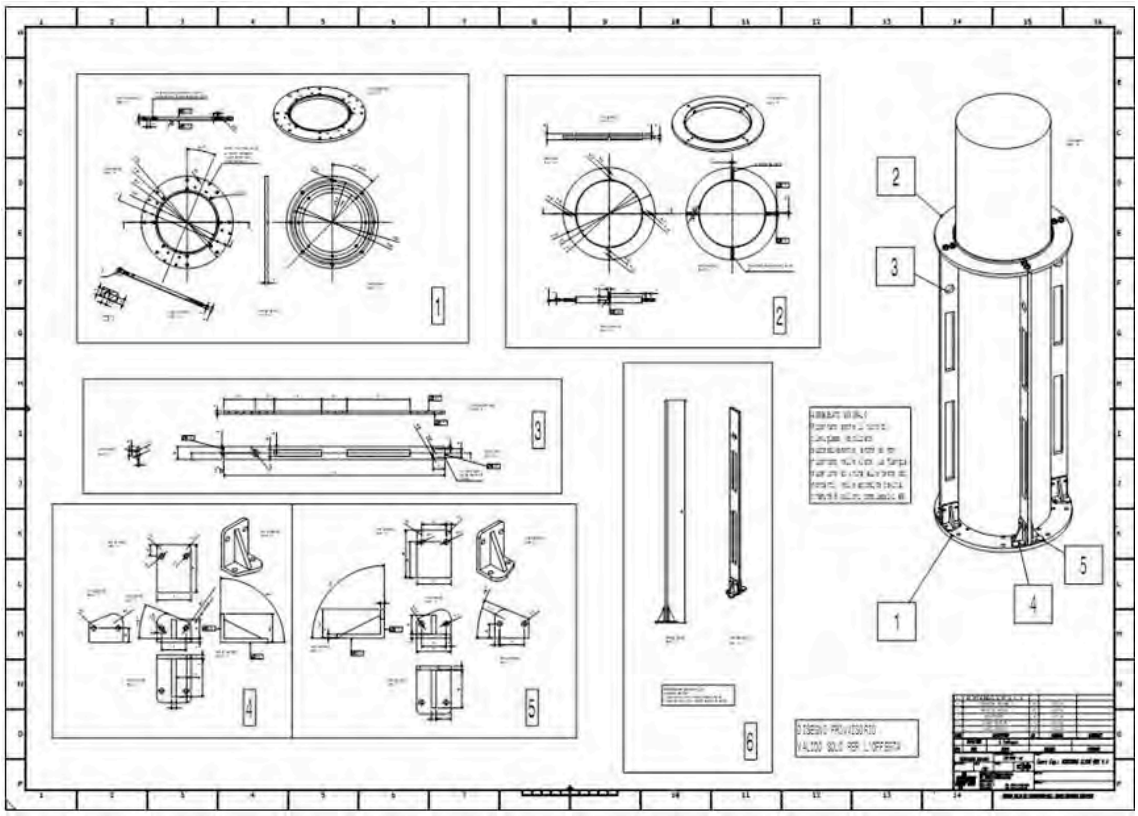

Fig. 7

The structure presents, as shown in the previous images, a *Plexiglas* tube fixed on the bottom circular flange, able to keep an internal Radon-free environment, suitable for shipping and storage of the assembled tower. The tube wall thickness is 4 mm; on the tube itself gas connections, for Nitrogen inlet/outlet, will be installed in order to have a continuous gas recycling. They are presently under study, and not yet represented in images.
The removing procedure will consist in 3 separate phases:

1. The *Removing Glove Box* is initially fixed on the Working Plane top surface, by 8 bolts M8 using the circular holes pattern, around the tower access point.
2. The garage lifts up the tower, until to send in contact the tower bottom flange and the Removing Glove Box bottom flange. These 2 flanges have been studied in order to guarantee an insulated environment using 2 concentric O-Ring, in each phase of the removing procedure. The tower will never go in contact with air or other contaminating agents. The 2 bottom flanges will be made in contact by an inner crown of 8 bolts M5 as shown in the following picture.

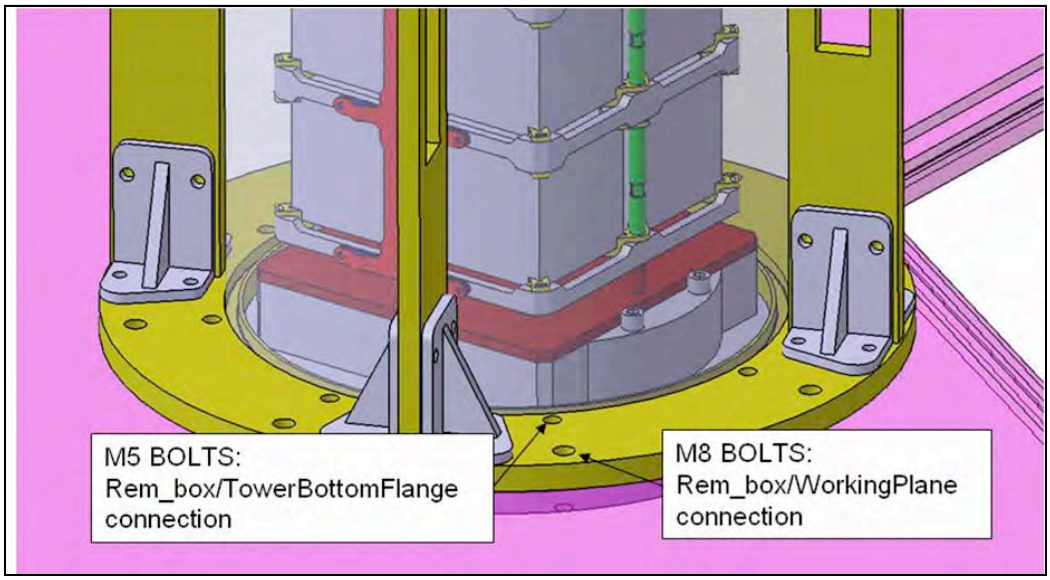

Fig. 8

3. Glove box removal: the outer M8 bolts are unscrewed and the removing box is carried away with the tower inside, hold by the inner M5 bolts. The tower's bottom flange is installed on 3 set-pins of the lifting and rotating system, able to ensure stability during the several movements. With this system, using a common forklift, it's possible to carry away the overall structure simply lifting up and unthreading from the 3 set-pins.

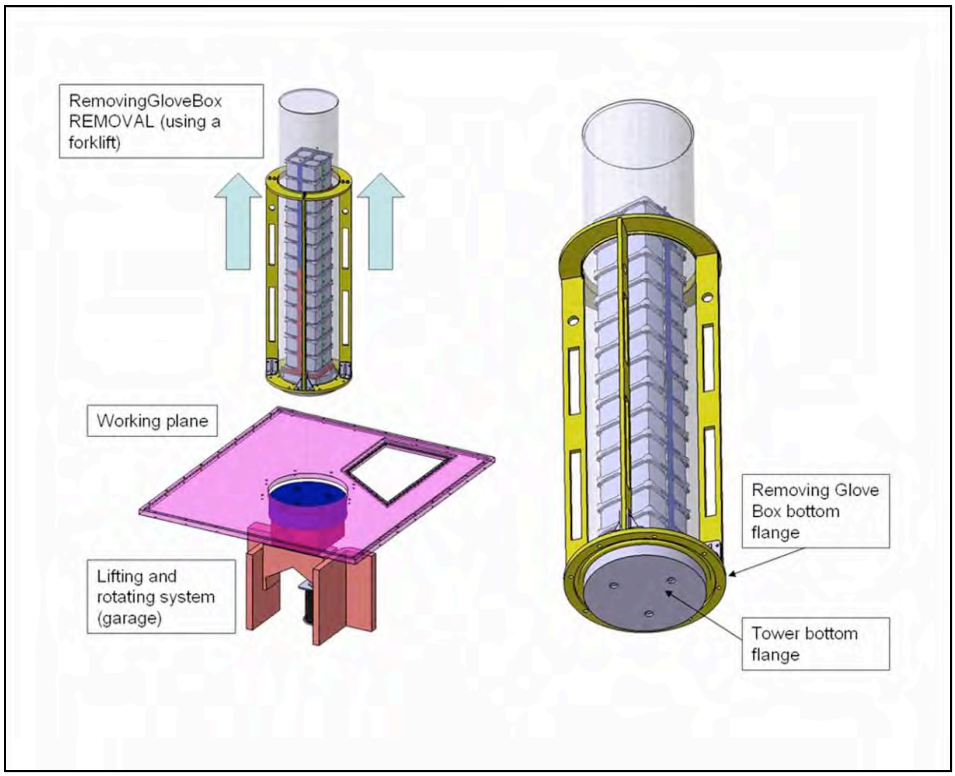

Fig. 9

As described before, this box is able to keep the assembled tower in a pure environment for the storage time. The double O-ring ensures insulation, first during the operation on the

working plane, and then for the storage period, once removed from the working plane itself. As shown in figure 1, the outer O-ring is on the Removing Glove Box bottom flange, and the inner on the tower bottom flange.

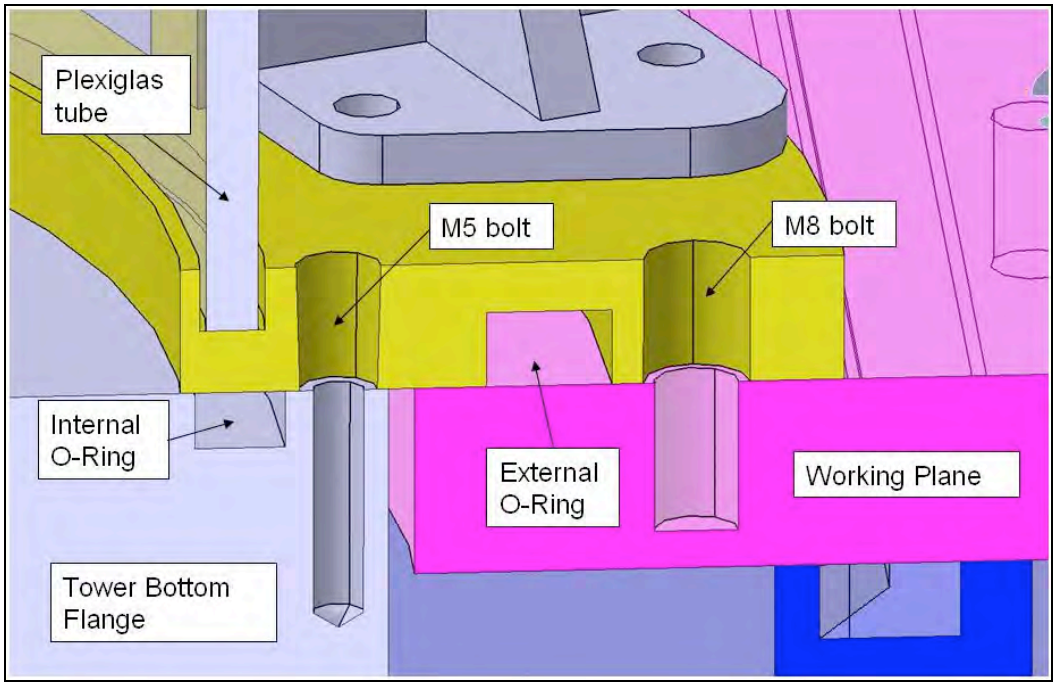

Fig. 10

The vertical beams connect top and bottom flange, and they ensure sufficient rigidity in each horizontal direction, with a thickness 8 mm. The top flange is connected by using 2 bolts M6 for each beam. A very fast and preliminary simulation in ANSYS has been performed to confirm a good behavior about mechanical strength and deformations.

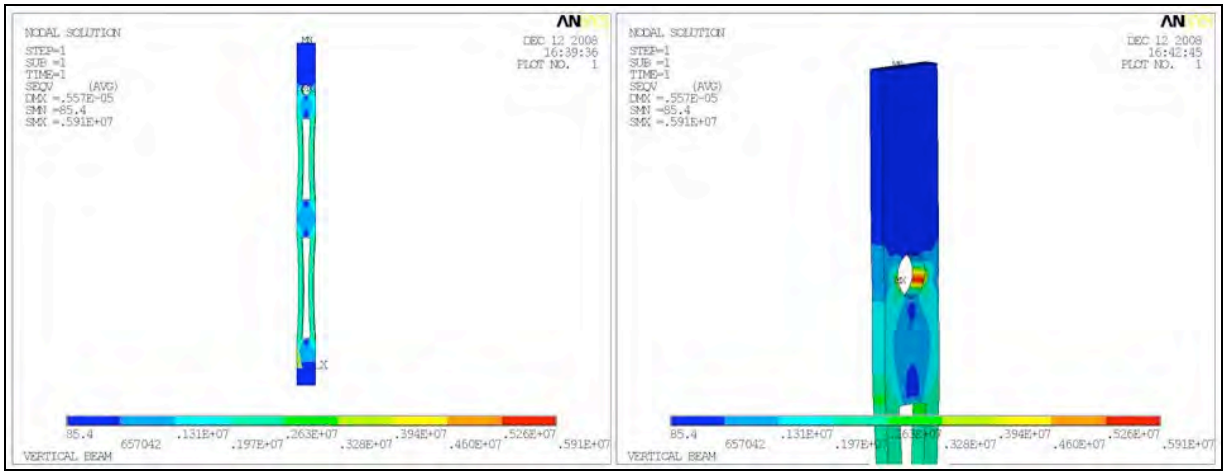

Fig. 11

The forklift nominate to move the assembly Removing Glove Box-Tower, will catch the structure on the top hole of the vertical beams. Then, once unscrewed the external M8 bolts, it will remove the structure from the working plane to the storage area.

4 CONCLUSIONS AND FUTURE DEVELOPMENTS

Presently the Removing Glove Box is almost definitive, ensuring each constraints about an uncontaminated atmosphere and a sufficient rigidity for the movement and storage of the assembled tower. The working plane also is almost definitive; it's possible to apply on it the glove box of each phase, ensuring an insulated environment for the tower's construction operations. It's suitable also to connect properly the *garage*, keeping a radioactively-free atmosphere, with a massive use of Nitrogen.

Future operations will be to generate a finite element model of the Removing Glove Box, in order to confirm a sufficient structure rigidity, respect to potential accelerations, due to movement with forklift. Furthermore, measurements about the Radon diffusion through the Plexiglas will be performed, in order to confirm the choice about the material used.

5 REFERENCES

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