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Two techniques to enhance particle reconstruction in JUNO:

Liquid Scintillator purification and Waveform analysis

Scientific/Disciplinary Sector (SDS) FIS/04

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A Lucia, compagna di viaggio, l'unica persona con cui vorrei vedere un tramonto sul mare.

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INTRODUCTION

Since when I was very young, I was intrigued by the challenge of finding the deep reasons of what is happening in my surroundings. This is the main reason why I have started my working life as a researcher in the Laboratori Nazionali del Gran Sasso (LNGS) after the master's degree in Energy Engineering. During my work in Borexino and Dark Side 50, the passion for research grew up and, thanks to my move to the Ferrara section of the Istituto Nazionale di Fisica Nucleare (INFN), I've expanded my knowledge in the neutrinos field.

Neutrinos are very elusive particles that can interact with matter only via the weak interaction and gravity. They are electrically neutral, excluding any electromagnetic interaction, and their mass is very small, leading to a negligible gravitational interaction. Thus, neutrinos can normally cross through matter without any obstacle and being undetected.

Neutrinos can be created in one of the three leptonic flavors in association with the corresponding charged lepton:

- Electron Neutrinos
- Muon Neutrinos
- Tau Neutrinos

The experiments SNO+ and Super-Kamiokande revealed, between the end of the last and the beginning of the new millennium, that a neutrino can change its leptonic flavor during its flight. This is a direct consequence of neutrinos having mass and it means, for example, that a neutrino, born as a muon neutrino during the interaction of the cosmic ray in the atmosphere, can be detected as an electron neutrino. This phenomenon is known as neutrino oscillation.

Neutrinos can be created by various radioactive decays such as:

- beta decay of atomic nuclei or hadrons,

- natural and artificial nuclear reactions
- during a supernova
- when cosmic rays or accelerated particle beams strike atoms.

The will of being part of a large and international collaboration and the desire to devote my research on the neutrino field, made me take the decision to join the JUNO collaboration and then to start the PhD program of the University of Ferrara.

In order to continue the work started in Borexino and DarkSide 50, I have offered my contribution to the JUNO collaboration in the Liquid Scintillator purification field. I was involved in the design, construction, erection and operation of the Distillation and Stripping plants. Following the precious suggestions of my tutor and colleagues, I was engaged also in the analysis of the waveform produced by large PMTs (Photo Multiplier Tubes), with the aim to reconstruct without bias the charge produced by multiple photons hitting the PMT.

Michele Montuschi

Two techniques to enhance particle reconstruction in JUNO:

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1.

JUNO AND MY RESEARCH

1.1 JUNO

1.1.1 Scientific Motivations

The standard three-flavor neutrino oscillation pattern is well established after the observation of the neutrino oscillation in solar, atmospheric, accelerator and reactor neutrino experiments. Two independent neutrino mass splitting $|\Delta m^2_{31}| = |m^2_3 - m^2_1|$ (or $|\Delta m^2_{32}| = |m^2_3 - m^2_2|$and $|\Delta m^2_{21}| = |m^2_2 - m^2_1|$, and three neutrino mixing angles from the Pontecorvo–Maki–Nakagawa–Sakata (PMNS) parametrization [1, 2] were measured with precisions at a level of few percents. However, several unknowns still exist and will be the focus of future neutrino oscillation experiments. They include:

- the Neutrino Mass Ordering (NMO),
- the leptonic CP-violating phase δ in the PMNS matrix,
- the octant of the mixing angle θ_{23} (i.e., $\theta_{23} < \pi/4$ or $\theta_{23} > \pi/4$).

The Jiangmen Underground Neutrino Observatory (JUNO), a 20 kton multi-purpose underground liquid scintillator detector, was proposed with the determination of the neutrino mass ordering as a primary physics goal [1-4]. The neutrino mass ordering has only two possibilities: the normal ordering (NO, $m_1 < m_3$) and the inverted ordering (IO, $m_1 > m_3$). The relatively large value of θ_{13} has provided excellent opportunities to resolve the NMO in various neutrino oscillation experiments, which include a medium baseline (~50 km) reactor antineutrino $\nu_e \rightarrow \nu_e$ oscillation experiment (JUNO), long-baseline accelerator (anti-)neutrino $\nu_\mu \rightarrow \nu_e$ oscillation experiments (NOνA [5] and DUNE [6]), and atmospheric (anti-)neutrino oscillation experiments (INO [7],PINGU [8], ORCA [9], DUNE [6] and Hyper-K [10]). The accelerator and atmospheric experiments rely on the matter effect in neutrino oscillations (the charge–current interaction between (anti-)ν_e and electrons in the matter). JUNO is a unique experiment designed to identify the NMO using the oscillation interplay between Δm^2_{31} and Δm^2_{32} [11]. The NMO sensitivity of JUNO has no dependence on the unknown CP-violating phase and the θ_{23} octant, playing a key role when combined with other neutrino experiments. The reactor antineutrino survival probability in vacuum can be written as

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\theta_{13}(\cos^2 2\theta_{13} \sin^2 \Delta_{31} + \sin^2 \theta_{12} \sin^2 \Delta_{32}) - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \Delta_{21} \quad (1)$$

where $\Delta_{ij} = \Delta m^2{}_{ij} \, {}^{L}\!/_{4E} = (m_i^2 - m_j^2) \, {}^{L}\!/_{4E}$ in which L is the baseline and E is the antineutrino energy. At a baseline of 53 km, JUNO will simultaneously measure oscillations driven by small mass splitting ($\Delta m^2{}_{21}$) and large mass splitting ($\Delta m^2{}_{31}$ and $\Delta m^2{}_{32}$) as shown in Fig. 1. The small oscillation peaks in the oscillated antineutrino spectrum contain the NMO information. Precise measurement of the oscillated antineutrino spectrum is a key for JUNO to determine the NMO. This requires a 20 kton liquid scintillator detector with an unprecedented relative energy resolution of $\sigma_E/E = 3\%/\sqrt{E_{vis}}$, with E_{vis} being the visible energy in the detector in MeV. Besides the neutrino mass ordering, the large fiducial volume and the excellent energy resolution of JUNO offer exciting opportunities for addressing many important topics in neutrino and astro-particle physics.

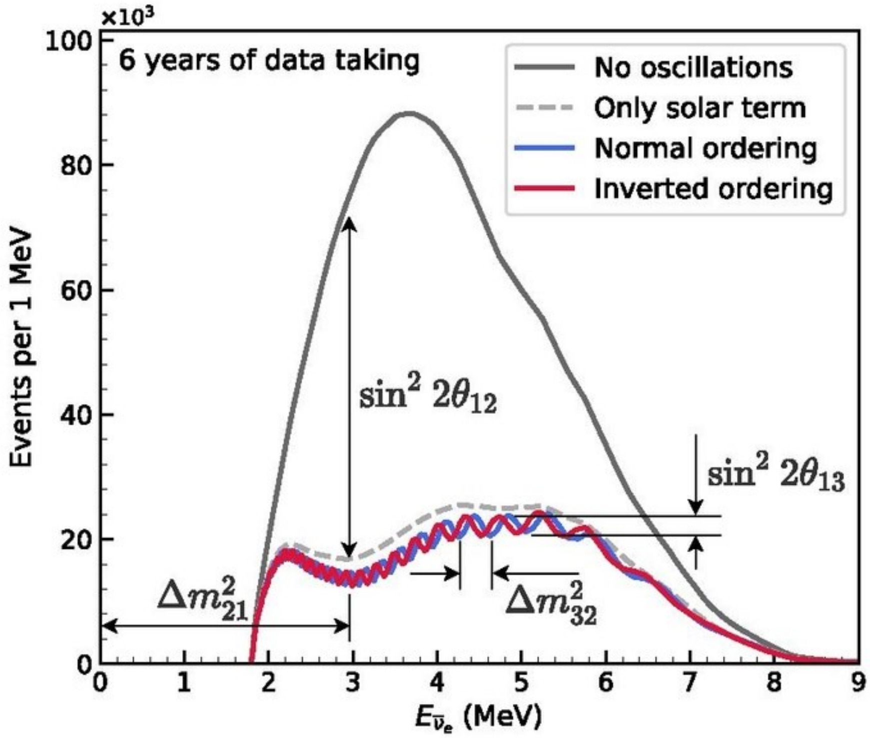

Fig. 1 The expected antineutrino energy spectrum weighted by IBD (Inverse Beta Decay) cross-section with and without oscillation at the JUNO experiment for normal ordering and inverted ordering assuming 2000 days of data-taking. Dependence on the four oscillation parameters is shown

The precision measurement of reactor antineutrino spectrum will also lead to the precise determination of the neutrino oscillation parameters $\sin^2\theta_{12}$, $\Delta m^2{}_{21}$, and $|\Delta m^2{}_{32}|$ as illustrated in Fig. 1. The expected accuracy of these measurements will be better than 0.6%, which will play a crucial role in the future unitarity test of the PMNS matrix. The JUNO detector is not limited to detect antineutrinos from the reactors, but also observe neutrinos/antineutrinos from terrestrial and extra-terrestrial sources, including supernova burst neutrinos, diffuse supernova neutrino background, geoneutrinos, atmospheric neutrinos, and solar neutrinos. For example, a neutrino burst from a typical core-collapse supernova at a distance of 10 kpc (kiloparsec) would lead to ~5000 inverse-beta-decay events and ~2000 all-flavor neutrino–electron elastic scattering events in JUNO, which are of crucial importance for understanding the mechanism of supernova explosion and for exploring novel phenomena such as collective neutrino oscillations. Detection of 1–2 neutrinos per year from all past core-collapse supernova explosions in the visible universe can further provide valuable information on the cosmic star-formation rate and the average core-collapse neutrino energy spectrum. Antineutrinos originating from the radioactive decay of uranium and thorium in the Earth can be detected in JUNO with a rate of ~400 events per year, significantly improving the statistics of existing geoneutrino event samples. Atmospheric neutrino events collected in JUNO can provide independent inputs for determining the mass ordering and the octant of the θ_{23} mixing angle. Detection of the ^{7}Be and ^{8}B solar neutrino events at JUNO would shed new light on the solar metallicity problem and examine the spectral transition region between the vacuum and matter-dominated neutrino oscillations. The JUNO detector provides sensitivity to physics searches beyond the Standard Model. As examples, we highlight the searches for proton decay via the $p \to K^+ + {}^-\nu_e$ decay channel, neutrinos resulting from dark-matter annihilation in the Sun, violation of Lorentz invariance via the sidereal modulation of the reactor neutrino event rate, and the effects of non-standard neutrino interactions. JUNO was first conceived in 2008[1, 2]. It was approved in 2013 after Daya Bay [12], Double Chooz [13], and RENO [14] measured an unexpectedly large value of θ_{13}, which meant that the NMO could be determined with current technologies. The civil construction started in 2015. The detector is expected to be ready in 2023, and data-taking is expected in 2023. In 2018, the Taishan Antineutrino Observatory (TAO, also known as JUNO-TAO) was proposed as a satellite experiment of JUNO to measure the reactor antineutrino spectrum with sub-percent energy resolution [15]. Since Daya Bay [16], Double Chooz [17], and RENO [18], among others, have found that the model prediction on the reactor antineutrino spectrum [19, 20] has large discrepancies with data, TAO will provide a reference spectrum for JUNO, and provide a benchmark measurement to test nuclear databases. TAO will be a ton-level liquid scintillator detector at ~30 m from a reactor core of the Taishan Nuclear Power Plant (NPP). It is expected to start operation at a similar time scale as JUNO. The physics potential of the JUNO experiment has been explored in the JUNO Yellow Book [4].

1.1.2.1 External Laboratories

The JUNO experiment is located in Jinji town, 43 km to the southwest of Kaiping city, a county-level city in the prefecture-level city Jiangmen in Guangdong province, China. The geographic location is 112◦31′05″ E and 22◦07′05″ N. The distances to several megacities, Guangzhou, Shenzhen, and Hong Kong, are all around 200 km. As shown in Fig. 2, the experimental site is at equal distances of ~53 km from the Yangjiang NPP and the Taishan NPP, optimized to have the best sensitivity for determining the mass ordering. Reactor antineutrino is the primary neutrino source in the JUNO detector.

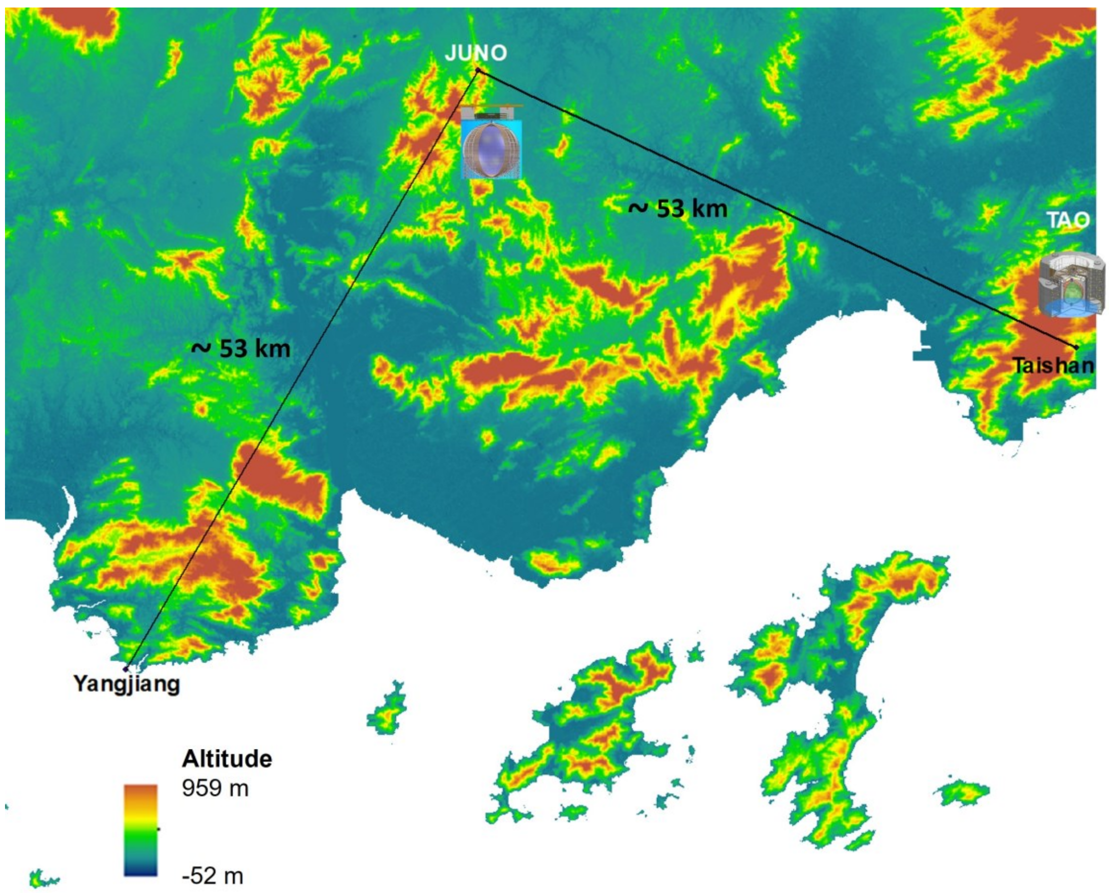

Fig. 2 JUNO location.

Yangjiang NPP has six reactor cores of 2.9 GW_{th} each (thermal power). All cores are the second-generation pressurized water reactors CPR1000, which is a derivative of Framatome

M310. The distances between any two cores of the Yangjiang NPP are between 89 m and 736 m. All six cores are in operation. Taishan NPP has two cores of 4.6 GW_{th} each in operation. Both are third-generation pressurized water reactors EPR. The distance between the two cores is 252.5 m. Possibly another two cores in the Taishan NPP will be built in the future, but the plan is unclear for now. The total thermal power of the Yangjiang and Taishan NPPs is 26.6 GW_{th}. The Daya Bay nuclear complex is 215 km away from the JUNO detector. It includes the Daya Bay NPP, the Ling Ao NPP, and the Ling Ao-II NPP in a spread of 1.1 km, each with 2 cores of 2.9 GW_{th}. The Daya Bay and Ling Ao cores are Framatome M310 and the Ling Ao-II cores are CPR1000. They will contribute about 6.4% of the reactor antineutrino events in the JUNO detector considering oscillation. Huizhou NPP is under construction with six 2.9 GW_{th} reactor cores and is expected to be ready around 2025. The plan of Lufeng NPP is unclear now. The Huizhou site is 265 km away from the JUNO detector and the Lufeng site is more than 300 km away. There is no other NPP or planned NPP in a radius of 500 km around the JUNO experimental site. The thermal power of all cores and the baselines (distances to the JUNO detector) are listed in Table 1.

Table 1. Summary of the thermal power and baseline to the JUNO detector for the Yangjiang (YJ) and Taishan (TS) reactor cores, as well as the remote reactors of Daya Bay (DYB) and Huizhou (HZ).

Cores	YJ-1	YJ-2	YJ-3	YJ-4	YJ5	YJ-6	TS-1	TS-2	DYB	HZ
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9	4.6	4.6	17.4	17.4
Baseline(km)	52.74	52.82	52.41	52.49	52.11	52.19	52.77	52.64	215	265

The distances from the detector site to the Yangjiang and Taishan cores are surveyed with a Global Positioning System (GPS) to a precision of 1 meter. All these NPPs are constructed and operated by the China General Nuclear Power Group (CGNPG). Due to the absence of high mountains in the allowed area where the sensitivity to the mass ordering is optimized, the JUNO detector will be deployed in an underground laboratory under the Dashi hill. Currently, the experiment hall has been excavated. The location has been shifted by ~60 m to the northwest of the originally designed location in Ref. [4]. The elevation of the hill above the detector is 240.6 m above sea level. The dome and the floor of the underground experimental hall are at −403.5 m and −430.5 m, respectively. The detector is in a cylindrical pit, with the detector center at −452.75 m. Therefore, the vertical overburden for the detector center is 693.35 m (1800 m.w.e). The experimental hall will have two accesses: a

564 m deep vertical shaft and a 1266 m long tunnel with a slope of 42.5%. The surrounding rock is granite. The average rock density along a 650 m borehole near the experimental hall is measured to be 2.61 g/cm3. The activities of the ^{238}U, ^{232}Th, and ^{40}K in the rock around the experimental hall are measured to be 120, 106, and 1320 Bq/kg, respectively, with 10% uncertainties. The muon rate and average energy in the JUNO detector are 0.004 Hz/m2 and 207 GeV estimated by simulation, taking the surveyed mountain profile into account.

1.1.2 Detector

The JUNO detector consists of a Central Detector (CD), a water Cherenkov detector and a Top Tracker (TT). A schematic view of the JUNO detector is shown in Fig. 3.

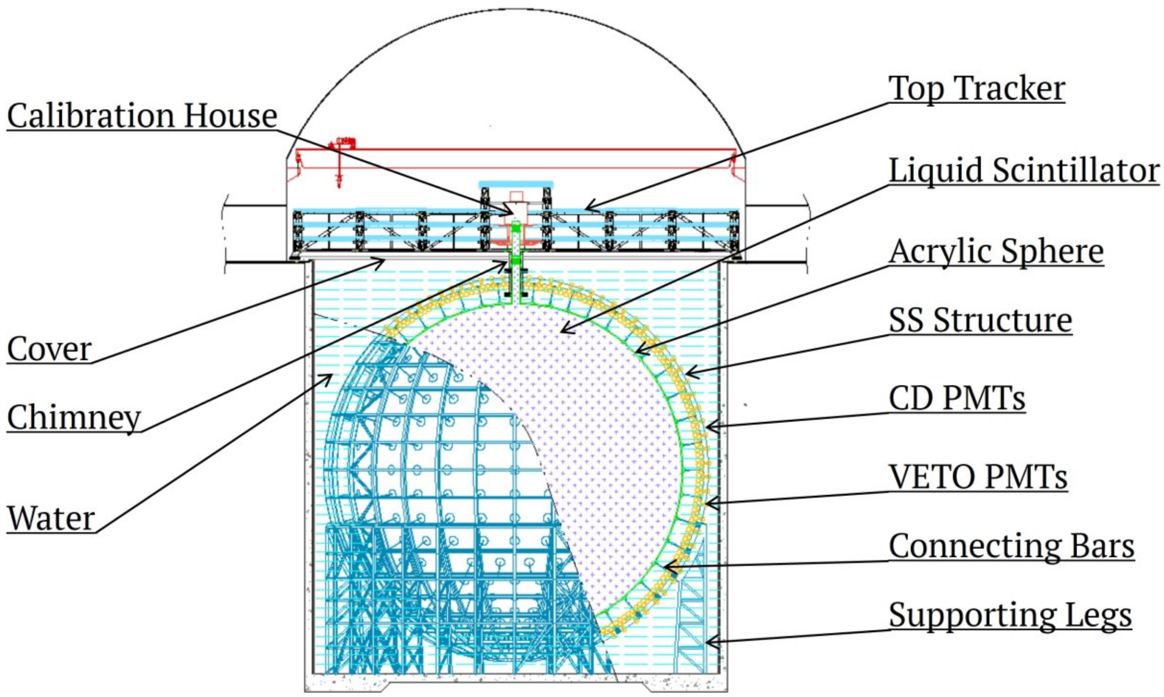

Fig. 3 Schematic view of the JUNO detector.

The CD is a liquid scintillator (LS) detector with a designed effective energy resolution of $\sigma_E/E = 3\%/\sqrt{E_{vis}}$. It contains 20 kton LS in a spherical acrylic vessel, which is submerged in a water pool. The acrylic vessel is supported by a stainless steel (SS) structure via Connecting Bars. The CD Photomultiplier Tubes (PMTs) are installed on the inner surface of the SS structure. The water pool is equipped with PMTs to detect the Cherenkov light from cosmic muons, acting as a veto detector. Compensation coils are mounted on the SS structure to suppress the Earth's magnetic field and minimize its impact on the photoelectron collection efficiency of the PMTs. The CD and the water Cherenkov detector are optically separated. On top of the water pool, there is a plastic scintillator array, i.e. Top Tracker, to accurately measure the muon tracks. A chimney for calibration operations connects the CD to the outside from the top. The calibration systems are operated in the

Calibration House, above which a special radioactivity shielding, and a muon detector are designed.

1.1.3 JUNO Signal

Reactor antineutrinos constitute the primary signal in the JUNO detector for determining the neutrino mass ordering and for precision measurements of the neutrino oscillation parameters. All reactors close to JUNO are commercial light water reactors, where fissions of four isotopes in fuel, ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu, contribute >99.7% of the antineutrinos. The antineutrino flux is composed of these four components weighted by the fission rate of the four isotopes, $\varphi(E_\nu) = \sum_i^4 F_i\, S_i(E_\nu)$, where F_i is the fission rate and $S_i(E_\nu)$ is the antineutrino energy spectrum per fission for the ith isotope. The fission rate can be evaluated based on the reactor running information provided by the NPPs, including the reactor thermal power, the burn-up of the fuel, the fission fractions of four isotopes, and the energy released per fission. The antineutrino spectrum per fission has been calculated using two methods. One is based on the summation method [21-23] which sums all the antineutrino energy spectra corresponding to thousands of beta decay branches for about 1000 isotopes in the fission products, utilizing information in nuclear databases.

The other is the beta conversion method which converts the measured β energy spectra from the individual fission isotopes ^{235}U, ^{239}Pu, and ^{241}Pu to the corresponding antineutrino energy spectra. The ^{238}U spectrum relies on the summation method and contributes <10% of the total events. Recent findings of the reactor antineutrino flux and spectrum anomalies have revealed unclear systematic effects in the reactor flux models. To provide a reliable reference antineutrino spectrum, the JUNO-TAO experiment was proposed as a satellite experiment of JUNO to measure the reactor antineutrino spectrum with sub-percent energy resolution. JUNO detects electron antineutrinos via IBD interactions, $^{-}\nu_e + p \rightarrow e^+ + n$. The e^+ quickly deposits its energy and annihilates into two 0.511 MeV photons, which provides a prompt signal. The prompt energy contains both the positron kinetic energy $T_{e^+}$and the annihilation energy of 2 × 0.511 MeV.

The neutron is mainly captured on protons. After approximately 200 μs of scattering in the detector, the capture releases a 2.2-MeV photon, providing a delayed signal. A set of preliminary antineutrino selection cuts is listed below:

- fiducial volume cut r < 17.2 m.
- the prompt energy cut 0.7 MeV < E_p < 12 MeV.
- the delayed energy cut 1.9 MeV < E_d < 2.5 MeV.
- time interval between the prompt and delayed signal ΔT < 1.0 ms.
- the prompt-delayed distance cut R_{p-d} < 1.5 m.
- muon veto criteria:
  - for muons tagged by the water Cerenkov detector or the Top Tracker, veto the whole LS volume for 1.5 ms.
  - for well-tracked muons in the Central Detector, veto the detector volume within a cylinder of distance to the muon track $R_{d2\mu}$ < 3 m and within time to the preceding muon $T_{d2\mu}$ < 1.2 s.
  - for tagged, non-trackable muons in the Central Detector, veto the whole LS volume for 1.2 s.

Table 2. Summary of detectable neutrino signals in the JUNO experiment and the expected signal rates and major background sources.

Research	Expected signal	Energy Region	Major background
Reactor Neutrino	60 IBD/day	0-12 MeV	Radioactivity, Cosmic muon
Supernova Burst	5000 IBDs at 10 kpc 2300 elastic scattering	0-80 MeV	Negligible
DSNB (w/o PSD)	2-4 IBDs/year	10-40 MeV	Atmospheric ν
Solar neutrino	Hundreds per year for 8B	0-16 MeV	Radioactivity
Atmospheric neutrino	Hundreds per year	0.1-100 GeV	Negligible
Geoneutrino	~400 per year	0-3 MeV	Reactor ν

Table 3 The efficiencies of antineutrino selection cuts, signal, and backgrounds rates, taken from Ref. [6].

<table>
<tr><th>Selection</th><th>IBD efficiency</th><th>IBD</th><th>Geo-νs</th><th>Accidental</th><th>$^{9}Li/^{8}He$</th><th>Fast n</th><th>(α, n)</th></tr>
<tr><td>-</td><td>-</td><td>83</td><td>1.5</td><td>-</td><td>84</td><td>-</td><td>-</td></tr>
<tr><td>Fiducial Volume</td><td>91.8%</td><td>76</td><td>1.4</td><td rowspan="3">410</td><td>77</td><td rowspan="5">0.1</td><td rowspan="5">0.05</td></tr>
<tr><td>Energy Cut</td><td>97.8%</td><td rowspan="3">73</td><td rowspan="3">1.3</td><td rowspan="3">71</td></tr>
<tr><td>Time Cut</td><td>99.1%</td></tr>
<tr><td>Vertex Cut</td><td>98.7%</td><td>1.1</td></tr>
<tr><td>Muon Veto</td><td>83%</td><td>60</td><td>1.1</td><td>0.9</td><td>1.6</td></tr>
<tr><td>Combined</td><td>73%</td><td>60</td><td>3.75</td><td></td><td></td><td></td><td></td></tr>
</table>

The detection efficiency for each cut is shown in Table 3. JUNO will detect 60 IBDs/day with the above selection criteria. The two major background sources of JUNO are natural radioactivity and the products of cosmic muons. Natural radioactivity comes from all materials and the environment. Huge efforts on material screening and a careful arrangement of the experimental apparatus reduce the single event rate to about 10 Hz in the fiducial volume. The accidental background due to radioactivity and neutrons is further reduced by applying selection cuts using the energy, time, and space signatures of both prompt and delayed signals. Moreover, ^{13}C (α, n) ^{16}O reactions in the liquid scintillator result in correlated background events.

For the reactor antineutrino program, the U/Th concentration is required to be lower than 10^{-15} g/g in the liquid scintillator, while the requirement is 10^{-17} g/g for the solar neutrino detection. With 693.35 m (1800 m.w.e) vertical overburden, the muon flux in the detector is 0.004 Hz/m^2. The double muon veto systems, formed by a Top Tracker system and a water Cherenkov detector, ensure a high muon tagging efficiency to reject the cosmogenic backgrounds: $^{9}Li/^{8}He$ and fast neutron backgrounds. An optimized veto strategy has been developed to obtain a <3% background to signal ratio for $^{9}Li/^{8}He$ and fast neutron backgrounds. The veto strategy utilizes the correlation time and distance to the parent muon, the muon track and energy deposition, the pulse shapes and the energies of prompt-delayed event pairs. Geoneutrinos, produced by U/Th in the Earth, have the same signatures as the reactor antineutrinos. Features of the energy spectrum shapes in the region of <3 MeV help to separate the geoneutrino components with a fraction of ~2%. The ratio of the residual backgrounds to the IBD signal, including geoneutrinos, accidentals, $^{9}Li/^{8}He$, fast neutrons and $^{13}C(\alpha, n)^{16}O$ is estimated to be about 6% using the same method as Ref. [4].

The JUNO detector requires an energy non-linearity uncertainty of better than 1% and a $3\%/\sqrt{E}$ effective energy resolution to determine the neutrino mass ordering. The relation between the true energy and the detected energy is non-linear due to quenching effects and Cherenkov light emission. The PMT instrumentation and readout electronics may contribute additional non-linearity for each channel. Various calibration sources covering most of the IBD energy range will be deployed regularly to calibrate the energy scale to a sub-percent level [24]. The novel dual calorimetry with 20-inch and 3-inch PMTs enables a clean determination of the instrumental non-linearity. As shown in Fig. 1, the NMO sensitivity relies on the difference of the multiple small oscillation pattern driven by Δm^2_{31} in normal and inverted mass ordering cases. Precise measurement of the oscillation pattern driven by Δm^2_{31} requires unprecedented effective energy resolution. Otherwise, the small oscillation pattern will be washed out. The unprecedented energy resolution puts stringent requirements on the transparency of the scintillator and the detection efficiency of PMTs.

With the R&D achievements described in this article, a yield of 1345 p.e./MeV at the detector center is obtained in simulations based on the nominal detector parameters. This contributes a statistical term of 2.73% in the energy resolution. The p.e. yield in the detector is position-dependent. A multi-positional source deployment calibration strategy is devolved to correct the non-uniformity. In general, the fractional energy resolution for a visible energy E_{vis} can be written as an approximate formula.

$$\frac{\sigma_{E_{vis}}}{E_{vis}} = \sqrt{\left(\frac{a}{\sqrt{E_{vis}}}\right)^2 + b^2 + \left(\frac{c}{E_{vis}}\right)^2} \tag{2}$$

where the *a* term is the statistical term driven by photo statistics, the b term is dominated by the position non-uniformity, and the c term represents the contribution of background noises. For the neutrino mass ordering determination, it was found that the impact of the b term is 1.6 times larger than that of the a term, and the impact of the c term is 1.6 times smaller than that of the *a* term [4]. Therefore, an effective energy resolution can be defined as $\sigma_{eff}/E = a_{eff}/\sqrt{E(MeV)}$, with

$$a_{eff} = \sqrt{a^2 + (1{,}6 * b)^2 + \left(\frac{c}{1{,}6}\right)^2} \tag{3}$$

Detailed studies on the effective energy resolution that could be achieved with the JUNO detector calibration strategy can be found in Ref. [24], considering the non-uniformity, vertex smearing, PMT quantum efficiency variation and charge resolution, energy nonlinearity, and PMT noises, etc. For the nominal setup, the *a* term is 2.61% (the 2.73% mentioned above corresponds to the statistics at the detector center while the p.e. yield increases with radius of the vertex), the b term is 0.82%, and the c term is 1.23%. Thus, an effective energy resolution of 3.02%/√E(MeV) is expected for the JUNO MO determination in simulations.

The expected neutrino signal rates and major background sources are summarized in Table 2. Only the MO determination requires a 3% energy resolution. The $|\Delta m^2{}_{32}|$ measurement benefits moderately from a high energy resolution. Solar neutrino studies require a U/Th radiopurity of the LS of 10^{-17} g/g. Reactor and Geoneutrino studies require 10^{-15} g/g and other studies are not sensitive.

1.2 Motivation and challenge of my research

1.2.1 Liquid Scintillator

The preparation of the liquid scintillator (LS) requires high quality of all the chemicals to satisfy the strict requirements of JUNO. There are three components in the JUNO LS recipe: Linear Alkyl Benzene (LAB), 2,5-diphenyloxazole (PPO), and 1,4-bis(2-methylstyryl)benzene (bis-MSB). The optimal LS composition was determined to be the purified solvent LAB with 2.5 g/L PPO and 3 mg/L bis-MSB [176]. For the raw materials, one LAB factory succeeded in providing high-quality LAB with a long attenuation length at 430 nm. The LAB will be transported by dedicatedly cleaned ISO-tanks with nitrogen covering, before being stored in a 5000 ton stainless steel tank and purged by nitrogen onsite. Similar long-term cooperation was established with one PPO supplier, which was able to provide purified PPO with residual contamination in ^{238}U and ^{232}Th around 1 ppt after a great effort. The requirement on the U/Th radiopurity of the LS is 1×10^{-15} g/g for the reactor neutrino studies and 1×10^{-17} g/g for the solar neutrino studies. It is difficult to quantitatively demonstrate that the LS could be purified to such a low level with our purification systems, until we can use the data of the JUNO detector. Therefore, the minimum requirement is determined to be 1×10^{-15} g/g upon filling, with a target radiopurity of $<1 \times 10^{-16}$ g/g. The LS will be further purified online, with the water extraction and gas stripping systems, to reach the goal of 1×10^{-17} g/g. More than five years of R&D efforts were devoted to raw material procurement and the design of the purification plants in order to produce the best possible LS in terms of optical and radio-purity properties.

In this framework, we have developed a pilot system to test the capabilities of several purification techniques in terms of removing optical and radioactive impurities. This system is composed by:

- Alumina filtration column to remove optical impurities
- Distillation column to remove heavy impurities (mainly optical impurities and heavy radioactive element such as U, Th, P)
- Water extraction to remove heavy radioactive element such as U, Th, P
- Steam stripping to remove light radioactive elements such as Ar, Rn, Kr.

I have designed, in collaboration with Polaris s.r.l, and operated the Distillation pilot plant and the Steam Stripping pilot plant at the Daya Bay laboratory purifying successfully more than 20 tons of LS (see paragraph **Errore. L'origine riferimento non è stata trovata.**). After the experience gained in these operations, I have designed and assembled at the JUNO site the final Distillation and Steam stripping plants.

1.2.2 Waveform Analysis

The consolidated Liquid Scintillator (LS) technology is driving neutrino physics into the era of precision calorimetry. The unprecedented scientific achievements of Borexino [25], Daya Bay [12], Double Chooz [26], KamLAND [27] and RENO [28] experiments have been the trailblazer for a new generation of multi-kiloton detectors (JUNO [4], Jinping [29], RENO50 [30], SNO+ [31], ANDES [32]). Going beyond the open issues in particle physics, the perspective will be some spin-off in applied antineutrino physics [33]. The experimental challenges of neutrino calorimetry revolve around improving both the energy and the spatial resolution of (anti)neutrino interaction detection. Since both resolution terms scale with the number of detected scintillation photons, maximizing the detector photo coverage—namely the sensitive area of the detector—is pivotal to improve them. In many current and future detectors, technical and budget constraints make the use of large-area Photo Multiplier Tubes (PMT) the only viable solution to achieve large photo coverage. In some cases, these constrains even justify a R&D program dedicated developing a novel PMT technology [34]. The largest PMT bulbs built to date are 20-inch diameter. Because of their large acceptance, they typically detect many photoelectrons (pe) per scintillation event, which are likely to pile up at the readout level. That is, the spacing between the pes' time of arrival is lower or comparable to the width of a single-photoelectrons (spe) pulse.

When pe pulses overlap, their identification becomes challenging. Especially if the pulses are affected by an overshoot (a distortion in the PMT output signal described in section 2), two subsequent pes (photo electrons) could easily be mis-reconstructed as a single one. A biased PMT charge reconstruction not only compromises the linearity—and therefore the resolution—of the detector-wise energy estimator, but also threatens the time-based reconstruction of the event vertex. In a large detector, a precise knowledge of the event vertex is crucial to define a fiducial volume meant to reject background energy depositions arising from natural radioactivity. The relevance of this issue can be further appreciated by noting that the Daya Bay experiment, after 4 years of smooth data taking, developed a new readout system based on fast digitizers, and its associated waveform reconstruction, to better assess the linearity of the detector energy response [35].

The goal of this study is twofold: (i) to propose an open-source detector-independent charge reconstruction algorithm [1] processing the output of a generic fast digitizer (FADC) connected to a PMT, and (ii) to define a procedure to assess the accuracy of the reconstructed charge, especially in the case of large pe pile-up. While (i) is based on realistic signal and noise assumptions, and particular care was devoted to model most of the PMT peculiarities, (ii) is meant to allow a comparison between any charge reconstruction algorithm. It is worth mentioning that our algorithm is specifically designed to minimize those charge reconstruction biases introduced by the presence of an overshoot in the pe pulses, and by the noise fluctuations embedded in the PMT output pulse.

Part of the content of this chapter is based on the following publication:

JUNO Collaboration, “JUNO physics and detector”, Progress in Particle and Nuclear Physics, 123, 2022, 103927, https://doi.org/10.1016/j.ppnp.2021.103927.

P. Lombardi, *et al* "Distillation and stripping pilot plants for the JUNO neutrino detector: Design, operations and reliability”, NIMA A, 925, 2019,6-17, https://doi.org/10.1016/j.nima.2019.01.071.

M. Grassi *et al.* “Charge reconstruction in large-area photomultipliers” 2018.*JINST* 13 P02008 https://iopscience.iop.org/article/10.1088/1748-0221/13/02/P02008

2.

PURIFICATION OF LIQUID SCINTILLATOR

2.1 Introduction

The extraordinary scientific results of Borexino [25], Daya Bay [12], Double Chooz [26], KamLAND [27] and RENO [28] experiments pave the way for a new generation of multi-kiloton detectors that adopt the Liquid Scintillator (LS) detection technique (JUNO [4], RENO50 [30], SNO+ [31], ANDES [32], JINPING [36]).

The LS that will be used in the JUNO detector is a specific organic compound containing molecules featuring benzene rings that can be excited by ionizing particles; it is designed to be composed by Linear Alkyl Benzene (LAB) as solvent, doped with 2,5-Diphenyloxazole (PPO) as primary solute, and 1,4-Bis(2-methylstyryl) benzene (bis-MSB) as wavelength shifter (a few g/l and mg/l respectively).

Low-background conditions are crucial for the success of JUNO. From the point of view of the LS, this means that the concentration of radioactive impurities inside the mixture should result in an activity on the same level or below the rate of neutrino events. Radiopurity levels are usually specified by the concentration of ^{232}Th, ^{238}U and ^{40}K in the LS and their typical concentration in the environmental sources are listed in Table 4. The baseline scenario, which will be desirable for the detection of reactor antineutrinos in JUNO, assumes a contamination on the level of 10^{-15} g/g of U and Th and 10^{-15} g/g of ^{40}K [37] in the LS. A more stringent regime in the realm of 10^{-17} g/g would instead be needed to accomplish the JUNO neutrino astroparticle program.

Table 4 List of the main radioisotopes solute in the organic liquid scintillators with their sources of contamination and the typical concentration of the impurities in the sources [38, 39]. In the last two columns are presented the removal strategies used by the main neutrino experiment to reduce the radioimpurities contained in the LS and the JUNO radiopurity requirements [4, 37].

Radioisotope	Contamination source	Typical value	Removal strategy	JUNO requirement
^{222}Rn	Air and emanation from material	<100 Bq/m^3	Stripping	-
^{238}U	Dust suspended in liquid	~10^{-6} g/g	Distillation and Water Extraction	<10^{-15} g/g
^{232}Th	Dust suspended in liquid	~10^{-5} g/g	Distillation and Water Extraction	<10^{-15} g/g
^{40}K	PPO used as doping material	~10^{-6} g/g	Distillation and Water Extraction	<10^{-15} g/g
^{39}Ar, ^{42}Ar	Air	~1 Bq/m^3	Stripping	-
^{85}Kr	Air	~1 Bq/m^3	Stripping	1 μBq/m^3

While members of the natural ^{232}Th and ^{238}U decay chains are the most common contaminants, also other sources of radioactive impurities for the LS must be considered.

The radioactive impurities can be divided in two main group according to the processes adopted to remove them from the LS. The heavy impurities, as ^{238}U, ^{232}Th and ^{40}K, can be discarded through the distillation plant and water extraction plant, while the more volatile impurities, as ^{222}Rn, ^{39}Ar, ^{42}Ar and ^{85}Kr, through the steam or nitrogen stripping plant. Table 5 displays the concentrations of LS contaminants obtained, after purification, by the main neutrino experiments. It is important to notice that only Borexino and KamLAND achieved the same radiopurity standard needed for JUNO.

Another crucial issue that could affect JUNO will be to reach an energy resolution never achieved in any large-mass liquid scintillator neutrino experiment. A LS property that can compromise the light collection by the Photo Multiplier Tube (PMT) is the attenuation length, that must be of the same order of magnitude of diameter of the LS chamber (higher than 25 m at 430 nm wavelength [4]) in the wavelength region where the PMTs are more sensitive (between 350 and 550 nm).

The optical performances of the LS are mainly affected by the solvent production methods, and its means of transportation, but the LS attenuation length [14] is influenced also by the different absorbance and cleanliness of each solute (see Table 6). The raw LAB attenuation length is about 15 m [40] if produced with the cleanest technique, while it could become less than 10 m if the liquid is moved inside PE bags, due to the chemical reactions between the plastics and the organic compound. Moreover, any oxidation of the LS worsens substantially its optical property, so it is mandatory to avoid any contact between oxygen and the LS, keeping any transportation and storage vessel under a nitrogen blanket while removing any air leak through the connections.

Table 5 Purification efficacy for different radioisotope in the main LS neutrino experiment (DayaBay [41], Borexino [42], KamLAND [43] and Double Chooz [44]) in terms of concentrations of radioactive impurities in the LS or event rate.

Experiment	Radioisotope	Concentration
DayaBay	^{238}U	<10^{-12} g/g
	^{232}Th	<10^{-12} g/g
Borexino	^{238}U	(5.3 ± 0.5) ·10^{-18} g/g
	^{232}Th	(3.8 ± 0.8) ·10^{-18} g/g
	^{40}K	< 0.42 cpd/100 ton-LS
	^{222}Rn	(1.72 ± 0.06) cpd/100 ton-LS
	^{39}Ar	~0.4 cpd/100 ton-LS (95% C.L.)
	^{210}Bi	(41.0 ± 1.5(stat) ± 2.3(sis)) cpd/100 ton-LS
	^{85}Kr	(30.4 ± 5.3(stat) ± 1.5(sis)) cpd/100 ton-LS
KamLAND	^{238}U	(1.87 ± 0.10)·10^{-18} g/g
	^{232}Th	(8.24 ± 0.49)·10^{-17} g/g
	^{40}K	(1.30 ± 0.11)·10^{-16} g/g
	^{39}Ar	<4.3·10^{-21} g/g
	^{210}Pb	(2.06 ± 0.04) ·10^{-20} g/g
	^{85}Kr	(6.10 ± 0.14)·10^{-20} g/g
Double Chooz	^{238}U	<10^{-13} g/g
	^{232}Th	<10^{-13} g/g

The plants in charge to remove the optical impurities are the Al_2O_3 (alumina oxide) filtering plant, as well as the distillation plant, which is designed to improve the attenuation length because it retains, in the lower part of the column, the high boiling point compounds (such as dust, metal particle and usually oxides) that can affect the light transmittance of the LS.

Because, these purification techniques, even if widely used in the oil industry, has never been proved efficient in removing impurities at such high level in LAB, the JUNO collaboration decided to prove the purification efficiency building the entire purification processes at a smaller scale and use one of the DayaBay detector to measure the residual radioactive and optical impurities.

In Sec.2.2.1 and Sec. **Errore. L'origine riferimento non è stata trovata.** are described in d etail the Distillation pilot plant and the Stripping pilot plant. These two plants were designed by me in collaboration with Polaris s.r.l. and I have operated them during the last years.

Table 6 Composition of the solvent and solute of the organic LS of the main neutrino experiments (DayaBay [38, 41, 45], Borexino [40, 42, 46, 47], KamLAND [27, 43, 48, 49], Double Chooz [26, 38, 44] and RENO [28, 30, 50]) together with the attenuation length measured at a wavelength of 430 nm after the purification cycle. The attenuation length given for KamLAND was measured at a wavelength of 436 nm.

Experiment	Solvent	Solute	Attenuation length (m)
DayaBay	LAB	1 g/l Gd 3 g/l PPO 15 mg/l bis-MSB	14 ± 4
Borexino	PC	1.45 g/l PPO	~10
KamLAND	80% Dodecane 20 % PC	1.36 g/l PPO	12.7 ± 0.4
Double Chooz	80% n-Dodecane 20 % o-PXE	4.5 g/l Gd-(thd)^3 0.5%wt Oxolane 7 g/l PPO 20 mg/l bis-MSB	7.8 ± 0.5
RENO	LAB	3 g/l PPO 30 mg/l bis-MSB 1 g/l Gd	>10

2.2 Pilot Plants

2.2.1 Distillation Pilot Plant

Distillation plant is used to remove form the LAB the heaviest impurities (mainly ^{238}U, ^{232}Th and ^{40}K) and to improve its optical property in terms of absorbance spectrum and attenuation length in the wavelength region of 350 nm – 550 nm. This process is based on the heat and mass transfer between a liquid and a gas stream, due to the equilibrium conditions reached on each stage of a distillation column. These conditions depend on the difference of volatility between the constituents of the input stream and on the temperature and pressure in the column. The low volatility components are concentrated in the bottom of the system, while the high volatility ones on the top.

The distillation is carried out with counter-current flow of the liquid and gaseous LAB in a 7 m high and 200 mm large column containing 6 sieve trays (see Fig. 4 and Table 7). In particular, the height of the column depends on the ease or difficulty of separation, while the width of the column on the internal vapour and liquid flow rates.

The three principal components of the distillation system are the column, the reboiler and the condenser. Liquid LAB is fed to the column at a flow rate of about 100 l/h in the middle tray section (1 in Fig. 4), after being preheated in the LAB vapour condenser (2 in Fig. 4) on the top of the column up to temperature of ~160 °C. The liquid stream, falling down by gravity through the sieve trays, reaches the re-boiler, which evaporates the liquid LAB with a 15 kW electric heater generating the counter current flow of vapour. The trays are designed in order to establish an intimate contact between the liquid stream and the gas stream for a sufficient period allowing the heat and mass transfer between the phases. This process enriches the liquid stream in the less volatile components (^{238}U and ^{232}Th and heaviest impurities) and decreases the temperature of the vapours. The liquid and vapour flows must be kept within a limited operating range to assure a good contact surface on the sieve trays.

On the top of the distillation column is installed the condenser (2 in Fig. 4), cooled by the LAB input flow, where the LAB vapours are liquefied. The product stream is than split by the condenser itself in two currents one inserted back inside the column as a reflux flow, used to increase the efficiency of the distillation process, and one directed to the water based heat-exchanger (3 in Fig. 4) for the sub-cooling to ambient temperature and then sent to the product tank.

The distillation pilot plant is operated with a nominal reflux ratio of 25%, adjusted varying the product flow, and a 2% of the input flow discharge from the bottom of the column in order to get a good compromise between the product purity and a reasonable throughput [40].

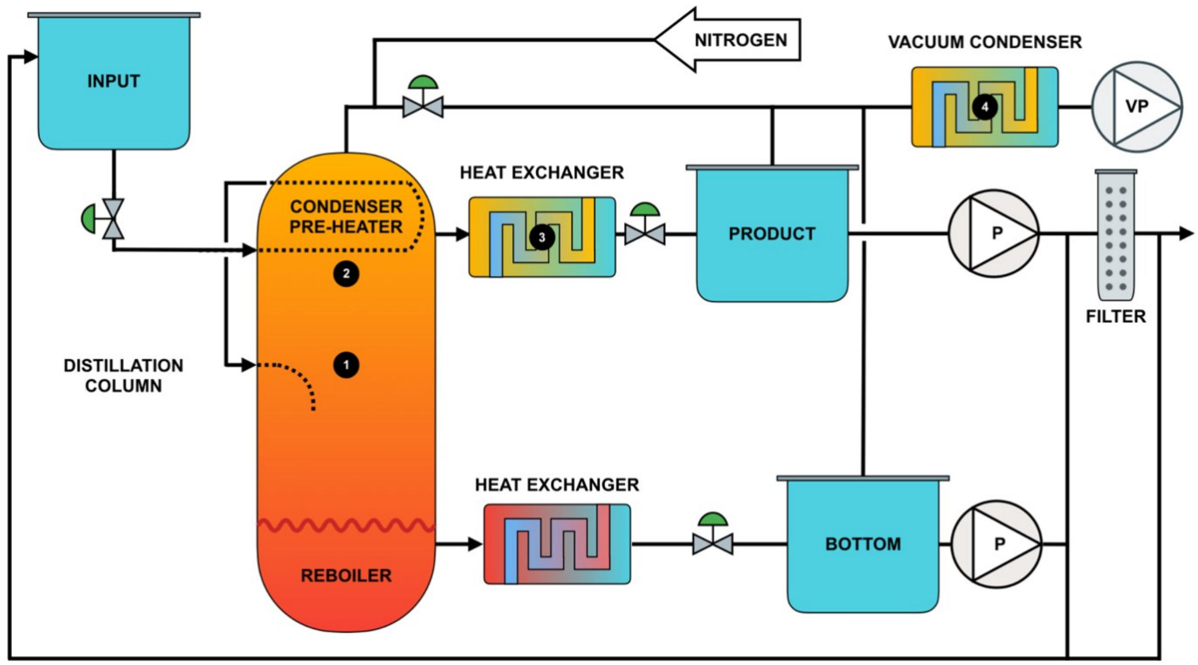

Fig. 4 Distillation pilot plant sketch (not in scale). The raw LAB from the input tank falls by gravity through the top of the column where is pre-heated by the LAB vapor inside the condenser installed right on top of the column (2). It is then, at a temperature of roughly 160 °C, sent to the column at the middle tray (1) where it falls in the electric reboiler integrated in the distillation column itself. The LAB vapors are than condensed in the top of the column and split in the product stream and in the reflux stream (~ 25% of the product stream). The flow of the distilled LAB is than cooled down at ambient temperature (3) and collected in the product tank. The discharge flow (~ 2% of the input stream) from the reboiler and sent to its collecting tank after being cooled down at ambient temperature. The pressure inside the distillation column, the product tank and the bottom tank is kept constant at a value of 5 $mbar_a$ with a scroll vacuum pump (VP) and a continuous purge of nitrogen. The distilled LAB can be than pumped back by a diaphragm pump (P) to the input tank, so to distil it in a batch mode, or sent to the next purification step passing through a 50 nm pore filter. In order to recover the LAB discharged from the bottom of the column it can be pumped back to the input tank.

The distilled LAB is then sent to the next purification process through a 50 nm pore filter to retain any dust or metal particle introduced in the stream by the plant itself.

The entire plant is kept under a N_2 blanket provided by a continuous gas flow to avoid any oxidation inside the column, thus reducing the fire risk. The incondensable gas stream is then removed from the top of the column by a dry scroll vacuum pump, in order to keep a constant pressure of 5 $mbar_a$ inside the column, passing through a vacuum condenser (4 in Fig. 4) adopted to liquefy any LAB vapour dragged by the nitrogen flow.

The plant can be operated with two different approaches, the batch mode, where the LAB from the product tank and through the filter, is sent back to the feed tank and the continuous mode where the feed tank is constantly filled with raw LAB and the distilled LAB is sent from the product tank to the next purification step continuously.

Table 7 Main operational parameters for the different features of the distillation pilot plant tested at Daya Bay.

Feature	Value
Height	7 m
Diameter	200 mm
Number of trays	6
Pressure	5 $mbar_a$
Temperature in the bottom of the column	200 °C
Temperature in the top of the column	160 °C
Input flow	100 l/h
Reflux flow	25 l/h
Discharge flow	2 l/h
Nitrogen flow	2 kg/h
Electrical Power for the heater	20 kW
Cooling Power	14 kW

The solutions listed below are adopted to achieve better performances in terms of removal of the radioactive impurities, energy saving and cleanliness.

- *Sieve Trays:* has the simple design among various tray types and no mechanical moving part neither welding, that permits an easy and very effective cleaning procedure. The trays have 55 holes with a diameter of 12 mm to permit a good contact surface between the vapour and liquid phase and no down-comer to avoid any parts that could be hardly cleaned.

The size and number of the holes in trays are based on nominal flow rates of vapour rising the column and liquid fall down the column. If the flows are too high or too low, bypassing occurs, reducing the contact surface and the stage efficiency.

- *Condenser*: the condenser is positioned directly on the top of the column to reduce the size of the total plant. Moreover, the LAB vapour is cooled down by the LAB liquid input stream. The pre-heating of LAB input stream permits an energy recovery of the order of 10 kW, while also avoiding the destabilization of the column temperature profile, due to the insertion of cool fluid in the middle of it.

- *Vacuum distillation column*: to achieve better purification performances, the distillation process pressure is kept below 5 $mbar_a$ increasing the difference between the vapour pressure of the LAB and of heaviest impurities. A very low pressure inside the column reduces the LAB boiling lower temperature (less than 200°C), effectively decreasing the risk of thermal degradation of LAB due to the high temperature.

2.2.2 Steam Stripping Pilot Plant

The gas stripping is a separation process in which, one or more dissolved gases are removed from the liquid phase and transferred to the gas phase by desorption mechanism. For example, radioactive gas (mainly ^{85}Kr, ^{39}Ar and ^{222}Rn) and oxygen (which potentially decreases the light yield due to photon quenching) can be removed from the LS by stripping it with a variable mixture of steam and nitrogen in counter current mode.

The liquid stream enters, preheated (2 in Fig. 5), in the stripping column (1 in Fig. 2) from the top and falls by gravity through an unstructured packing that permits a high contact surface between the liquid stream and the gas stream coming from the bottom of the column (see Fig. 5 and Table 8).

The molar concentrations of the dissolved gases in the two streams (y_i for the LS in the liquid phase and x_i for the gas mixture) vary in each stage of the column, depending on the equilibrium conditions between the liquid and gaseous flows, as governed by the Henry law:

$$y_i * p_i = H_i * x_i \tag{4}$$

where p_i is the process pressure and H_i the Henry constant that depends on the temperature, the pressure, and the composition of the streams at the i-th theoretical stage. In order to keep the pressure gradient constant inside the stripping column, the steam is condensed in vacuum condensers, while the incondensable constituents of the gas stream are discharged by a scroll vacuum pump (3 in Fig. 5).

The Henry constant, in combination with the molar fraction, determine the maximum ratio between liquid flow L and gas flow G rates applying the mass balance on the column:

$$\frac{L}{G}|_{max} = \frac{x_2 - x_1}{y_1 - y_2} \tag{5}$$

The optimal liquid-gas ratio is higher than 70% of the maximum L/G ratio, to avoid large gas flow and high-pressure loss inside the column, and lower than 85% of L/G max, not to increase too much the height of the column due to a minor driving force between liquid and gas.

The stripped liquid, collected in the bottom of the column, is sent to the product tank by a pump through a water-based heat exchanger to lower its temperature, and through a 50 nm filter used to retain the dust and the particulate that can be released by the plant itself.

The nitrogen used in the stripping pilot plant is carefully purified with active carbon to reach low concentration of radio-contaminants, because they set a lower limit for the radiopurity that can be achieved by gas stripping.

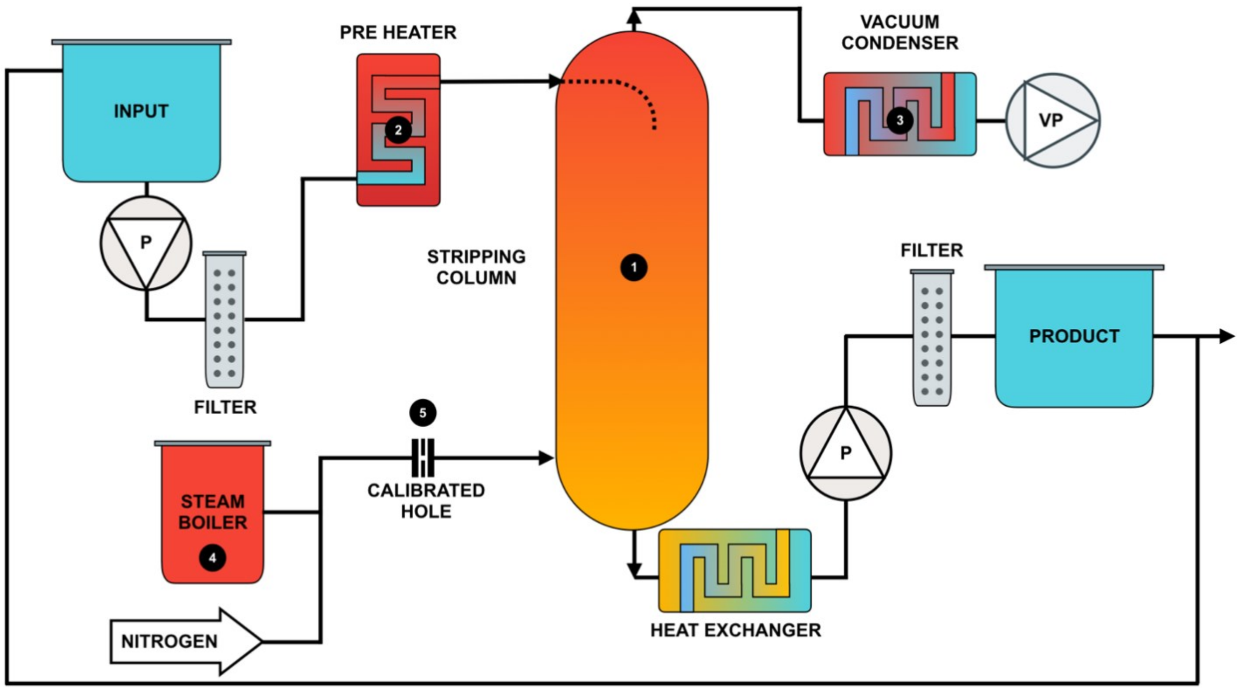

Fig. 5 Stripping pilot plant sketch (not in scale). The LS, collected in the input tank from the previous purification steps, is pumped by a diaphragm pump (P) to the top of the stripping column after being filtered through a 50 nm pore filter and preheated at 80 °C in the oil-based heater (1) in order to avoid the condensation of steam inside the liquid stream. The gas flow is an adjustable mix of nitrogen and steam produced inside the electrical steam boiler (2) at a pressure > 150 $mbar_a$ kept constant by the continuous flow of the steam through a calibrated orifice (5) to the stripping column (1). The stripping column is filled with Pall rings in order to maximize the contact surface between the liquid and the gas stream. The stripped LS is than collected in the bottom of the column and sent to the product tank after being cooled down in a water-based heat exchanger and filtered. The liquid can be than sent back to the input tank or pumped out to the filling station of the detector. The gas flow is discharged by a scroll vacuum pump (VP) after being cooled down in the vacuum condenser (3) in order to condense the steam, remove the water from the stream.

The steam flow, produced in batch mode in a 50 l volume steam boiler (4 in Fig. 5) with ultrapure water from the water plant of Daya Bay [41], is controlled by a calibrated hole with a diameter of 0.3 mm (5 in Fig. 5) set between the heater and the needle valve installed on the steam line before the column.

This plant can be operated in the internal loop mode (during the start-up operations and the self-cleaning procedure) and in the continuous mode where the purified LAB is sent, stripped, from the product tank to the filling station of the Daya Bay detector.

It has been decided, in order to reach the purity and optical standards needed for JUNO, to adopt the following solutions.

- *Unstructured Packing*: the column is filled with AISI316 Pall rings to increase the contact area between the liquid and gas stream. Moreover, they can be easily and effectively cleaned before the installation inside the column with an ultrasonic bath and/or electropolishing.

- *Stripping under vacuum*: the reduced pressure can improve the efficiency per theoretical stage of gas stripping; however, the inter-facial mass transport rate is substantially reduced in the absence of gas flow. In a stripping column of fixed size, there is an optimal pressure for gas stripping; reducing pressure increases the efficiency per theoretical stage, but also decreases the number of theoretical stages. The optimal pressure for our stripping operations is between 150 and 300 $mbar_a$.

- *Steam*: the use of steam instead of Nitrogen, as in Borexino [40], has two advantages. Firstly, it is generally easier to produce ultrapure water than N_2 with a low content of radioactive contaminant and to reach a concentration of $^{222}Rn < 3.4\ 10^{-6}$ Bq/kg. [48]. Moreover, using Nitrogen as a stripping gas requires adopting an exhaust system to displace it in a sufficiently well-ventilated place.

Table 8 Main operational parameters for the different features of the stripping pilot plant tested at Daya Bay.

Feature	Value
Height	7 m
Diameter	75 mm
Packing Material	AISI 316 Pall rings
Pressure	150 $mbar_a$
Input LS Flow temperature	80 °C
Steam temperature	50 °C
Input LS flow	100 l/h
Steam flow	250 g/h
Nitrogen flow	250 g/h
Electrical Power for the heater	10 kW
Cooling Power	5 kW

2.2.3 Common features

In order to leave the surfaces free of any dust, dirt or oxide particles, which could be released into the detector or liquid handling systems, it is mandatory to use electro-polished 316L stainless steel, wherever possible, and to have cleanliness procedures that assure the capability to reach the desired standard. Small parts could be cleaned in ultrasonic bath, while bigger parts should be cleaned with appropriate methods, like spray ball or immersion.

The desired cleanliness standard for the plant is MIL STD 1246 Level 25 [51], which defines limits on the residual particulate size distribution. This goal assumes the scintillator causes particulate wash-off like water, and that Class 25 is the acceptable level for the scintillator, assuming the remaining particulates has a similar radioactivity to dust. Hopefully the second assumption is not true, and the remaining particulates are mostly metallic which are less radioactive than dust, resulting in very conservative specifications for the lines.

The procedure has followed these steps [47]:

- pickling and passivation of all the welding

- detergent cycle, to remove oil, grease and residuals with Alconox Detergent 8 or equivalent (concentration 3% at 60 °C)
- Ultra-Pure Water (UPW) cycle for rinsing (Until resistivity > 4 MΩ×cm)
- EDTA (EthyleneDiamineTetraAcetic acid) cycle to remove metallic compounds (concentration 0.1% at 60 °C)
- UPW (Ultra-pure water) cycle for final rinsing (Until resistivity > 14 MΩ×cm.)

Moreover, at the end of each plant we decided to install a filter with the nominal pore diameter of 50 nm, pre-wetted, to retain any kind of particle that can be released by the plant itself.

Specific attention is given to avoid any leak through the connection. In particular, all large flanges and the ones withstanding low temperature are sealed with Ansiflex gaskets or Viton Teflon coated gaskets, while in the high temperature parts of the plant the tightness is assured by using metal loaded TUF-STEEL gaskets. All the process lines connections are orbital welded or TIG welded using low thorium content electrode. Where welding is not possible, metal gasket VCR fittings are used. Moreover, all instrument probes are connected to the plant with vacuum tight fittings for high seal, and stainless-steel diaphragm sealed valves are used throughout the system. (All the valves had specifications for leak-tightness of 10^{-9} mbar-l/s)

The skids have to meet safety European and Chinese requirements in terms of certification of seismic safety. An HazOps procedure were used to identify potential problems during operation and led to modifications for the sensing and alarming the system. In order to avoid the prescription of the PED directive, rupture disks are installed to assure in every tank a local pressure lower than 0.49 bar_g. In particular, it is used full vacuum to trigger point rupture disk with a rupture pressure of 0.45 bar_g.

The electric equipment is under ATEX specification [52], in Class 1 Zone 2 T2, to prevent any fire risk because, in the bottom of distillation plant, the LAB temperature is over its flash point.

All the process pumps used are volumetric diaphragm pumps with Teflon membrane and installed in the lower part of the plants in order to help the pump priming and to avoid the cavitation in comply with instrument NPSH. The pumps used to move liquid from a low-pressure tank to an ambient pressure tank are compressed air driven DEBEM pump, while in all the other cases we use motor driven PROMINENT pump.

These purification plants need a very stable and reliable Distributed Control System (DCS) to adjust the purification parameters and to assure the safety of both the plants and the operators, considering the elevated temperatures that exist in the plant (in distillation mode) and the enclosed environment in which the plants are located. The purification system must be under the control of a master system that provides, for 24 h/day operation, alarm notification, and automated shutdown in case of problems.

2.2.4 Reliability study

The JUNO purification plants will have to face the highly demanding challenge of assuring a constant delivery of purified LS for the entire filling period. A further hurdle arises from the fact that the last stages of the purification process will take place in the underground laboratory with the aim of minimizing the length of the pipe linking the stripping plant to the filling stations and of reducing the risk of contaminating the purified LS. In this scenario, the replacement of LS in case of failure of the purification process will be almost unfeasible. For these reasons, a reliability assessment is mandatory in order to identify the less resilient components and possibly maximize the hardness and safety of the whole purification system. Essentially it has been decided to use the experience gained by the design and the operation done on the pilot purification plants in order to develop a reliability study of the future JUNO purification plants.

Reliability is generally defined as the probability $R(t)$ of successful performance under specified conditions of time and use and it is related with the failure rate $\lambda(t)$ of every single component of the system [53]:

$$R(t) = e^{-\int \lambda(t) dt} \tag{6}$$

The lifetime of a component can be divided in three stages, the infant mortality period when the failure rate is not constant and decrease rapidly with time, the life period when the failure rate is considered constant and the wear out period where the failure rate increases rapidly due to increasing the age of the component.

In our case, the infant mortality period will be considered passed after the commissioning of the plants, so we consider the components inside the constant failure rate period, and it is possible to use failure rate form literature or from similar plants.

The total reliability of a complex structure can be calculated using the probability theory breaking down the entire system in simpler modules or subsystem arranged in series or in parallel [53].

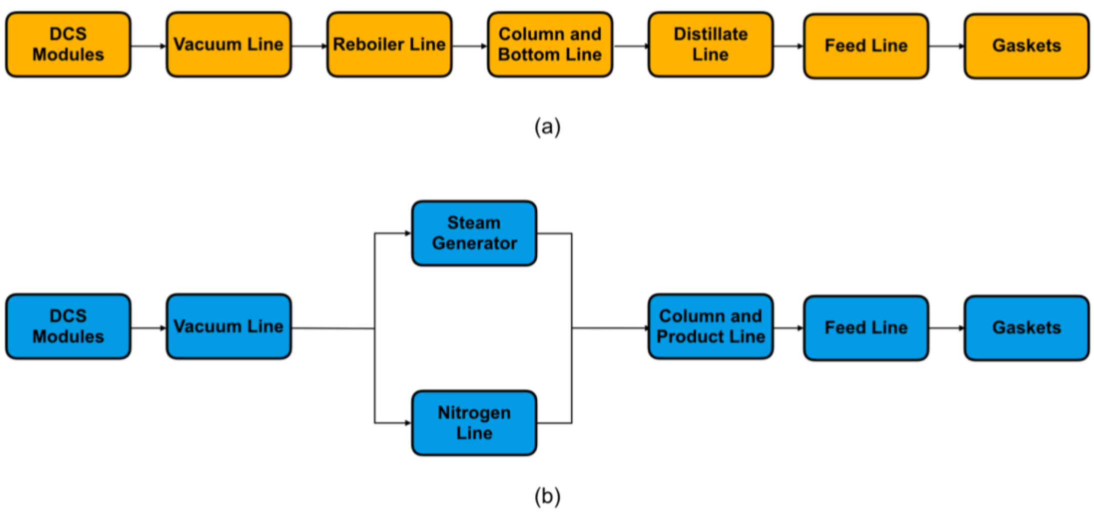

Fig. 6 Subsystem of the distillation pilot plant (a) and stripping pilot plant (b). The distillation pilot plant total reliability can be calculated as the product of the reliability of the single subsystem because all the plant works in series one to each other. While the stripping plant reliability can be evaluated as the product of all the other subsystem with the reliability of the subsystem composed by the Steam Generator and the Nitrogen.

In the distillation plant all the subsystems are arranged in series (see Fig. 6a), implying that the total reliability can be estimated using Eq. 7. In the stripping pilot plant one stage involves a parallel between the Steam Generator and the Nitrogen Line (see Fig. 6b): therefore, the total reliability R_{tot} can be evaluated by combining the reliability of the Steam Generator plus Nitrogen Line subsystem in parallel using Eq. 7 with the reliabilities of the remaining components:

$$R_{tot} = \prod_i R_{tot} \tag{7}$$

$$R_{tot} = 1 - \prod_i (1 - R_{tot}) \tag{8}$$

The failure rate of each components, listed in Table 9, are combined with the previous equations to get the final reliability and the Mean Time Between Failure ($MTBF$) (see Table 10) in order to estimate the number of stops for the plants, considering the reliability of the external utilities, provided by the lab (i.e. chiller, water supply, nitrogen supply) and the reliability of the hand-operated valves equal to 1. The $MTBF$ (measured in hours) is correlated with the failure rate through the following equation, when $\lambda(t)$ is considered constant.

$$MTBF = \frac{1}{\lambda(t)} \tag{9}$$

Due to a less complex system and less physical objects inside the plant, the stripping plant has less failure probability than the distillation one; it yields to a longer MTBF meaning a longer continuous activity between two stops for maintenance. Finally, considering 6 months of continuous working time to fill the JUNO detector, we will have 2 stops in 6 months of continuous operation for each plant (stripping and distillation) with a mean down time estimated of 36 h/failure, with a total of 3 days of stops for each plant.

Table 9 List of the main components of the distillation and stripping pilot plant used, and their failure rate given by the production company and from Borexino experience.

Component	Failure Rate λ (fail/10^6 h)
Pressure sensor	1.7
Regulating valve	30
Heat exchanger	20
Vacuum pump	15
Level sensor	12
Thermocouple	10.1
Level switch	4.5
On/Off valve	20
Rupture disk	13.5
Centrifugal pump	20
Flow meter	5
Filter	1
Gaskets	0.2
DCS module	1
Filter	1
Steam generator	50
Pressure reducer	0.3

Table 10 Probability of successful performances (R) and Mean Time Before Failure (MTBF) in months calculated for each subsystem composing the distillation and stripping pilot plant and for the entire plants. The model used for the calculation is shown in Fig. 6 and the failure rate for each component of the subsystem are listed in

	Line description	R	MTBF (10^3 h)
Distillation	Vacuum line	0.637	30.9
	Reboiler line	0.797	23.8
	Column + bottom	0.576	7.9
	Distillate line	0.665	7.9
	Feed line	0.722	15.8
	Gaskets (200)	0.916	14.4
	DCS modules	0.961	98.6
	Total	0.124	2.2
Stripping	Vacuum Line	0.835	36.7
	GV	0.698	12.2
	Column + product	0.524	5.8
	Feed line	0.613	8.6
	Nitrogen line	0.978	98.6
	Gaskets (150)	0.936	19.4
	DCS modules	0.961	98.6
	Total	0.235	2.9

2.2.5 Operation Procedure

2.2.6 Commissioning

In 2014-2015 the design and the construction of the JUNO purification pilot plants was started, with the aim to test them in the Daya Bay Laboratory and to find the optimal process parameters for the design of the final plants.

In the following years, the construction work for the distillation and stripping plants was carried out in conjunction with Polaris Engineering (MB, Italy) under the supervision of Istituto Nazionale di Fisica Nucleare (INFN) crew.

The plants were designed and built as a skid-mounted system (see Fig. 7) for transportation flexibility in China (they fit into two 2.15m x 2.4m x 7m skids). INFN reviewed and approved all materials, equipment selections and fabrication methods to ensure that the system was leak tight and has the possibility to be completely cleaned.

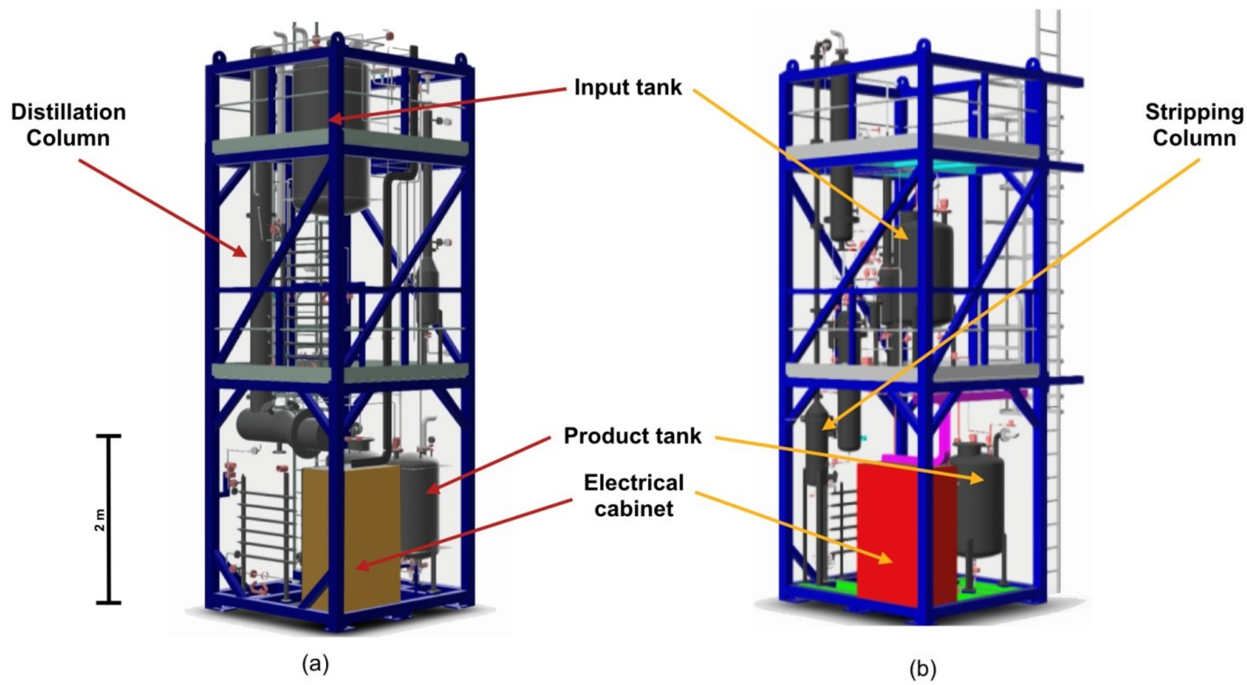

Fig. 7 3D drawing of the distillation plants skid (a) and stripping plant skid (b). The plants are mounted inside a blue skid that can fit a standard ISO container for transportation. They are divided in three floors: in the top floor are mounted the vacuum pumps and the input tanks while in the bottom the product tanks in order to minimize the usage of pumps. The distillation column and the stripping column are placed on a side of the skids, and they run from the top floor to the bottom floor to minimize the space required for the installation. In the bottom floor, it is enlightened the electrical cabinet containing the connection for the heaters and pumps power supply and for the CPU of the slow control system receiving the signals from the instruments.

Then, distillation and stripping pilot plants, under nitrogen atmosphere, were crated in a container and shipped to Shenzhen, China, by sea and after 1 month they arrived at the Daya Bay laboratory. After the skids were established, all the final connections were made, including the connections to the process lines in Hall 5 of Daya Bay Underground Laboratory.

Before the detector filling each plant has been operated in internal loop mode (described in sec. 2.2.1 and **Errore. L'origine riferimento non è stata trovata.**) to ensure that they work properly and to adjust the stripping and distillation process parameters. During these steps some problems on the level sensors were identified and were solved with a re-calibration of the instrument via a HART communicator.

The main features investigated during the commissioning phase were the discharge process of the LAB from the bottom of the distillation column and the thermodynamic parameters that assure a stable and efficient functioning of the stripping column. Regarding the first item, it was decided to avoid a continuous discharge of liquid from the bottom of the distillation column because the magnitude of the flow would have been lower than the minimum value measurable by the flow meter.

Regarding the stripping plant, it was decided to decrease the pressure inside the column to reduce the temperature of the LAB and avoid any degradation of the organic compound. Consequently, the measured consumption of water in these conditions were increased from 100 g/h to 150 g/h.

In total, around 4000 l of LAB has been distilled and stripped for plant commissioning and final self-cleaning.

After these tests, the plants were connected with Alumina oxide and Water Extraction purification systems through the interconnection system, to the goal of testing the complete purification chain.

The Gd loaded LS of one near detector of the Daya Bay experiment [45] was replaced with water and then with 20 ton of purified LAB during a one-month operation (see Fig. 8). In the first four days it has been purified almost 8000 l of LAB that was partially used for the preparation of a mixture of distilled LAB and PPO at high concentration called Master Solution (MS). After four cycles of Water Extraction of the MS, in order to reduce the radio impurity content of the PPO, it was added to the LAB purification cycle in order to obtain a total concentration of 0.5 g/L of PPO in the purified LAB.

The total time required to fill the detector was two weeks (including stops for maintenance) and during this period, it was distilled, and nitrogen stripped more than 20000 kg of LAB at an average speed of 100 l/h. The thorough description of the entire procedure will be subject of a separated paper.

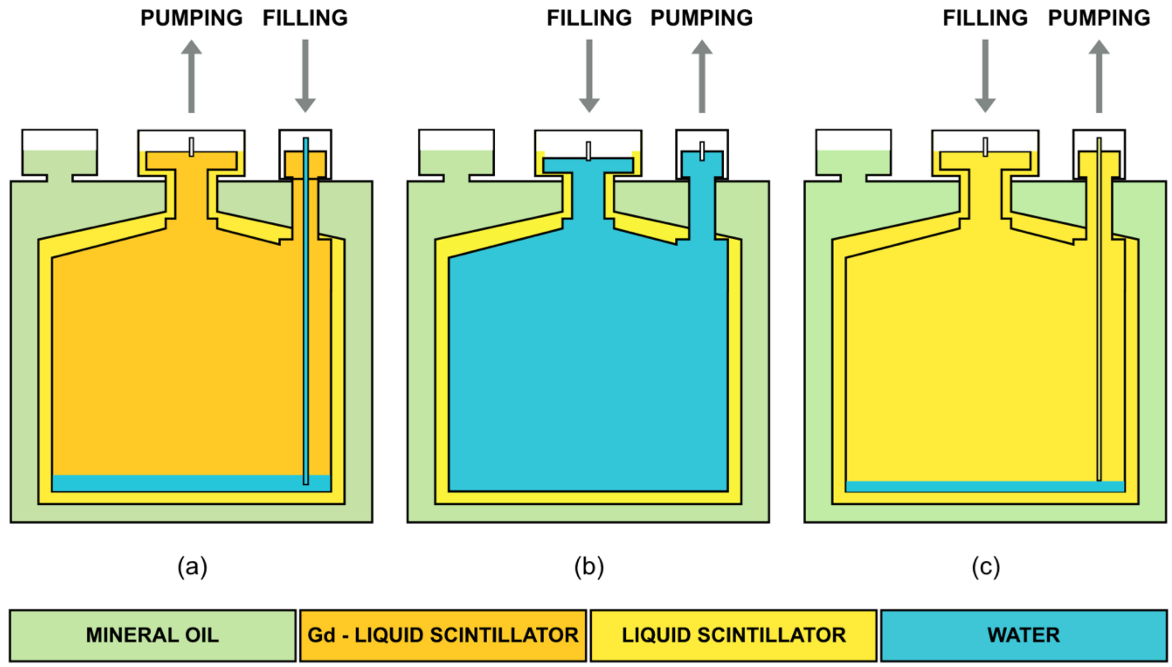

Fig. 8 Scheme of the replacement of the Gd-LS, in the Daya Bay detector, performed in two steps. In the first the Gd-LS was completely pumped out by inserting deionized water from the bottom (a). Then the water was replaced by the LS filling the detector from the top port and pumping out the water from the bottom (b). At the end a small level of water in the bottom of the detector is retained (c).

2.2.7 Results

The performances of the distillation and stripping pilot plants are assessed measuring the remaining content of radio-impurities in the LS and its absorption spectra evaluated after each purification process. The effectiveness of these purification methods on removing the radio-impurities cannot be measured by laboratory tests, that can give only generic hints on their efficacy. The Daya Bay detector, instead, enables the quantitative evaluation of the residual background in the LS, which will be reported in the paper describing the full procedure of tests and measurements performed on the whole sets of pilot plants at Daya Bay[54].

However, meaningful preliminary indications of the effectiveness of the plants can be gathered indirectly through the inspections of the absorption spectra. Indeed, the LS attenuation length and the absorption spectra were measured before filling the detector and after each purification step [55].

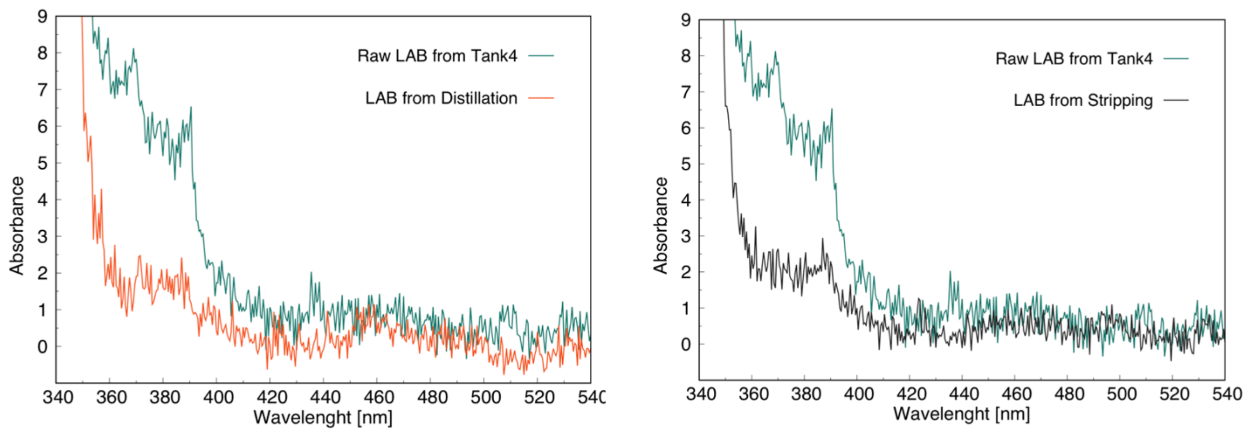

Fig. 9 Comparison of the absorption spectra of raw LAB, LAB purified with Al_2O_3 column, distilled LAB (a) and stripped LAB (b), modified from [55]. It is important to notice that even if the most reduction of the optical impurities is carried out by the alumina plant, the distillation has a small effect on reducing the absorption length in the wavelength region around 365 nm. While the absorption spectrum of the stripped LAB is almost superimposed with the one measured form LAB purified with Al_2O_3 column. This confirms that the stripping process has no effect on the absorption length.

In Fig. 9 the absorption spectrum is reported as a function of the wavelength (where on abscissa there is the wavelength in nm, and on y-axis the absorbance in arbitrary unit).

From Fig. 9a, by the comparison of the spectrum of the raw LAB with that after the distillation, we can infer the very high effectiveness of the distillation plant to remove the optical impurities over the whole region of interest.

Moreover, from Fig. 9b, it is possible to conclude that the stripping procedure, intended to remove gaseous compound and hence not expected to affect the absorption spectrum, is clean enough not to spoil the optical quality as obtained from the previous distillation step.

2.3 From Pilot plants to final plants

After the results gained form the operations on the plant, we have designed the purification process to produce the JUNO LS using the same technology of the pilot plants scaled to a much bigger flow of 7000 l/h.

The purification process starts in the JUNO surface area, where raw LAB will pass through the alumina columns and the distillation plant, before being mixed with PPO and bis-MSB. The resulting LS will be sent underground through an electro-polished pipe for the last two purification stages, water extraction and stripping plants. After the final quality check in the Online Scintillator Internal Radioactivity Investigation System (OSIRIS) detector, the LS will be sent to the FOC system.

Some new precaution was taken after the experience at the DayaBay:

- *Internal surface roughness*: In order to reduce radon emanation and diffusion, the internal surface roughness of all the equipment is kept below 0.4 μm with mechanical polishing followed by electrochemical polishing.
- *Flanges*: All joints are realized with double O-ring flanges with internal nitrogen purging and a tested overall leakage rate less than 10^{-6} mbar·l/s.
- *High Purity Nitrogen*: A high purity nitrogen system is designed for blanketing and running of all the plants. The system consists of two Low Temperature Absorber (LTA) columns filled with ultralow radioactive background activated carbon. One LTA column can continuously work for more than 7 days at 50 Nm3/h flux rate before its activated carbon needs to be regenerated. The radon content of the high purity nitrogen can be less than 10 μBq/m3.
- *LS Filters*: The two-stage filters (220 nm and 50 nm) are used in each sub-system to remove small particulates in LS and to reduce the ^{238}U and ^{232}Th radioactive background.

2.3.1 Distillation Plant

Following the experience gained from the design and operations done at the Daya Bay site with the distillation pilot plant, we have realized an industrial scale distillation plant as one of the purification systems for the LAB, solvent of the JUNO LS (see Fig. 10). Distillation plant will remove the heaviest radioactive impurities, mainly ^{238}Ur, ^{232}Th, ^{40}K. The LAB distillation technique was proved effective in terms of radio-purity and optical transparency in the pilot plant experiments performed at Daya Bay [54].

Distillation is one of the oldest and best-known separation method and it is based on the different volatility (i.e. boiling point) of the substances involved in the process. We have designed a multi-stage distillation column that can operate in continuous mode keeping the condition stable in time.

The feed flow from the T-101 tank is pumped to the column after being preheated in two heat exchangers (E-104 and E-107). In the first one the fluid is warmed by the product fluid exiting from the distillation column, while in the second the LAB is heated by hot oil at a temperature of 190°C. The fluid is then collected in the bottom of the column where is vaporized in a reboiler heated by hot oil at a temperature of 220°C and flows up in the column to be subsequently condensed. The gas flow is then liquefied in the condenser (E-102) by cooling water at a temperature of 7°C and then subcooled in E-104 permitting a partial energy recovery. During the passage into the tower the gas flow is in intimate contact with the feed liquid flow entering at a mid-point in the column and the product liquid flow entering at the top of the column as a fraction of the product is fed back to the column as a reflux. To increase the contact between the gas phase and the liquid phase we installed inside the distillation column 6 sieve trays without downcomers, that permit higher efficiency since phase contact occurs throughout the stage volume rather than restricted to the liquid zone, as with down-comers. After being subcooled by chilling water in E-106, the distilled LAB is than collected in T-102 and filtered by 0.05 μm pore-sized filters before being sent to the next purification system.

A liquid level is constantly kept in the bottom of the column in order to concentrate the impurities with a lower volatility. A small amount of the liquid collected in the bottom is discarded continuously to remove the contaminants keeping the bottom concentration.

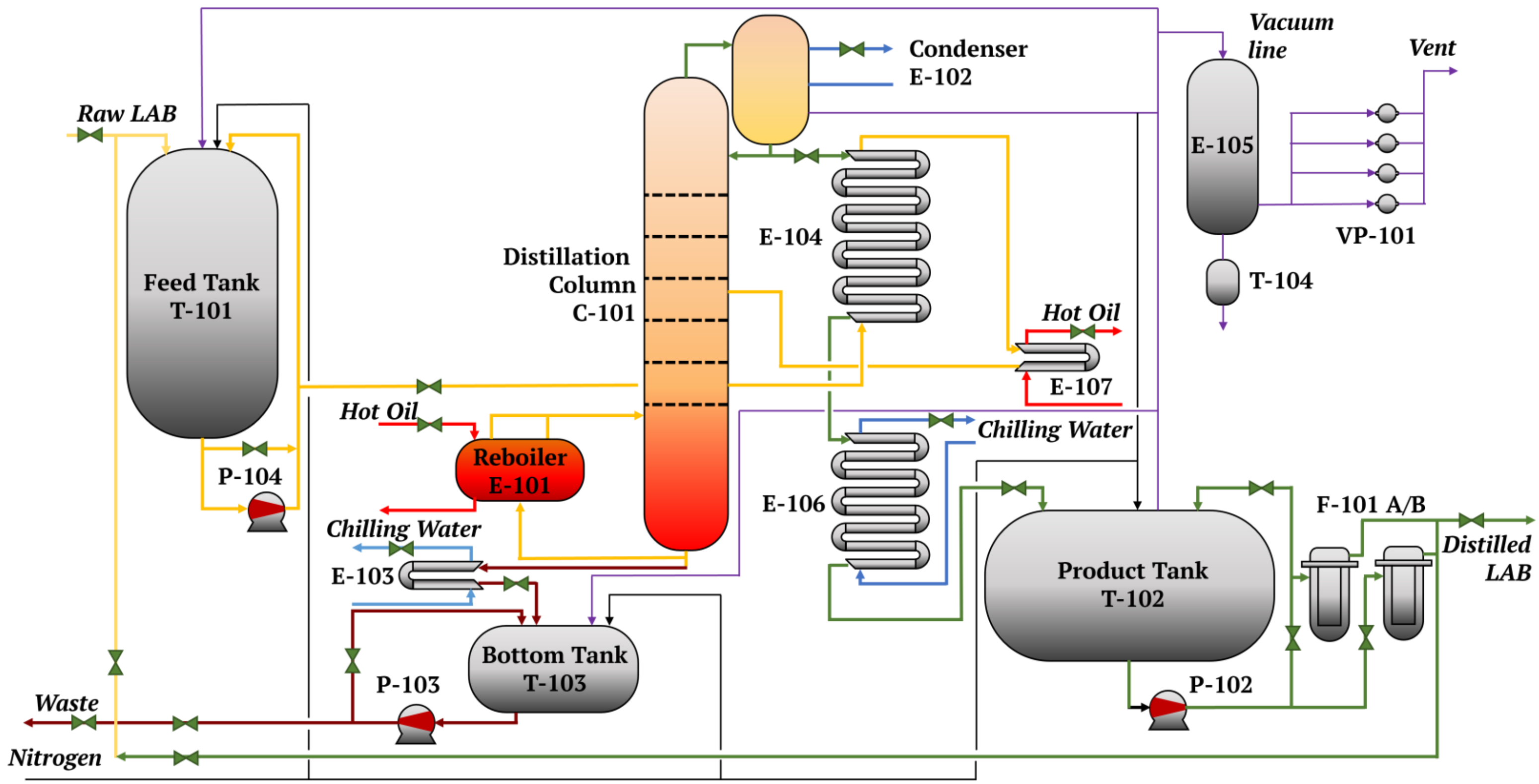

Fig. 10 Distillation in a partial vacuum (10 mbar) is used in the second stage of the purification process to remove the heaviest radio-impurities (238U, 232Th and 40K) from the LAB and to further improve its optical property in terms of absorbance and attenuation length. After a preheating up to 200◦C inside a counter-current heat exchanger (heat recovery), the LAB is delivered to the distillation column (7 m height and 2 m wide with 6 sieve trays) where the purification process is carried out with a counter-current flow of gaseous LAB produced inside a tube-bundle hot oil reboiler. The gas stream is collected in the top of the column and liquefied in a condenser cooled with chilled water at 35 ◦C from a water-cooling tower. The purified LAB flow is partially sent back on the top of the column as reflux to increase the purification efficiency (up to 40%). The distillation plant is designed to operate with a nominal discharge flow from the column bottom of 1%–2% of the input stream, in order to get a better compromise between the product purity and reasonable throughput.

Since the volatility for the heavy elements (Ra, Th, Po, Pb, Bi, K, U) and compound are very large in comparison with the volatility of LAB, distillation is very effective on removing these heavy metals. Moreover, distillation is one of the best processes for removing optical impurities that can affect the attenuation length of the scintillator.

The column and the process were designed in collaboration with the engineering company Polaris s.r.l. based on the experience gained with the operation of the pilot distillation plant. See Table 11 for the process parameters.

The Distillation is performed under vacuum for safety improvement as the boiling point range of LAB (278-313°C) is close to the auto-ignition temperature 323°C. Keeping the temperature as low as possible permits to also avoid any possible damage at the LAB.

The main features of the JUNO distillation plant are:

- Flow rate 7000 l/h with temperature around 200 °C
- Distillation under vacuum with sieve trays without downcomers
- 6 physical trays
- 1-2% bottom column discharge (sent back to Alumina column)
- High adjustable reflux rate (up to 40%)
- Filtration up to 0.05 microns
- Parallelization and spare parts on shelf to minimize filling dead time
- Heat exchanger energy recovery
- Nominal Electrical Power: ~1000 kW (plants + heating) (1250 kW available)
- Cooling water: ~1000 kW (thermal power) or ~350 kW electrical power (or less if evaporative cooling tower)
- Hot Oil system (electrical)
- All the plant is kept under continues nitrogen blanket either to avoid oxidation/contamination but also for safety reason (LAB temperature > flash point only inside the distillation column)
- Vapor condenser before nitrogen exhaust for safety (avoid LAB vapor exhausting)
- Rupture disks for pressure safety (plant certified up to 3.5 bar PED an SELO Norm.)
- Single leak rate < 10^{-8} mbar L / s
- Integral leak rate < 10^{-6} mbar L / s

Table 11 Main operational parameters for the different features of the JUNO Distillation plant

Feature	Value
Height	7 m
Diameter	2000 mm
Number of trays	6
Pressure	10 $mbar_a$
Temperature in the bottom of the column	200 °C
Temperature in the top of the column	160 °C
Input flow	7000 l/h
Reflux flow	2000 l/h
Discharge flow	140 l/h
Nitrogen flow	50 kg/h
Electrical Power for the heater	1 MW
Cooling Power	350 kW

2.3.2 Steam Stripping Plant

Following the experience gained from the design and operations done at the Daya Bay site with the stripping plant, the JUNO collaboration has realized an industrial scale stripping plant as one of the purification systems for the JUNO LS. Stripping plant will remove the lightest and more volatile radioactive impurities, mainly Ar, Kr, and Rn.

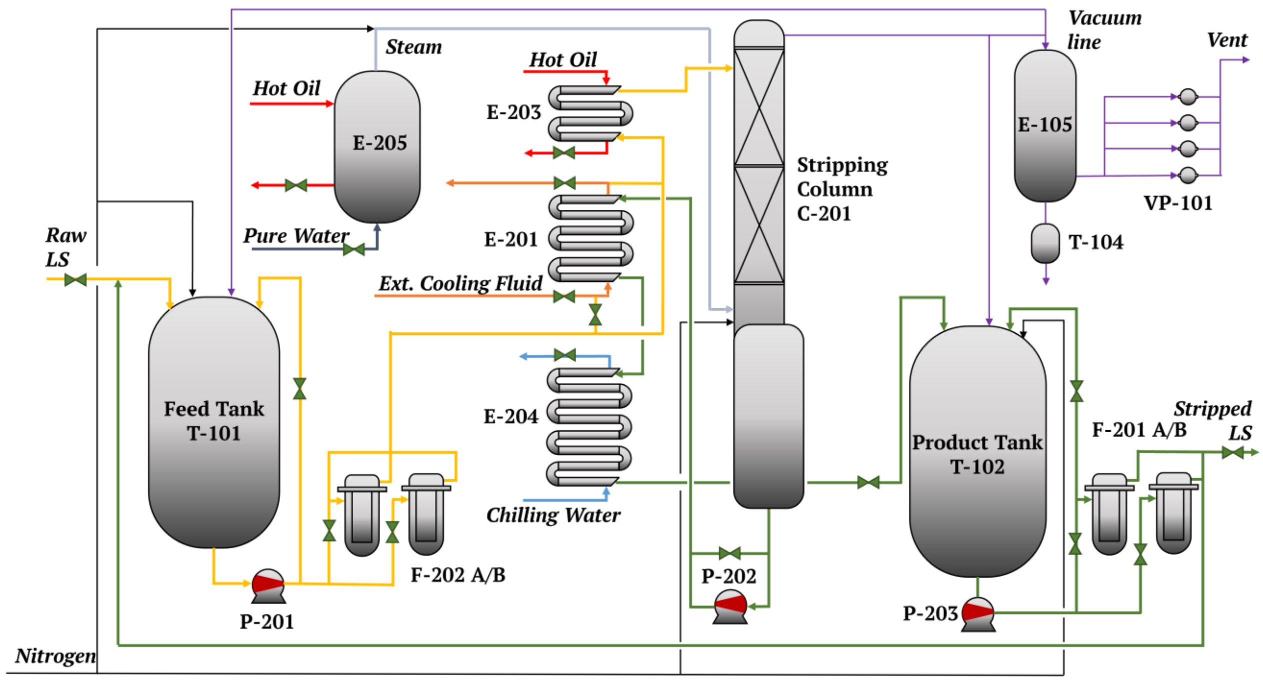

Fig. 11 Stripping system. The stripping plant is the final stage of the purification procedure. The main purpose of the plant is the removal of radioactive gases and gaseous impurities from the liquid scintillator phase, using a gaseous stream of nitrogen and/or superheated steam in counter-current flow mode. The purification process is performed inside a 9-meters-high stripping column, filled with AISI 316 L metal pall rings. LAB entering the plant is pumped at 7 m3/h by a magnetic driven pump through a set of input fine filters (50 nm pore size) and heated up by tube-bundle heat exchangers up to 90 ◦C, to reduce the LAB viscosity and increase the process efficiency. The stripping column is fed at the top with pre-heated liquid LAB while at the bottom with an adjustable mixture of ultra-pure nitrogen and UPW steam (30–60 kg/h). The stripping process is performed in a partial vacuum, at about 250 mbar. During pilot plant tests, carried out at the Daya Bay laboratory in 2018, this combination of parameters allowed to achieve 95% purification efficiency in Rn removal [54]. The full-size plant has been improved with a 50% higher stripping column; therefore, we expect better efficiency.

Steam stripping is a counter-current dual phase separation process based on the difference in partitioning in the vapour or in the liquid stream of a volatile element or compound as a function of the temperature (or equivalently the partial pressure represented by the Henry coefficients). The process is more efficient for impurities with large vapor pressure, such as gases and volatile liquids.

The LS collected in the feed tank (T-201) is pumped to a 0.05 μm filter and then preheated in E-201 and in E-202. In the first heat-exchanger the heating fluid is the product exiting from the column while in the second is hot-oil. The LS is than sent to the column from the top and it will be collected in the bottom after being in intimate contact with a flow of super-heated steam coming from the bottom of the column. The steam is produced inside the boiler E-205, that is continuously fed with fresh water. To avoid any condensation of the water along the piping the tubes are insulated and heated with heat stripes. The purified LS is than sent to the product tank (T-202) after being cooled in the heat exchanger E-201 (exchanging heat with the feed flow) and in the E-204 (exchanging het with cooling water). Before being sent to the filling station and then to the detector, the stripped LS is filtered again through a 0,05 μm pore-sized filter.

The main purpose of the stripping process in JUNO is to remove Rn, Ar and Kr because they represent a radioactive background, and oxygen and water because they can degrade the optical properties of the scintillator. The solubility of the noble gases in aromatic solvent is very high (the Henry coefficient for Rn in LAB is about ~11 atm/mf, so that the Rn partitions about 87% into the LAB at 1 atm). In order to increase the stage effectiveness, we designed the process to be carried under partial vacuum. This leads to a significant reduction of the effective stages, so we filled the stripping column with unstructured packing that guarantees the higher contact surface between the two phases increasing the overall process efficiency.

A significant challenge raised during the design was to not use nitrogen as it poses safety issues in underground and confined spaces. Therefore, the stripping plant operate using primarily steam (25 kg/h) and nitrogen. See Table 12 for the process parameters.

The main features of the JUNO stripping plant are:

- Flow rate 7000 l/h
- Temperature around 90 °C for higher column efficiency
- Partial vacuum (around 300 mbar)
- Both steam and nitrogen stripping could be used
- Filtration up to 0.05 microns
- Parallelization and spare parts on shelf to minimize filling dead time
- Nominal Electrical Power: ~200 kW (plants + Hot Oil)
- Cooling Power: ~200 kW (thermal power 100 kW electrical power)
- Pure water from water plant (approx. 25 l/h)
- Hot Oil system (electrical)
- All the plant is kept under continues nitrogen blanket either to avoid oxidation/contamination
- Vapor condenser before water vapor/nitrogen exhaust for safety
- Rupture disks for pressure safety (plant certified up to 3.5 bar PED an SELO Norm.)
- Single leak rate < 10^{-8} mbar L / s
- Integral leak rate < 10^{-6} mbar L / s

Table 12 Main operational parameters for the different features of the JUNO Steam Stripping plant.

Feature	Value
Height	6.0 m
Diameter	450 mm
Packing Material	AISI 316 Pall rings
Pressure	300 $mbar_a$
Input LS Flow temperature	90 °C
Steam temperature	95 °C
Input LS flow	7000 l/h
Steam flow	25 kg/h
Nitrogen flow	60 l/h
Electrical Power for the heater	200 kW
Cooling Power	100 kW

2.4 Distillation Operation Procedure

This procedure offers a very comprehensive description of the good practices for the operation of the Distillation plant. These procedures are annexed to this thesis in the **Errore. L'origine riferimento non è stata trovata.**. These procedures assume the plant is commissioned and functionally tested. It is also assumed that the system has already at least a minimal inventory of LAB. This procedure refers to Slow Control instructions, by referring to the control loop or equipment, but do not refer to specific graphical pages, which are under constant revision and upgrade. It is assumed here that the operator is familiar with logging into and using the Slow Control System and has a valid individual operator's account.

Following a brief description of the procedure section:

Hazards of Unit Operations & Safety Instructions: It is given a brief description of the substances in use in the plant (i.e., Linear Alkylbenzene, Mineral Oil, Water and Nitrogen), enlisting their hazard with reference to the operation of the plant, together with the external and environmental impact of all the chemicals. The main hazards are the ignition of LAB and leaking of the substances, therefore we report the counter measurement in case of spilling of LAB and the firefighting operations. In this section are described, also, the major safety equipment to adopt during the operations and the first aid procedures in case of contact with the chemicals (Inhalation, skin contact, eye contact and swallowing).

Purification of LAB Solvent: This section provides a very detailed description of the general operating procedures for starting, running, and stopping the distillation plant. The operation list refers to the Slow Control instruction and it assumes that the plant is commissioned and functionally tested. This chapter is divided into several sections, each containing a brief description of a singular process and the action to take in order to successfully achieve the operation. The processes described are:

- *Pre-Start Checkout:* a list of the administrative operations to fulfill (i.e., authorization request, check of any restriction) and a list of the equipment, utilities and services to be checked before the before starting the plant.
- *Purging Vacuum/Nitrogen:* Before operating the plant is mandatory to remove any air present in the plant and to replace it with Nitrogen. In this section are listed the action to perform to reduce the contentment of air to a negligible level. The plant

sections are firstly emptied through the vacuum pumps sequentially till the pressure of the plant is 5 $mbar_a$. Then the connection with the vacuum pump is closed and the plant is filled with nitrogen till a pressure of 1 bar_a. These operations are repeated 3 times in order to reach reduction of the air content inside the plant at a level (10^{-9} $g_{air}/g_{nitrogen}$). Since the distillation process is under vacuum the plant is left at 5 $mbar_a$.

- *Process startup:* In this section are described the preliminary operation for starting up the plant in internal loop mode. The process starts opening the hot oil and the chilled water circuits and filling the column bypassing the plant with LAB from the feed tank. If the hot oil and the chilled water system are working, it is possible to start the hot oil resistances to reach the desired temperature.
- *Distillation Startup in Loop Mode:* In this section are described the operation to be performed to start the distillation process in loop mode. In particular after the filling of the feed tank T-101 with Nitrogen, the column C-101 and the tanks T-102 and T-103 (product tank and bottom tank) are connected to the Vacuum Pumps in order to keep the pressure at a 5 mbar. After reaching the proper level in the column, it is possible to open the hot oil valve to the column in order to heat the LAB. When the LAB starts to be vaporized in the reboiler and subsequently condensed in the condenser, some liquid level starts to build on the sieve trays because al the condensed LAB is sent back to the column as reflux. If the level in the column drops under the lower limit it is mandatory to refill the column with LAB from T-101. When the reflux flow is 9 m3/h it is possible to open the valve to the product tank T-102 and start to collect the distilled LAB in the product tank. In the meanwhile, it is mandatory to start the flow LAB form T-101 to the column. When the level in T-102 is higher than the low limit alarm it is possible to pump the distilled LAB back to the feed tank.
- *Process Operation, Controls*: In this chapter are described the action to be taken during the switching from internal loop mode and continuous distillation mode. The operation is simply opening the proper valves to stop the flow of the distilled LAB back to T-101 while clearing the piping to the next purification process.
- *Draining of the Distillation bottoms:* For purification, the distillation process works by evaporating higher volatility components, while leaving behind the contaminants, which are typically heavier (heavy metals, suspended particles etc). The liquid remaining in the evaporation column is called "bottoms" and it concentrates the

impurities. In this chapter are described the action to be taken to remove part of the liquid inside the column in order to avoid the buildup of the contaminants.

- *Drain of the plant:* When the plant will be not operated for a long time, a complete drain of the plant is required. The actions described in this chapter lead to a complete drain of the plant.
- *Change output filter:* If the difference between the pressure before and after the filter is too high it means that the filter are plugged. In this section are listed the operation to be performed to remove and replace the filter with clean ones.
- *Drain of E-105*: the pressure in the column is constantly kept at 5 $mbar_a$ with a connection to the vacuum pump through E-105. E-105 is a small condenser, refrigerated with chilled water, the prevent any LAB vapor to reach the vacuum pump. If the level in E-105 became too high, it is necessary to remove the collected liquid following the operation described in this chapter.
- *Process Stop/Standby and Shutdown*: the process can be stopped by the operator if some maintenance is needed or by the control system if an alarm happens. In this chapter are described to be taken to bring the plant in the following conditions:
    - Internal loop mode: the distillation is still ongoing, but the plant is disconnected from the general JUNO LS purification process
    - Software Process Shutdown: the distillation is stopped, and the plant is disconnected from the general JUNO LS purification process

Alarms: in this section are enlisted al the alarms threshold for each value measure by the instruments mounted on the plants and the actions to be taken in order to mitigate the effect of the alarm.

Equipment List: Table with name, position, and description of all the components of the plant

Instrument List: Table with name, position, and description of all the instruments of the plant

Valve List: Table with name, position, and description of all the valves of the plant

Distillation Plant Layout: Drawings of the general layout of the plant

2.5 Stripping Operation Procedure

This procedure offers a very comprehensive description of the good practices for the operation of the Stripping plant. These procedures are annexed to this thesis in the **Errore. L'origine riferimento non è stata trovata.**. These procedures assume the plant is commissioned and functionally tested. It is also assumed that the system has already at least a minimal inventory of Liquid Scintillator. This procedure refers to Slow Control instructions, by referring to the control loop or equipment, but do not refer to specific graphical pages, which are under constant revision and upgrade. It is assumed here that the operator is familiar with logging into and using the Slow Control System and has a valid individual operator's account.

Following a brief description of the procedure section:

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Purification of Liquid Scintillator: This section provides a very detailed description of the general operating procedures for starting, running, and stopping the distillation plant. The operation list refers to the Slow Control instruction and it assumes that the plant is commissioned and functionally tested. This chapter is divided into several sections, each containing a brief description of a singular process and the action to take in order to successfully achieve the operation. The processes described are:

- *Pre-Start Checkout:* a list of the administrative operations to fulfill (i.e., authorization request, check of any restriction) and a list of the equipment, utilities and services to be checked before the before starting the plant.
- *Purging Vacuum/Nitrogen:* Before operating the plant is mandatory to remove any air present in the plant and to replace it with Nitrogen. In this section are listed the action to perform to reduce the contentment of air to a negligible level. The plant

sections are firstly emptied through the vacuum pumps sequentially till the pressure of the plant is 5 $mbar_a$. Then the connection with the vacuum pump is closed and the plant is filled with nitrogen till a pressure of 1 bar_a. These operations are repeated 3 times in order to reach reduction of the air content inside the plant at a level (10^{-9} $g_{air}/g_{nitrogen}$). Since the distillation process is under vacuum the plant is left at 5 $mbar_a$.

- *Process startup:* In this section are described the preliminary operation for starting up the plant in internal loop mode. The process starts opening the hot oil and the chilled water circuits bypassing the plant and filling the stripping column with LS from the feed tank. If the hot oil and the chilled water system are working, it is possible to start the hot oil resistances are turned on in order to reach the desired temperature.
- *Stripping Startup in Loop Mode:* In this section are described the operation to be performed to start the distillation process in loop mode. The first operation is to create a Nitrogen blanket in the feed tank T-201 and in the product tank T-202. Then, the stripping column C-201 is connected to the Vacuum Pumps in order to keep the pressure at a 200 mbar. When the pressure in the columns is correct it is possible to start the flow of LS from the feed tank to the column C-201 through the input filter and then open the hot oil valve to heat the LS passing through E-201. After reaching the correct level inside C-201 it is possible to pump the LS to the product tank and start to collect the LS in T-202. When the level in T-102 is higher than the low limit alarm it is possible to pump the distilled LAB back to the feed tank. After the establishment of the loop, it is possible to start producing steam and start the purification process. In order to do so, the steam line heater should be turned to avoid any condensation of the steam inside the line, and the valves on the hot oil line and on the Ultra-Pure Water line to the steam producer E-205 should be open. When the Temperature in E-205 reach 90°C it is possible to start the steam flow opening the valves on the steam line
- *Process Operation, Controls*: In this chapter are described the action to be taken during the switching from internal loop mode and continuous distillation mode. The operation is simply opening the proper valves to stop the flow of the distilled LAB back to T-201 while clearing the piping to JUNO Detector filling station.
- *Drain of the plant:* When the plant will be not operated for a long time, a complete drain of the plant is required. The actions described in this chapter lead to a complete drain of the plant.

- *Change output filter*: If the difference between the pressure before and after the filter is too high it means that the filter are plugged. In this section are listed the operation to be performed to remove and replace the filter with clean ones.
- *Drain of E-203:* the pressure in the column is constantly kept at 200 $mbar_a$ with a connection to the vacuum pump through E-203. E-203 is a small condenser, refrigerated with chilled water. The steam condenser has to be emptied regularly to avoid the level in E-203 became too high.
- *Process Stop/Standby and Shutdown:* the process can be stopped by the operator if some maintenance is needed or by the control system if an alarm happens. In this chapter are described the actions to be taken to bring the plant in the following conditions:
  - Internal loop mode: the distillation is still ongoing, but the plant is disconnected from the general JUNO LS purification process
  - Software Process Shutdown: the distillation is stopped, and the plant is disconnected from the general JUNO LS purification process

Alarms: in this section are enlisted all the alarms threshold for each value measure by the instruments mounted on the plants and the actions to be taken in order to mitigate the effect of the alarm.

Equipment List: Table with name, position, and description of all the components of the plant

Instrument List: Table with name, position, and description of all the instruments of the plant

Valve List: Table with name, position, and description of all the valves of the plant

Stripping Plant Layout: Drawings of the general layout of the plant

2.6 Plants Erection

Despite the significant delays due to the global pandemic situation, the construction of the underground laboratory, started in 2018, was continued in the following years. However, not being able to guarantee the presence of personnel from Polaris s.r.l., the manufacturing company, during the assembly phase of the purification plants at the experiment site, it was necessary to provide the collaboration with an alternative solution involving assembly by a Chinese company.

For this reason, we have produced the procedures for the correct installation of the distillation and stripping systems (see **Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.**) and, thanks to the comparison with the engineers of the company Polaris s.r.l., we defined the correct sequence for connecting the various skids that make up the two systems. In particular, we pay particular attention to transcribing all those good practices acquired during the experience in the design, construction and operation of these systems that were intended to minimize the risk of damage to the most delicate parts, such as the connections between the skids, the instruments and the valves already mounted.

In the beginning of 2022, we traveled to China in order to coordinate the Chinese mounting company for the erection of the Distillation Plant in the overground Distillation Hall and of the Stripping Plant in the underground Purification Hall.

In the next section I present a brief description of the Distillation Plant Erection procedure and the Stripping Plant Erection Procedure.

2.7 Distillation Plant Erection procedure

In this procedure is reported the optimal sequence considered by Polaris and agreed with INFN for the erection of the Distillation plant. This procedure is annexed to this thesis in **Errore. L'origine riferimento non è stata trovata.** and was used for the assembling of the Distillation Plant form 20th April 2022 to 29th April 2022.

The procedure includes several references to other engineering documents, and it assumes that all contractors involved for the required works are supposed to carry out an adequate site survey.

The main purpose of this procedure is to describe in detail the correct process to assembly each unit in which the Distillation plant is divided. The units are prefabricated, and skid mounted. The general arrangement of each unit is shown in the layout drawing (Fig. 12). All the main equipment, including piping, insulation, instrumentation, etc., are pre-installed on the skids, excluding the interconnecting piping lines already prefabricated and to be connected on site. Most of the instruments are pre-wired up to junction boxes provided on skids; the motors are not pre-wired since a direct connection from the electrical panel is required. Some other materials, which are part of the supply, are delivered loose.

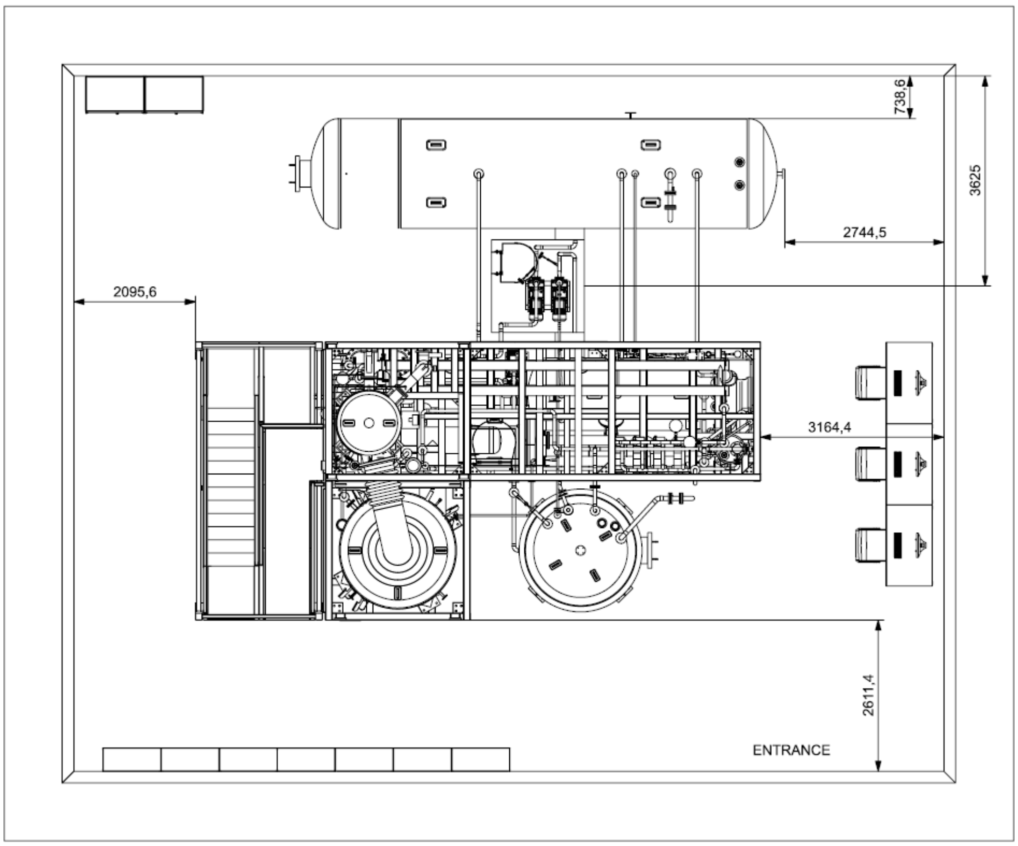

Fig. 12 Layout of the Distillation Plant

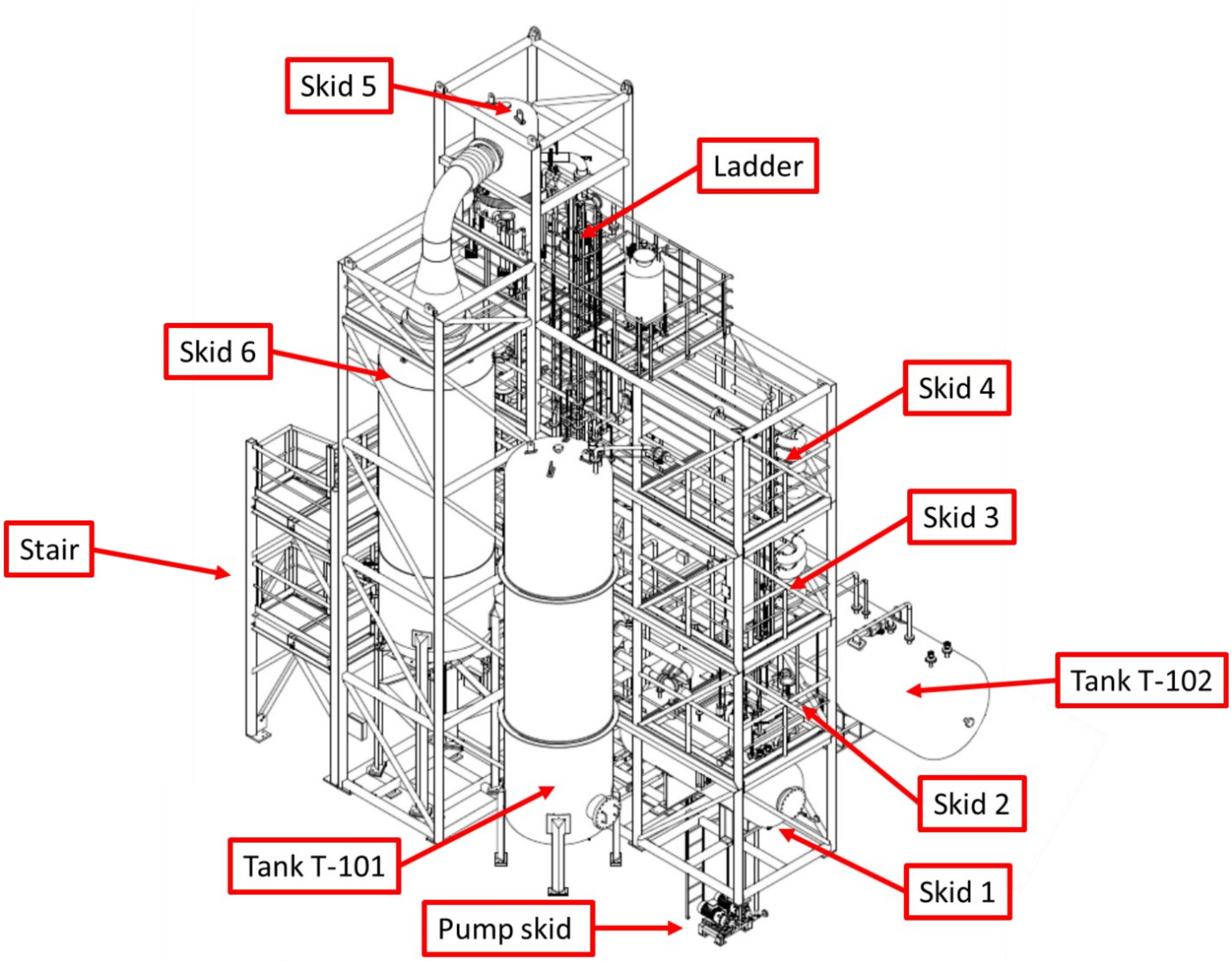

Fig. 13 Skids composing the Distillation plant.

A brief description of the procedure section is set out below:

Description of the plant: In this section, the units in which the distillation plant is divided are listed. From assembly point of view, the plant is composed of the following main parts (see Fig. 13):

- N. 6 prefabricated skids: n° 1 to 4 are horizontal skids, 5 and 6 are vertical skids
- N. 1 stair
- N. 2 external tanks (one vertical and one horizontal)
- N. 1 pump skid

Interconnecting piping between skids and tanks, and other small parts, are delivered loose.

Erection scope of work: The Distillation plant erection procedure could be divided in 3 different phases:

- Phase 1: transportation of plant components to JUNO site near the LS ground hall, the erection of all the main plant components and finally the ground anchoring with chemical bolts.
- Phase 2: interconnection of the pipelines mounting and coupling and installation of instruments and sensors. It also includes the cleaning and leak test of flange surfaces, the installation of the electric cabinet, electric connections, cabling of pumps, instruments, and other devices.
- Phase 3: first start-up and the early commissioning of the plant.

Unloading, Handling and Storage operations: The Distillation plant was sent from Italy to China via ship inside container. In this chapter are described the proper actions to unload the units from the container and how to store them before assembling.

Transport and preparation for installation: The Distillation plants units will be installed removing the roof of the Overground Distillation Hall and they can weight up to 10545 kg. In this chapter are described the proper means to use to move the skids (crane, forklift, and slides) and the actions to take to unload them from the container. Before the installation it also required to draw on the ground the final position in order to check the distances with the walls and between the skids

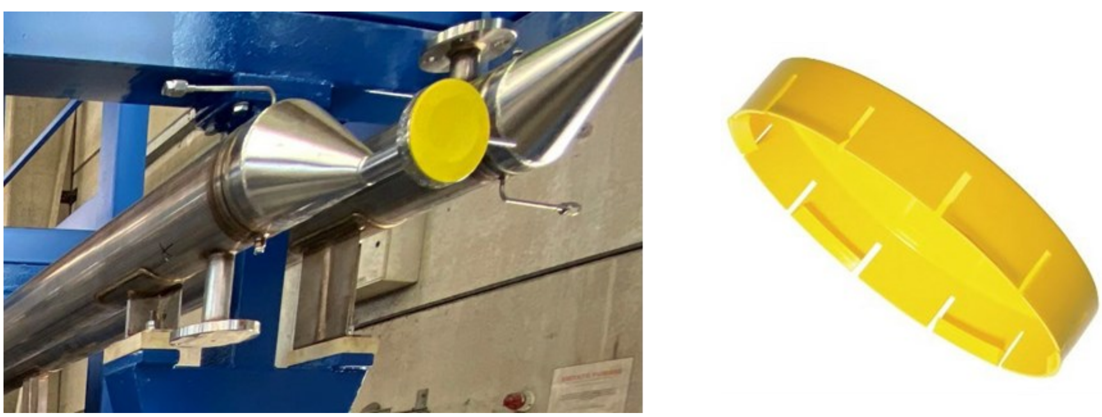

Fig. 14 Plastic cap to be used for protecting the opened flange after the removal of the blind flange

Erection sequence: Introduction and general description: The erection of the plant could be performed in 9 days. In this section are enlisted the general operation that should be done in each day. Special attention should be paid while removing the blind flange on the interconnection, because they are exposed to the risk of damaging. So, it is necessary to protect them with caps and plastic sheet before placing the skid (see Fig. 14).

Detailed description of the erection sequence: the operations to be done for the erection of the Distillation plant are:

- Removal of the roof of the building
- Insertion of tank t-102 into the building
- Positioning of the pumps inside the well
- Insertion of the line 121, 122, 106 and 127 inside the pump well
- Positioning of skid 1
- Check relative position of t-102 tank, skid 1 and pump skid
- Anchoring of skid 1 and t-102 tank to the ground
- Positioning of skid 2 on skid 1
- Positioning of skid 3 on skid 2
- Positioning of skid 4 on skid 3
- Erection and positioning of skid 6 (vertical skid)
- Erection and positioning of skid 5 on skid 4
- Mounting of line 163 from c-101 to e-102
- Positioning of t-101 vertical tank
- Stairs
- Mounting of the internal ladder
- Anchoring of skid 6, tank t-101 and stairs
- Close the roof of the building

Other mechanical works: In this section are described the operation to finalize the plant installation and connect the Distillation plant with the other plants and auxiliary systems in the LS Hall after the plant positioning and the main erection activities have been completed. The flanges those requires the use of Karlez O-ring are listed in this chapter.

Electrical works: Description of the activities to be done on the power cabinet and how to connect the instruments to the control system

Cleaning procedures and background control strategies: Background control is one of the main issues to reach JUNO detection goals. In this section are enlisted the dedicated operations and strategies adopted to remove and control the exposure of all internal surfaces to radioactive contaminants. All the precautions taken both during construction and installation phases will be listed.

2.8 Stripping Plant Erection procedure

In this procedure is reported the optimal sequence considered by Polaris and agreed with INFN for the erection of the Stripping plant. This procedure is annexed to this thesis in **Errore. L'origine riferimento non è stata trovata.** and was used for the assembling of the Distillation Plant form 29th April 2022 to 05th May 2022.

The procedure includes several references to other engineering documents, and it assumes that all contractors involved for the required works are supposed to carry out an adequate site survey.

The main purpose of this procedure is to describe in detail the correct process to assembly each unit in which the Stripping plant is divided. The units are prefabricated, and skid mounted. The general arrangement of each unit is shown in the layout drawing. All the main equipment, including piping, insulation, instrumentation, etc., are pre-installed on the skids, excluding the interconnecting piping lines already prefabricated and to be connected on site. Most of the instruments are pre-wired up to junction boxes provided on skids; the motors are not pre-wired since a direct connection from the electrical panel is required. Some other materials, which are part of the supply, are delivered loose.

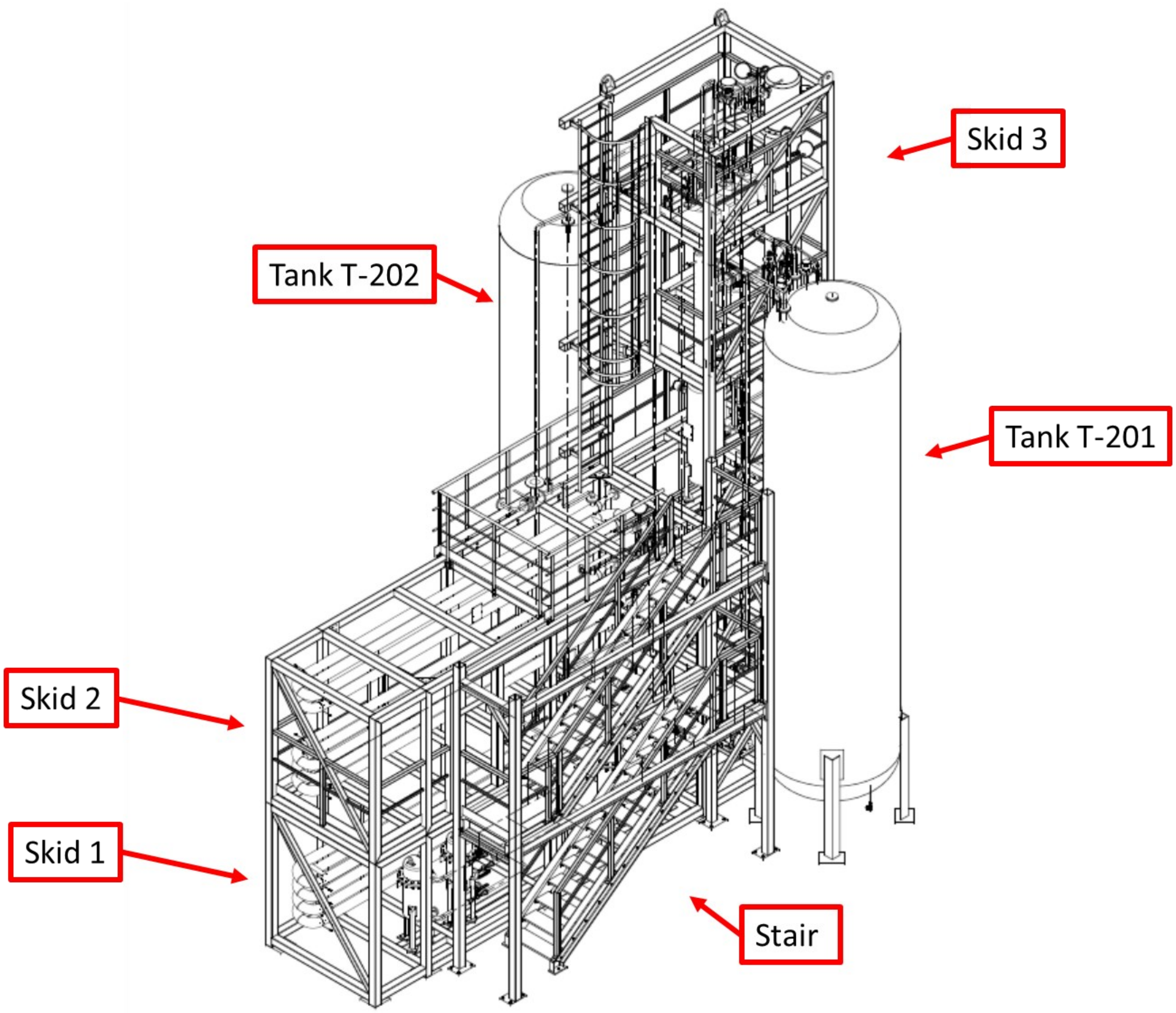

Fig. 15 Skid composing the Stripping plant

A brief description of the procedure section is set out below:

Description of the plant: In this section, the units in which the stripping plant is divided are listed. From assembly point of view, the plant is composed of the following main parts (see Fig. 15):

- N. 3 prefabricated skids: n° 1 and 2 are horizontal skids, 3 is a vertical skid
- N. 1 stair
- N. 2 external vertical tanks

Interconnecting piping between skids and tanks, and other small parts, are delivered loose.

Erection scope of work: The Stripping plant erection procedure could be divided in 3 different phases:

- Phase 1: transportation of plant components to JUNO site near the LS ground hall, the erection of all the main plant components and finally the ground anchoring with chemical bolts.
- Phase 2: interconnection of the pipelines mounting and coupling and installation of instruments and sensors. It also includes the cleaning and leak test of flange surfaces, the installation of the electric cabinet, electric connections, cabling of pumps, instruments, and other devices.
- Phase 3: first start-up and the early commissioning of the plant.

Unloading, Handling and Storage operations: The Stripping plant was sent from Italy to China via ship inside container. In this chapter are described the proper actions to unload the units from the container and how to store them before assembling.

Transport and preparation for installation: The Stripping plants units will be installed in the underground Liquid Scintillator Hall. It will be bring underground using a transportation rail truck and the in the skids are installed some plate to secure the unit to the truck. In the liquid scintillator hall is installed a crane that can move only on the central axis of the room, so in this chapter are described the proper means to use to move the skids inside the hall using a forklift and sliding blocks or skates. Before the installation it also required to draw on the ground the final position to check the distances with the walls and between the skids

Erection sequence: Introduction and general description: The erection of the plant could be performed in 5-6 days. In this section are enlisted the general operation that should be done in each day. Special attention should be paid while removing the blind flange on the interconnection, because they are exposed to the risk of damaging. So, it is necessary to protect them with caps and plastic sheet before placing the skid on over the other (see Fig. 14).

Detailed description of the erection sequence: In this section, the erection sequence will be described in detail, step by step. The operations to be done for the erection of the Stripping plant are:

- Positioning of skid 1
- Installation of vertical ladder on skid 3
- Erection and positioning of skid 3
- Positioning of skid 2
- Erection of T-201 tank
- Erection of T-202 tank
- Stair
- Fixing and ground anchoring

Other mechanical works: In this section are described the operation to finalize the plant installation and connect the Stripping plant with the other plants and auxiliary systems in the LS Hall after the plant positioning and the main erection activities have been completed. Part of the plant should be insulated in order to deliver the liquid scintillator to the stripping column at the proper temperature.

Electrical works: Description of the activities to be done on the power cabinet and how to connect the instruments to the control system

Cleaning procedures and background control strategies: Background control is one of the main issues to reach JUNO detection goals. In this section are enlisted the dedicated operations and strategies adopted to remove and control the exposure of all internal surfaces to radioactive contaminants. All the precautions taken both during construction and installation phases will be listed.

2.9 Slow Control

It has been decided to adopt a Siemens system for distributed automation because it guarantees good performances in terms of reliability and a modular and safety-oriented design. Moreover, it can be used in hazardous area (ATEX Zone 2). The Interface and CPU module chosen is the 1512SP-1PN model that assures different communication options between the PLC and the PC and the possibility to integrate a channel specific diagnostic.

The DCS can be controlled and monitored via a SCADA application, designed integrating an operator friendly User Interface (UI), with the purpose to permit a quick learning of the plant operations and to easily understand the cause of any alarms generated by the DCS and then solve to them. This application runs on a Local PC, where it saves all the processes parameter values every minute, and it is linked to the PLC via an Ethernet connection.

The general UI is divided in three tabs: an overview of the plant (see Fig. 16), an alarm panel and a trend panel.

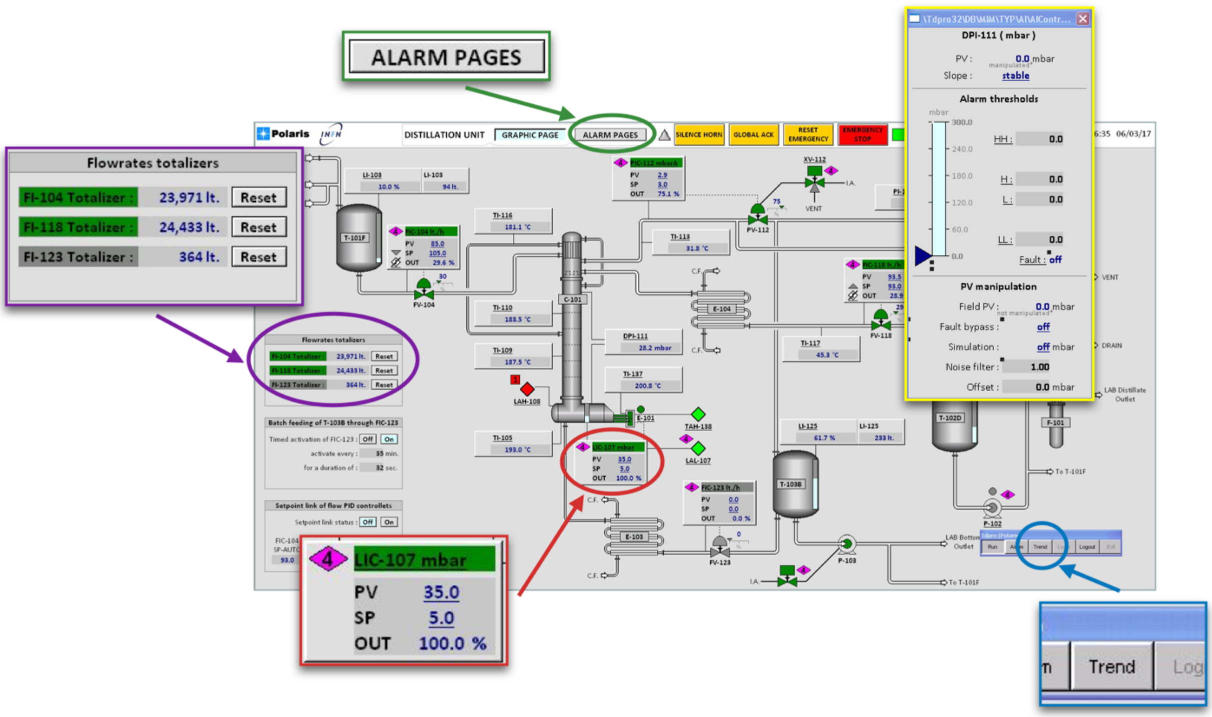

Fig. 17 The slow control User Interface (UI) is designed in order to guarantee a fast identification of the values of the process parameter. It is possible to set each instrument alarm thresholds (HighHigh, High, Low and LowLow) and to adjust the process parameters with the instrument panel. In the Alarm Pages tab are collected all the previous and active alarms and it is possible to examine the progress of each instrument value with the trend graph. The slow control User Interface (UI) shows also the flowrates totalizer keeping always under control the amount of processed LS.

In the first tab, the core of the UI, it is possible to set the process parameters and the alarm thresholds, open and close the automatic valve and turn on and off the pumps. Here the measured value of each instrument connected to the DCS are also displayed.

The second panel collects all the alarms that are active or were active, but not acknowledged, while in the last it is possible to monitor the trend over the time of the process values, that are also saved on the PC.

The DCS also manages part of the safety rules that prevent any damage to the plant and to the operators. It prevents the switch-on of the equipment if the correct conditions are not satisfied: for example, if the LAB level in distillation reboiler is not high enough the heaters cannot be turned on.

It is foreseen also an account-based system in order to establish a hierarchy between users of the DCS and to give the privileges of change the settings only to the properly trained operators and just monitor capabilities to the guests.

Part of the content of this chapter is based on the following publication:

P. Lombardi, *et al* "Distillation and stripping pilot plants for the JUNO neutrino detector: Design, operations and reliability", NIMA A, 925, 2019,6-17, https://doi.org/10.1016/j.nima.2019.01.071.

A. Abusleme, *et al.* "Optimization of the JUNO liquid scintillator composition using a Daya Bay antineutrino detector", NIMA A, 988, 2021, 164823, https://doi.org/10.1016/j.nima.2020.164823.

3.

WAVEFORM ANALYSIS AND CHARGE RECONSTRUCTION

3.1 Introduction

The Liquid Scintillator (LS) technology is widely used to detect particles such as neutrinos and antineutrinos. The primary experimental challenges in neutrino calorimetry involve enhancing both the energy and spatial resolution of detecting (anti)neutrino interactions. As both resolution terms are proportional to the number of detected scintillation photons, optimizing the detector's photo coverage, i.e., its sensitive area, is crucial to improve resolution. In many current and future detectors, due to technical and budget limitations, the utilization of large-area Photo Multiplier Tubes (PMT) is the only feasible solution to achieve large photo coverage. However, because of their high acceptance, these PMTs typically detect numerous photoelectrons (pe) per scintillation event, resulting in a pile-up of signals at the readout level, making their identification difficult. Biased PMT charge reconstruction jeopardizes the linearity of the detector's energy estimator and threatens the time-based reconstruction of the event vertex.

This study has two objectives: (i) proposing an open-source detector-independent charge reconstruction algorithm that processes the output of a generic fast digitizer (FADC) connected to a PMT and (ii) defining a procedure to evaluate the accuracy of the reconstructed charge, primarily in scenarios with significant pe pile-up.

3.2 Photo-Multiplier tubes waveform simulation

We build a PMT waveform simulation with the aim to develop and validate the charge reconstruction algorithm with a known input signal. To avoid relying on the specification of a given manufacturer and/or model, we implement a parametric simulation of a generic PMT response. The emission of a pe from the photocathode, its collection by the anode, and its subsequent amplification are simulated as an instantaneous PMT charge output. In accordance with experimental data [56], the charge value q is generated randomly according to the distribution f(q) in eq. 10 , adapted from [57].

$$f(q) = \begin{cases} (1-\omega)\,(1/(\sigma\sqrt{2\pi}))exp[-(q-q_0)^2/2\sigma^2] + (\omega/\tau)exp-(q/t) & q \geq q_p \\ 0 & q < q_p \end{cases} \tag{10}$$

Table 13 Parameters used in eq. 10 together with their nominal values.

Parameter	Description	Value
q_0	SPE calibrated gain	1 PE
q_p	Pedestal cutoff	0.3 PE
σ	SPE Gauss width	0.3 PE
ω	Under-amplified PE function	0.2
τ	Exponential decay constant	0.5 PE

Table 14 Parameters involved in the signal (top rows) and noise (bottom rows) simulation of the PMT waveform. Parameters for which the "Range" column is filled are generated randomly according to a flat probability density function at the beginning of the simulation.

Parameter	Value	Range	Description	Function
U_0	20 ADC		SPE template	
σ_0	0.15			
τ_0	30 ns			
U_1	-1.2 ADC		Overshoot	
σ_1	55 ns			
τ_1	-4 ns			
U_2	-2.8 ADC		Overshoot	
τ_2	80 ns			
μ_N	1.5 ADC		Baseline White Noise	
σ_N	1 ADC			
n_{FF}	5		# Components	
f_{FF}		[1, 480] MHz	Frequency	
A_{ff}		[0.1, 0.3] ADC	Amplitude	

The weight ω determines the relative contribution of a Gaussian distribution with respect to an exponential tail, modeling the faction of under-amplified pes. The width of the former (σ) is set to 30% to describe the typical uncertainty induced by the first dynode amplification ($\sim 1/\sqrt{10}$). The Gaussian mean value (q_0) is set to 1, as in the case of a perfect gain calibration. The exponential tail accounts for low amplitude hits due to elastically scattered and backscattered electrons from the first dynode [57]. The parameter q_p sets the threshold for the minimum charge to be considered in order to avoid simulating the pedestal. The values of all the parameters used in eq. 10 are listed in Table 13, and the analysis of their variability is described in section **Errore. L'origine riferimento non è stata trovata.**. The time at which a charge output occurs is randomly sampled from a flat distribution spanning a 1 µs-long time window, and each charge-time pair is defined as a hit.

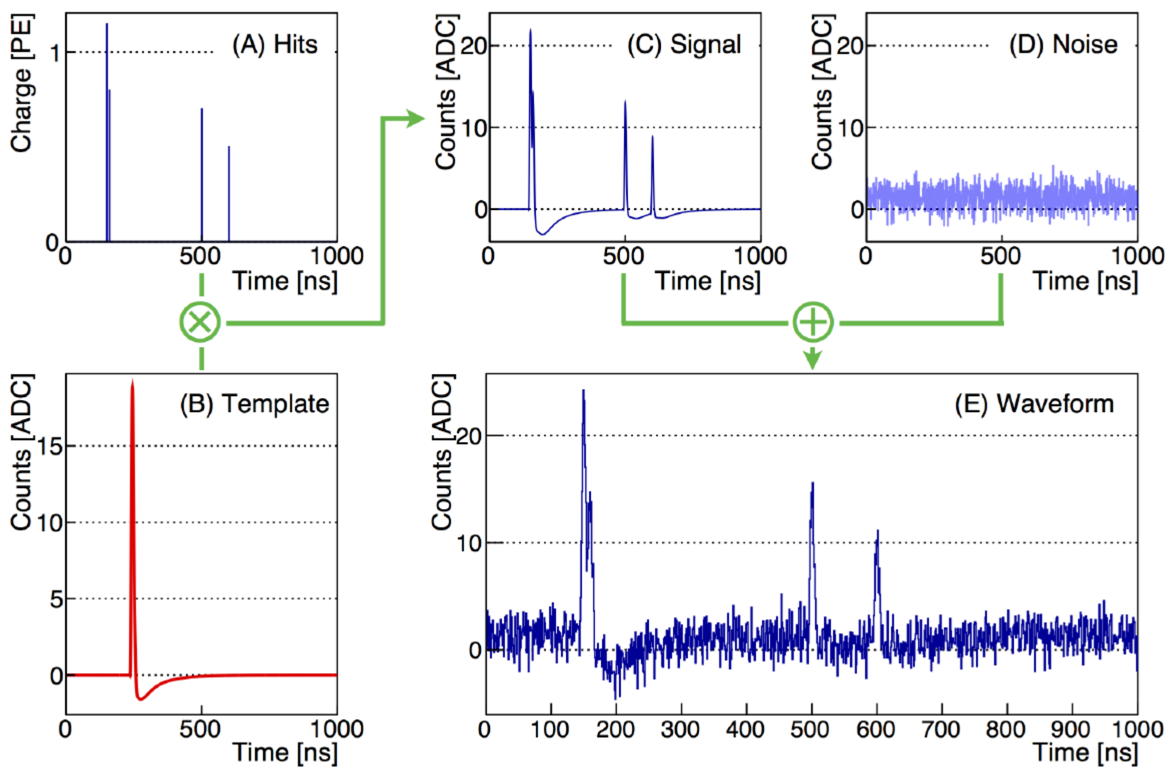

Fig. 18 Building blocks of the waveform simulation. Panel A shows the hit generation, where for each detected pe a random charge value is generated. Panel B shows the analytical shape of a single pe template. Panel C is the result of the convolution between the spe template and the hits. Panel D contains the pmt simulated noise. Panel E shows the final PMT waveform resulting from the sum of the signal and of the noise components.

A sequence of hits, resulting from several pes impinging on the same PMT, are shown as instantaneous pulses in Fig. 18a. The pulse position on the horizontal axis represents the hit time with respect to a reference t_0 —for example a global detector trigger—, and the pulse amplitude represents the PMT output charge. We assume the PMT to be connected to a fast electronics able to sample its output at 1 GSample/s, and we describe the voltage drop resulting from the detection of each hit with a log-normal function (eq. 11) [56-58]. The AC coupling often used to split the PMT high-voltage from the PMT output signal might induce a distortion in the PMT output waveform.

We refer to the component of the signal with a polarity opposite to the log-normal as the overshoot, and we follow [56] to describe it using the sum of a Gaussian (eq. 12) and an exponential tail (eq. 13). The values of the parameters used in eq. 11, 12 and 13 are listed in Table 14. The values related to the spe amplitude are chosen to obtain an approximate

0.5 mV/count resolution, resulting in a dynamic range of 50pe when using a commercial 10-bit digitizer. The overshoot values are adapted from the Daya Bay experience [15]. The analytical shape of a spe-waveform is reported in eq. 14 and shown in Fig. 18b. We name this shape the spe template. The signal-only waveform resulting from the hits shown is Fig. 18a is built by convolving each hit with the spe template, and it is shown in Fig. 18c.

$$U_{peak}(t) = U_0 \cdot \exp\left(-\frac{1}{2}\left(\frac{\ln(t/\tau_0)}{\sigma_0}\right)^2\right) \tag{11}$$

$$U_{OS1}(t) = U_1 \cdot \exp\left(-\frac{1}{2}\left(\frac{t-t_1}{\sigma_1}\right)^2\right) \tag{12}$$

$$U_{OS2}(t) = U_2 \cdot \frac{1}{1+\exp\left(\frac{50\,ns - t}{10\,ns}\right)} \cdot \exp\left(-\frac{t}{\tau_2}\right) \tag{13}$$

$$U(t) = U_{peak}(t) + U_{OS1}(t) + U_{OS2}(t) \tag{14}$$

To make the simulation more realistic, we add a noise waveform (Fig. 18d) to the waveform built using only signal hits. The simulated noise includes a Gaussian component and some periodic components with fixed frequency. The former describes an overall baseline offset and time uncorrelated baseline fluctuations. The Gaussian mean (N) is set to 1.5 ADC counts, and the Gaussian width (N) to 1 ADC count. The fixed-frequency components describe potential noise sources embedded in, or due to, the readout circuit. We simulate 5 such components (nFF), with a random amplitude generated flat in the 0.1-0.3 ADC counts range, and with a random frequency in the 1-480 MHz range. The ultimate waveform comprising signal hits and all noise components is shown in Fig. 18e.

3.3 Charge reconstruction

The simplest way to determine the PMT output charge is to sum up all the waveform samples collected in a readout window. However, this approach would embed both the noise and the overshoot into the charge measurement, resulting in a rough and biased charge estimator. The charge reconstruction algorithm described in this section and sketched in Fig. 19 is meant to mitigate the role of both noise and overshoot. It comprises two steps: (i) the Deconvolution Algorithm (DA), which filters the raw waveforms reducing the noise, and deconvolves spe templates out of the filtered waveforms; and (ii) the Integration Algorithm (IA), which integrates the deconvolved waveforms with the aim to determine the overall PMT output charge.

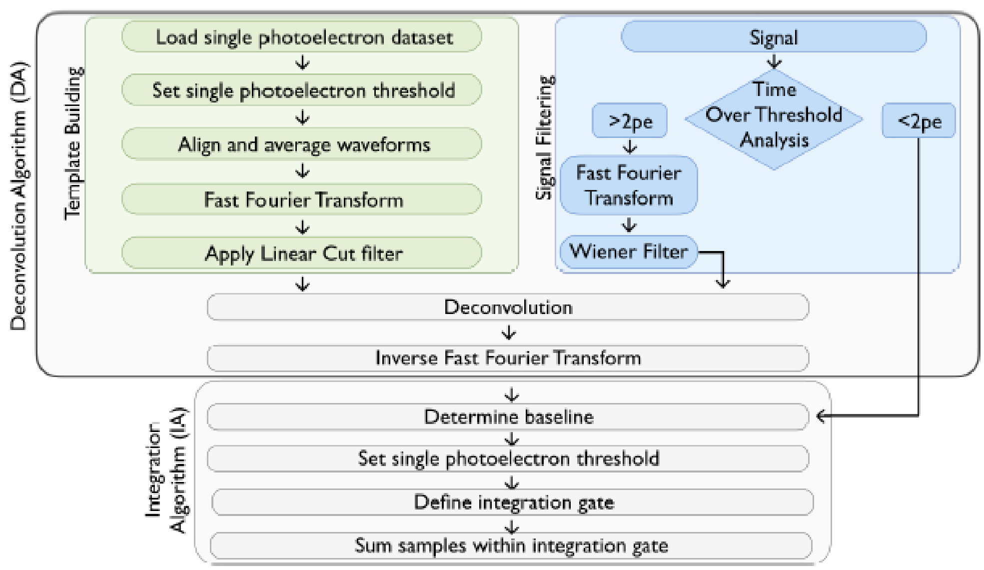

Fig. 19 Schematic diagram of the charge reconstruction algorithm. The spe template in the time domain is computed by averaging 104 spe waveforms that simulate a LED-based calibration dataset. A Fast Fourier Transform (FFT) is applied to both the spe template and the PMT waveform to be reconstructed. The latter is processed using the Wiener Filter to minimize the noise and suppress the overshoot. The spe template in the frequency domain is then used as a benchmark pattern to deconvolve the filtered waveform in the frequency domain. We eventually process the deconvolved waveform with an Inverse FFT, so that the waveform in the time domain could be integrated to compute the PMT output charge.

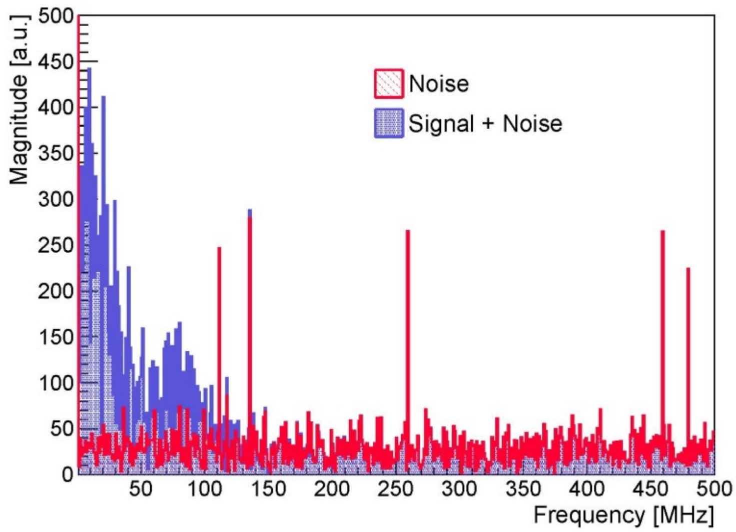

Fig. 20 Frequency power spectra of a pure-noise waveform (red) and a complete waveform comprising noise and pe pulses (blue). The two spectra are used in eq. 15 to derive the Wiener Filter. The spikes in the noise spectrum are due to the fixed-frequency noise components.

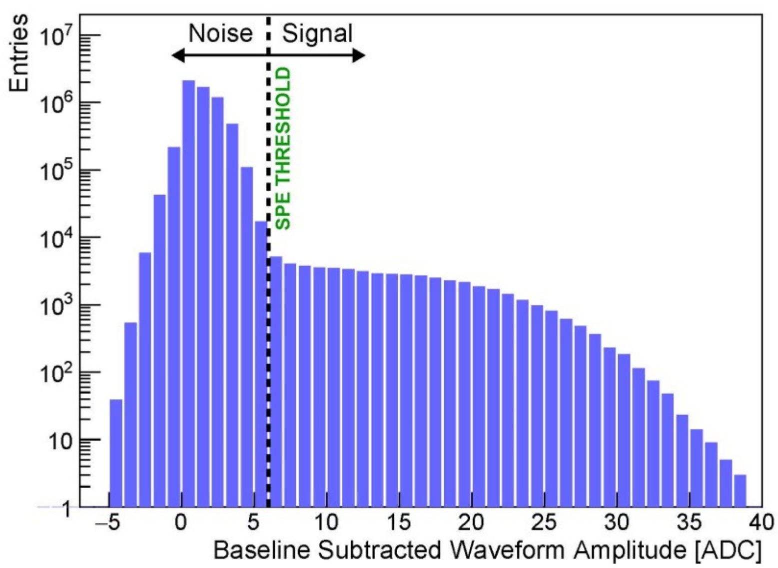

Fig. 21 Distribution of all the baseline-subtracted FADC samples in a waveform, built using 10^4 waveforms containing mostly 0 or 1 hit (dataset S). Noise fluctuations are responsible for the peak centered at zero. FADC samples related to the fraction of the waveform where spe pulses occurred are responsible for the tail extending to large ADC values. A 6 ADC trigger threshold is chosen to identify waveforms where at least 1 hit is present.

Both filtering and deconvolution are data-driven methods that need to be trained and tested. To this end, we rely on waveforms generated using the simulation package described in section 2. We produce two large datasets, one comprising mostly spe waveforms (S dataset), and one with waveforms containing multiple hits (M dataset). In order to emulate a real experimental setup, the charge reconstruction algorithm is designed not to use the true hit information (time and charge). We unblind such parameters only when assessing its performance —as described in section 4. The first dataset emulates the behavior of a low-intensity LED placed in front of a PMT to measure its spe response, where one typically gets either 0 hits or a single hit in the resulting waveform ($p(0) \cong 0.3, p(1) \cong 0.6, p(>1) \cong 0.1$) . In the second dataset, waveforms are generated such that the number of true hits follows a flat distribution in the [0-15] range. This distribution is chosen to investigate the performance of the reconstruction algorithm even in those events experiencing high pile-up. The noise pattern present in simulated waveforms consists mostly of bin-to-bin uncorrelated fluctuations. On the contrary, a spe pulse lasts for a few tens of ns. The difference between the two time-scales is highlighted in Fig. 20, where the frequency spectra of a waveform with no hits (pure noise, red curve) and a waveform with 4 hits (blue curve) are compared. The former is rather flat, except for the fixed-frequency noise components, which manifest as spikes in the frequency domain. The latter, on the contrary, is peaked at low frequencies, because of spe pulses being much slower than the noise fluctuations. We exploit such a difference to suppress the noise by means of a Wiener Filter —a technique commonly employed in signal processing [59]. The filter is defined by the following kernel equation

$$H[f] = \frac{|S[f]|^2}{|S[f]|^2 + |N[f]|^2} \tag{15}$$

where $S[f]$ and $N[f]$ are the frequency spectra of the signal and of the noise. In literature, this filter is referred to as the optimal linear filter for the removal of additive noise [60]. Namely, the coefficients $H[f]$ of the Wiener Filter are calculated to minimize the average squared distance between the filter output and the desired signal [61]. Such coefficients are then used to weight the frequency components of the waveform being processed.

Eq. 15 can be rearranged by dividing both the numerator and the denominator by the noise power spectrum $|N[f]|^2$, and by substituting the variable $SNR[f] = |S[f]|^2/|N[f]|^2$. This manipulation yields

$$H[f] = \frac{SNR[f]}{SNR[f] + 1} \tag{16}$$

where SNR is a ratio of the signal power to the noise power. Eq. 16 makes the frequency response of the filter more intuitive, being a real positive number in the range $0 \le H[f] \le 1$. Frequencies that are barely affected by noise ($SNR[f] \to \infty$) result in the filter being close to unity, hence applying little or no attenuation to the input components. On the contrary, frequencies that are severely affected by noise ($SNR[f] \sim 0$) result in the filter to heavily attenuate them ($H[f] \sim 0$). In summary, the Wiener Filter attenuates each frequency component in proportion to an estimate of its signal-to-noise ratio.

The deconvolution is a technique meant to identify and resolve the presence of spe pulses within a filtered waveform, with the aim to perform an unbiased measurement of the PMT output charge. It is implemented as a division in the frequency domain between the waveform to be reconstructed and the template of a spe pulse. We build the template by time-aligning and averaging 104 spe waveforms selected from the S dataset, which emulates calibration data collected by illuminating the PMT with a low intensity LED. The selection determining which waveforms are to be used in the template building is based on a threshold-crossing criterion: only waveforms whose baseline subtracted amplitude exceeds 30% of the mean spe amplitude are retained. The distribution of all the digitized samples in the S dataset (1000 samples per waveform) is shown in Fig. 21, where the selection threshold clearly marks the transition between the noise region and the signal region. To further clean the spe template from those noise contributions not suppressed by the averaging process, all frequencies above 120 MHz are stripped.

The outcome of the deconvolution performed on the waveform in Fig. 18e is shown in Fig. 22. The deconvolved waveform is brought back to the time domain by means of an Inverse Fast Fourier transform, and it shows narrow pulses whose amplitude is proportional to the original hit charge. However, rather than using the pulse amplitude, we find a better estimator of the hit charge to be the integral of the pulse.

To minimize the contribution of residual noise to the pulse integral, and the possible biases arising from the ringing visible in the vicinity of the pulses (Gibbs effect), only waveform samples falling within a Region Of Interest (ROI) are summed up to yield the final charge value. A ROI is opened any time the deconvolved waveform crosses a threshold corresponding to 30% of the amplitude of a deconvolved spe pulse. We define the minimal ROI to be 6 ns wide, and we extend it if at its end the waveform is still above the threshold. Following an extensive optimization procedure, we determine that our reconstruction algorithm is better suited to process waveforms with more than two hits. Below this value, the CPU power required to filter and deconvolve the waveform is not paying off in terms of charge reconstruction

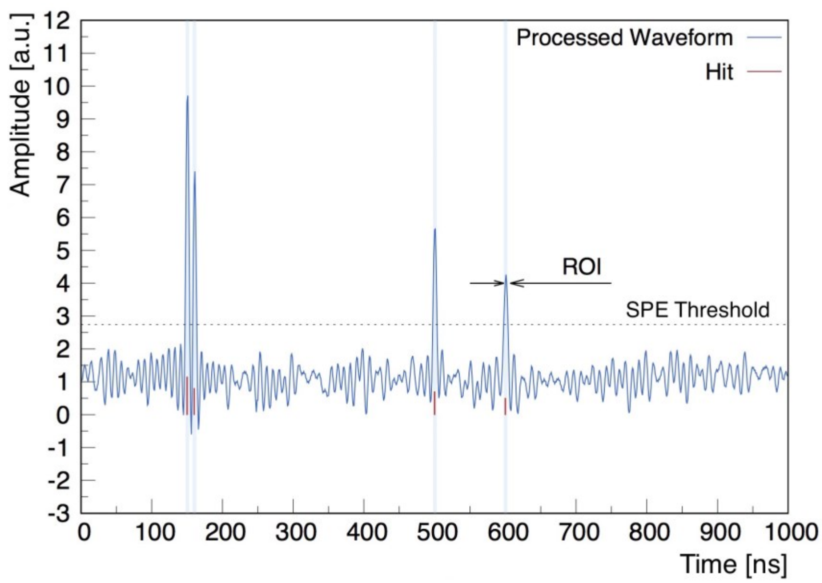

Fig. 22 Waveform arising from filtering and deconvolving Fig. 18e. True hits are shown for reference in red. The charge of each pe is reconstructed by integrating the bins falling within a ROI (shaded areas) defined starting from the time at which the waveform crosses a trigger threshold (dashed line). The threshold is set to be 30% of the amplitude of a spe pulse.

performance. Therefore, we implement a waveform preselection to determine how to process each waveform. We define t to be the time during which the spe template stays over threshold (6 ns). When a waveform is found to be over threshold for at least 2 t, it undergoes the full charge reconstruction comprising filtering and deconvolution. Otherwise, a simple integral of the bins over threshold is used to compute the reconstructed charge.

3.4 Results and Discussion

The performance of the charge reconstruction algorithm is assessed by processing a set of 10^4 simulated waveforms containing a random number of pe in the range [0,15], namely the M dataset. We aim to show how the algorithm improves the precision and accuracy of the charge estimate with respect to a simple integration. To quantify the performance of the algorithm, we process the M dataset waveforms twice, once using the IA alone, and once using both the DA and the IA. For each of the two reconstruction approaches we build a correlation plot using pairs of reconstructed and true charge values, as shown in Fig. 23. An ideal reconstruction algorithm would result in the two quantities to be maximally correlated, and a linear regression would yield unitary slope and null intercept. Any deviation from such behavior is therefore to be interpreted as a bias in the reconstruction. In particular, a non-null intercept (q) models any bias that does not depend on the number of reconstructed pe, while a non-unitary slope (m) models any pe-dependent bias effectively compromising the linearity of the reconstruction algorithm. To further measure how scattered the reconstructed charge values are with respect to the true charge values, we use the Pearson correlation coefficient (ρ). We interpret the latter as an estimator of the charge reconstruction precision, while we interpret the linear regression coefficients as a measurement of its accuracy. By comparing the two plots shown in Fig. 23, it can be noticed that the algorithm significantly improves both the precision and the accuracy of the charge reconstruction. Indeed, m improves from 0.769 to 0.989, q improves from 0.540 to 0.053, and ρ improves from 0.979 to 0.988. To make the meaning of these numbers more evident, we report that if waveforms with 5 and 10 true pes are processed with the IA alone, the average reconstructed charge is biased by 7% and 12% respectively. While, in the case of DA+IA, the bias becomes negligible (at permille level) in both cases. Fig. 24 additionally shows the distribution of the true and reconstructed charge values for events with a number of pes ranging between 1 and 15. We further assess the resilience of the reconstruction algorithm to possible distortions in the input waveform. The data taking of a typical neutrino experiment spans indeed several years —if not decades—, during which several aging issues might compromise the initial PMT performance. Such issues often affect both the noise level and the shape of spe pulses. To evaluate how the precision and the accuracy of the charge reconstruction degrades due to variations in the PMT waveforms with varying shape, we produce new datasets in which all the PMT input parameters are smeared by 10%, one at a time. In analogy to the procedure described above, (i) we process all these datasets using the full reconstruction algorithm (IA+DA); (ii) for each dataset we build the reco-true charge correlation plots; (iii) we use these plots to perform a linear regression and to compute the Pearson correlation coefficient. The discrepancy between the resulting values and the nominal values are plotted in terms of residuals in Fig. 25. Some considerations follow.

- Given the different role that, m and q play in assessing the algorithm performance, only residuals within the same panel can be compared. That is, residuals here are meant to draw a hierarchy among the parameters describing the spe shape, with the aim to show which of them affects the reconstruction algorithm the most.
- From the left panel it is evident that injecting spes with varying amplitude (U0) compromises the algorithm precision. This is expected, since the spe template now fails to describe the spe pulses present in the PMT output waveforms.
- The parameters defining the width of the spe shape, namely 0 and 0, heavily affect the accuracy of the linear regression parameters.
- The parameters shaping the overshoot (U1, 1, t1, U2, 2) play a negligible role, because of the successful overshoot stripping by the DA.
- The white noise amplitude (N) can introduce a non-negligible charge bias, suggesting that the implementation of the filter has room to be improved.

This manuscript describes a new method to reconstruct the output charge of a PMT when sampled with a fast digitizer. Its originality stands in putting together several well-established signal processing techniques with the aim to improve the charge reconstruction accuracy over a large dynamic range, in terms of both mean value of the reconstructed charge and of dispersion around the mean.

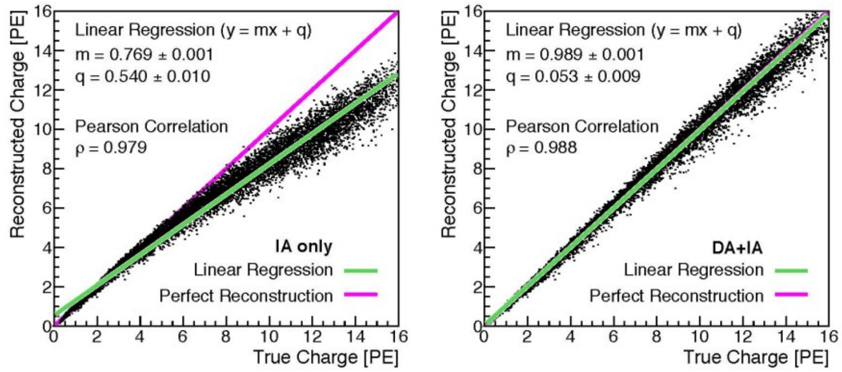

Fig. 23 Reconstructed charge versus true charge for 104 PMT waveforms. The reconstructed charge is computed using the IA alone (left) and DA+IA (right). In both panels the green line is the result of a linear regression performed on the 104 data points.

The algorithm comprises a filtering step, a deconvolution step, and an integration step, which aim to reduce the PMT noise, to compensate for predictable distortions in the PMT waveform, and to infer the number of pes detected by the PMT. Some of its features are summarized here below.

The filter allows to mitigate not only white noise, but also noise at fixed frequencies often introduced at the level of the readout electronics (e.g. due to grounding issues).

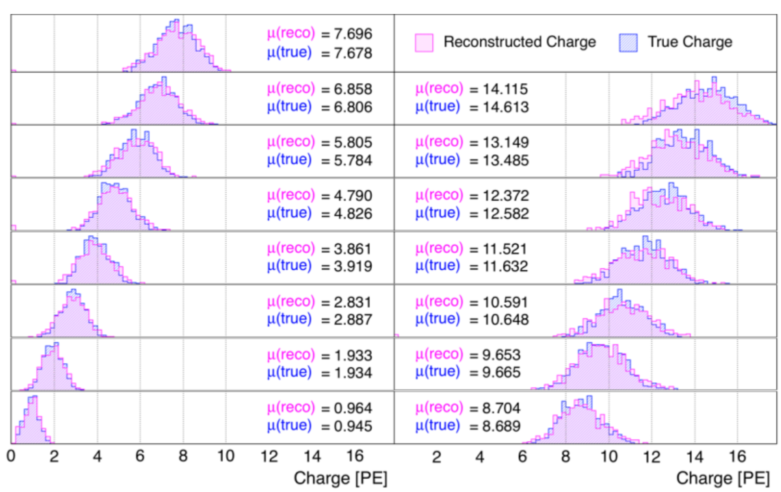

Fig. 24 Distribution of the true charge (blue) and of the reconstructed charge (pink) using the full reconstruction algorithm (DA + IA). Each plot is built using waveforms with a defined number of pes ranging from 1 (bottom left) to 15 (top right). The mean true charge is consistently lower than the true number of pes because of the exponential tail used to simulate the spe distribution in eq. 10.

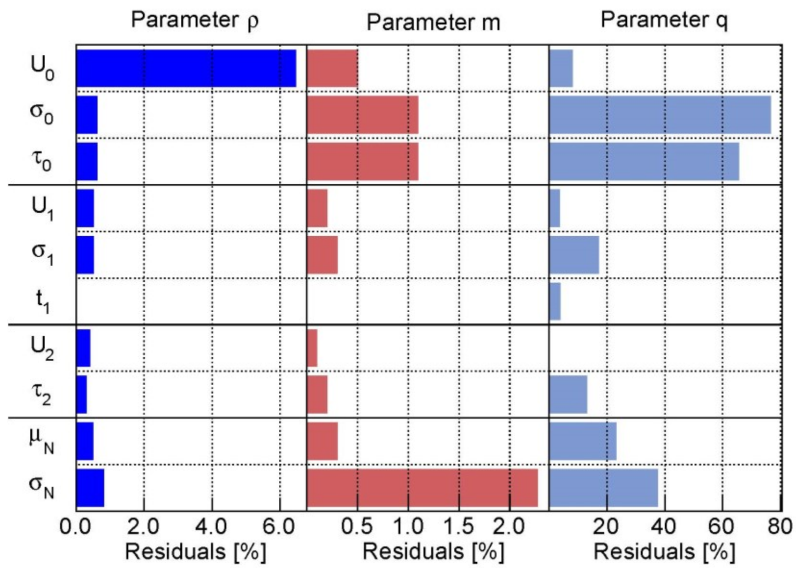

Fig. 25 Residuals of the three performance parameters (linear regression coefficients and correlation coefficient) assessing how the charge reconstruction worsens when the input waveforms contain pulses that are different from the spe template. The input waveforms here are produced by applying a 10% smearing to each of the parameters listed on the vertical axis of the plot.

The deconvolution is based on a spe template, which can be automatically derived from dark count events, effectively introducing a zero dead-time calibration procedure. In the case of an experiment using different PMT types, the algorithm can handle all of them naturally by computing a different template for each type. Moreover, the capability to build new templates continuously allows to account for any variation in the PMT performance over time.

The deconvolution allows an a-priori estimation of the time needed to reconstruct each waveform. The time needed to perform the most CPU-intensive operation (Fast Fourier Transform) depends only on the number of samples within a waveform, and not on its complexity. On the contrary, an approach based on reconstructing the charge by means of an analytic fit would become slow and unreliable in case of large pile-up. Such consideration becomes even more relevant in detectors instrumented with many PMTs.

The deconvolution effectively reduces the undesired spe features from the PMT waveform (such as the overshoot), which can in principle bias the charge reconstruction, making the integration step much more robust.

We tested the reconstruction algorithm by analyzing waveform datasets produced with a custom made PMT simulation. The latter allowed us to simulate a generic PMT readout starting from an analytic spe signal template. We investigated the effect of processing waveforms with a shape different from the spe template. We did it by producing a sample of waveforms where the parameters describing the spe pulses were smeared randomly by 10% around their nominal value. The aim was to test the resilience of the algorithm to any change in the PMT waveform due, for instance, to aging issues. We determined that the reconstruction algorithm is differently sensitive to the input parameters. Those describing the amplitude and the duration of a spe pulse are the most likely to bias the reconstruction performance. The overall charge reconstruction algorithm here described is geared to play a key role in improving the energy resolution of LS detectors with large photo coverage. Such detectors are indeed expected to be severely affected by energy-related systematic uncertainties stemming from the charge reconstruction of PMT waveforms where several pes pile up. To provide the community with the possibility to test our reconstruction algorithm on different inputs, and to compare its performance to different reconstruction tools, we made a C++ implementation available at [62].

Part of the content of this chapter is based on the following publication:

M. Grassi *et al.* "Charge reconstruction in large-area photomultipliers" 2018.*JINST* 13 P02008 https://iopscience.iop.org/article/10.1088/1748-0221/13/02/P02008

CONCLUSION

The studies I have conducted in the last 3 years allowed me to give a significant contribution to the JUNO experiment. I had the opportunity to investigate two different techniques to improve the particle reconstruction in JUNO, focusing on the design and production of industrial-scale plants and on the coding of software for the analysis.

I have developed an algorithm for the reconstruction of the charge produced by large PMT. The algorithm uses conventional signal processing techniques to enhance the accuracy of the reconstruction of the charge produced by large PMTs. The algorithm is composed by the following steps:

- *Wiener Filter* to reduce the PMT white noise and the noise at fixed frequencies that could be introduced by the read-out electronics
- *Deconvolution* with a spe template to give prominence to the waveform shape and cut down possible distortions (e.g., overshoot)
- *Integration* of the waveform shape to reconstruct the number of the photons detected by the PMT

The algorithm was tested with a waveform dataset produced with a custom made PMT simulation. The dataset was composed starting from an analytic spe template, adjusting the shape of the waveforms in terms of amplitude and undesired features such as noise and overshoot and varying the number of photons hitting the PMT in the read-out window from 0 to 15.

This procedure was assessed processing the dataset using the Integration Algorithm alone and using the entire algorithm described before. We improved the reconstruction bias dependent on the number of spe from 23.1% to 1.1% and the bias not dependent on the charge by a factor 10.

My research during the PhD was mainly devoted to the design of the proper purification process of the liquid scintillator to be used in JUNO. It started with the design of two pilot plants with the aim to test the purification capability of the distillation and the steam stripping techniques. After the construction at Polaris s.r.l., the two plants were installed at the Daya Bay experimental site in China and operated for several month in batch and continuous mode.

The efficiencies of these two techniques were tested measuring the absorption spectra of the LS in the wavelength region around 365 nm after each purification process and the remaining content of radio-impurities in the LS using one of the Daya Bay detector.

After the successful operations on the pilot plants, we have designed and built the distillation and steam stripping plants that will be used for the production that will be used in JUNO. In particular, I focused my research on the coding of the control software for the conduction of these plants. The philosophy behind the design of this software was to give the operator maximum flexibility while conducting the plant and ensuring the safety of the personnel and the efficiency of the process. This was achieved thanks to the experience gained while managing the pilot plants and implementing in the software several alarms and local shutdowns as a response at an anomaly originated during the process.

Thanks to my work on the control software, I was involved in the composing of the operative procedure of the distillation plant and of the stripping plant. I had the opportunity to write down all the good practices that should be taken during the conduction of the plants and the precautions to be adopted to reduce the risk of the failure of the purification process and to ensure the safety of the operators and of the plant.

Due to the Covid-19 pandemic, the erection of the two plants had to be performed by a local Chinese company. That had given to me the chance to write the procedures for the erection of both plants. These procedures were written with the aim to keep the overall cleanliness of the plants and to avoid any leaks on the connections that will be mounted during the construction of the plants.

I had also the opportunity to lead and follow the erection operations at the experimental site during my last visit in China between March and May 2022. With the help of a local company, we succeeded on erecting both the distillation plant in the overground distillation hall and the steam stripping plant in the underground liquid scintillator hall.

Many other research activities and many other experiences of human value have not found a place among the written words of my thesis but represent an invaluable heritage that I will always carry with me.

LIST OF SYMBOLS

LNGS	Laboratori Nazionali del Gran Sasso
$\lvert\Delta m_{ij}^2\rvert = \lvert m_i^2 - m_j^2\rvert$	Mass Splitting
δ	Leptonic CP-violating phase in the PMNS Matrix
θ_{ij}	Mixing Angle ij
σ_E/E	Energy Resolution
NMO	Neutrino Mass Ordering
PMNS	Pontecorvo–Maki–Nakagawa–Sakata
NPP	Nuclear Power Plant
YJ	Yangjiang
TS	Taishan
DYB	Daya Bay
HZ	Huizhou
CD	Central Detector
LS	Liquid Scintillator
SS	Stainless Steel
PMT	Photo Multiplier Tubes
TT	Top Tracker
φ	Total Antineutino Flux
F_i	Fission rate of the i-th element
$S_i(E_\nu)$	Antineutrino energy spectrum
p.e.	photon-electron
LAB	Linear Alkyl Benzene
PPO	2,5-diphenyloxazole
Bis-MSB	1,4-bis(2-methylstyryl)benzene
Spe	Single photon electron
pes	Photon-electrons
H_i	Henry Constant
p_i	Process pressure of the i-th element
UPW	Ultra-Pure Water
EDTA	EthyleneDiamineTetraAcetic acid
$R(t)$	Probability of successful performance
$\lambda(t)$	Failure rate of a single component
$MTBF$	Mean Time Between Failure
DCS	Distribuited Control System
UI	User Interface
q_0	SPE calibrated gain
q_p	Pedestal cutoff
σ	SPE Gauss width
ω	Under-amplified PE function
τ	Exponential decay constant
U_0	SPE Template amplitude

σ_0	SPE Template width
τ_0	SPE Template delay
U_1	Overshoot Intensity
σ_1	Overshoot width
τ_1	Overshoot delay
U_2	Overshoot Intensity
τ_2	Overshoot delay
μ_N	White Noise average intensity
σ_N	White noise width
n_{FF}	Noise number of frequencies
f_{FF}	Noise frequencies
A_{ff}	Noise frequencies Amplitude
ADC	Analog Digital Converter
IA	Integration Algorithm
DA	Deconvolution Algorithm
$H[f]$	Wiener Filter
$S[f]$	Signal frequency spectra
$N[f]$	Noise frequency spectra
$SNR[f]$	Signal to Noise Ratio spectra
ROI	Region of Interest

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APPENDIXES
JUNO LIQUID SCINTILLATOR PLANT PROCEDURES

APPENDIX A.
Distillation plant operation procedure

Istituto Nazionale di Fisica Nucleare

JUNO Liquid Scintillator Plant Procedure

Distillation Plant

Process Procedure Number:	Distillation Rev. 8
Last Revision Date:	**September 2020**

Procedure Author(s):

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Reviewed by:

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Last Revised and Approved by:

Paolo Lombardi	________________________

Procedure validity:	from:	Revision Date
	to:	End of Project

1. Table of Contents

2. Revision History

Revision #	Date	Author(s)	Rationale	Sections Updated
1	10/12/2019	Michele Montuschi	First Version	All
2	08/01/2019	Paolo Lombardi	Comments / Corrections	All
3	10/01/2019	Augusto Brigatti Paolo Lombardi	Procedure revision	All
4	04/02/2019	Paolo Lombardi	Valves sequence	All
5	19/02/2019	Paolo Lombardi Augusto Brigatti	Procedure revision	8-19
6	10/2019	Cecilia Landini	Valves update and general revision	All
7	11/05/2020	Cecilia Landini	Valve List updated. Equipment List and Instrument List added. Plant layout drawings added.	All
8	25/09/2020	Cecilia Landini		All

The last revision of this document refers to the revision n.11 of the Distillation P&Id Diagram (C-367-101 Rev.11.pdf, see Document List).

3. Description

The JUNO (Jiangmen Underground Neutrino Observatory) Liquid Scintillator (LS) will be composed by Linear AlkylBenzene (LAB, $C_6H_5C_nH_{2n+1}$) and several solute, in particular DyPhenylOxazole (PPO) and 1,4-bis(2-metil) benzene (bis-MSB).
Following the experience gained from the design and operations done at the Daya Bay site with the distillation pilot plant, the JUNO collaboration has realized an industrial scale distillation plant as one of the purification systems for the JUNO LS. Distillation plant will remove the heaviest radioactive impurities, mainly ^{238}Ur, ^{232}Th, ^{40}K.
This procedure covers the distillation operations of pure LAB for the JUNO Scintillator that has to be accomplished in order to guarantee the better performances in terms of contaminant removal and safety.

The LAB will be pumped in the Input buffer tank of the Distillation Plant and then to the Distillation Column after being pre-heated.
After the Purification inside the column the LAB will be stored in the Output Buffer Tank waiting to be processed by other plants or tested for its properties.

4. Plants in Use and Reference Documents

The plant in use are JUNO Distillation Plant, Hot Oil system, Chilled water system and Nitrogen purification plant.

Reference documents:

- FDR report (JUNO-doc-3534-3538)
- HAZOP: Distillation and Stripping Plant (JUNO-doc-3772-v1)
- P&Id (JUNOEng-doc-11-v9)
- Distillation Plant Layout (JUNOEng-doc-11-v9)
- Procedures and other technical documents (JUNOEng-doc-11-v9)
- Manufacture certificates and operating manuals (JUNOEng-doc-11-v9)

In the document "Flow diagrams on P&Id" (DocDB JUNOEng-doc-11-v9) are reported the following flow diagrams:

- Pre-start checkout
- Pumping & Purging
- Process startup
- Startup in loop mode
- Continuous process operation
- Shutdown
- Change filters

5. Distribution list

- JUNO Collaboration through the database
  http://JUNO.ihep.ac.cn/cgi-bin/Dev_DocDB/DocumentDatabase.
- JUNO Chief Engineer (CE)
- JUNO Local Installation Manager (LIM)
- JUNO Local Safety Officers (LSOs)

6. References

- D. Lgs. 81/08 and later modifications.
- D. Lgs. 334/99 and later modifications.
- Directive 2014/68/UE (PED)
- Directive 2014/34/UE (ATEX)

7. Hazards of Unit Operations & Safety Instructions

7.1. Introduction

The plants of the experiment should be operated only with management approval, and only at agreed scheduled times, with authorized personnel, and only for the specific operations planned.

Regular operation of the plants (i.e. using valves, heaters and/or any pumps) requires a minimum of 2 authorized persons. Authorized personnel are the operators that have been trained for technical specific purpose and safety. For each shift of operations, check with the shift supervisor or operations manager, that there are no scheduled access restrictions or planned interruptions in electrical, telephone, ventilation, nitrogen, cooling water or fire services. All operations, in progress in each shift or daily, and notes must be recorded (date and signature) in the Operations Logbook.

Check that all operating and equipment manuals, MSDS and P&IDs are available and up to date.

Check that the safety manual, site evacuation plan, and emergency contact telephone numbers are available.

7.2. Chemical safety

Process hydrocarbons, chemicals and utilities used, or wastes produced in the process are as follows: LAB, Cooling Water, Mineral Oil, and Nitrogen. A summary of the hazards, precautions and first aid to be used for each of these chemicals is listed below. Technical Data Sheets and MSDS are provided for each of the chemicals above on the JUNO Document DataBase.

7.2.1. Exposure limits and definitions

- **PEL.** U.S. Government OSHA Permissible Exposure Limits. PEL and TLV refers to airborne concentrations measured in the breathing zone by appropriate sampling techniques.
- **ACGIH.** American Conference of Governmental Industrial Hygienists.
- **TLV-TWA.** The time-weighted average concentrations for a normal 8-hour workday or 40 hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.
- **TLV-STEL.** The short term exposure limit (TLV-STEL) is the maximum concentration to which workers can be exposed for a period of up to

15 minutes continuously without suffering from (1) irritation, (2) chronic or irreversible tissue change, or (3) narcosis of sufficient degree to increase accident proneness, impair self-rescue, or materially reduce work efficiency, provided that no more than four excursions per day are permitted, with at least 60 minutes between exposure periods, and provided that the daily TLV-TWA also is not exceeded. The STEL should be considered a maximum allowable concentration or absolute ceiling not to be exceeded at any time during the 15-minute excursion period.

- **TLV-C.** The threshold limit value - ceiling concentration that should not be exceeded even instantaneously. For most substances, e.g., irritant gases, only one category, the TLV-Ceiling, may be relevant. For other substances, either two or three categories may be relevant depending upon their physiologic action. It is important to observe that if any one of these three TLV's is exceeded, a potential hazard from that substance is presumed to exist. The TWA-STEL should not be used as engineering design criterion or considered as an emergency control of health hazards and should not be used as fine lines between safe and dangerous concentrations.

7.2.2. Definition of species

- Linear AlkylBenzene (LAB, C6H5CnH2n+1, CAS 68890-99-3). LAB is a liquid at ambient conditions. It boils in a temperature range of 278°C - 316°C and freezes at a temperature below -50 °C. It is not considerable flammable at ambient pressure and temperature because its flash point is 140°C, so well above the ambient temperature, but it is slightly toxic. Its properties are detailed in the MSDS available on the Document DataBase.
- Mineral OIL (ENI ALARIA 3 - CAS: 101316-72-7). Mineral oil is used in order to provide heat for the distillation processes. It is grant through a closed loop. It is not considered a hazard. Its properties are detailed in the MSDS available on the Document DataBase.
- Water (CAS: 7732-18-5). Chilled water for cooling is provided through a closed loop. This water is non-potable. It is not considered a hazard. Its properties are detailed in the MSDS available on the Document DataBase.
- Nitrogen (CAS: 7727-37-9). Nitrogen gas is used for internal gas blanketing, and instrument control. In the distillation hall is not considered a hazard, except in confined areas where it could displace air and suffocate the inhabitants.

- Its properties are detailed in the MSDS available on the Document DataBase.

7.3. First Aid

In case of contact with the substances written in the last paragraph, act as below (if applicable):

- If inhaled: move person to fresh air. If breathing has stopped, administer artificial respiration, oxygen or cardiopulmonary resuscitation if needed. Seek medical attention
- In case of skin contact: Remove contaminated clothing and wash it before reuse. Flush affected areas with large amounts of water for at least 20 minutes. Wash area with mild soap and water. If irritation occurs, seek medical attention.
- In case of eye contact: Flush thoroughly with water for at least 20 minutes. Seek medical attention.
- If swallowed: Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

7.4. Firefighting measure

LAB

- Small Fire: Use a dry chemical, CO2, water spray or AFFF foam.
- Large Fires: Water spray, fog or AFFF foam. Use water spray or fog; do not use straight streams. Move containers from fire area if you can do it without risk.
- Fire involving Tanks or Car/Trailer Loads: fight fire from maximum distance, use unmanned hose holders, or monitor nozzles. Cool containers with flooding quantities of water until well after fire is out. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. ALWAYS stay away from tanks engulfed in fire.
- For massive fire, use unmanned hose holders or monitor nozzles; if this is impossible, withdraw from area and let fire burn. Self-contained breathing apparatus should be worn during fires in confined spaces

7.5. LAB Leaking from pipes or Equipment

ELIMINATE all ignition sources (no smoking sparks or flames in immediate area). All equipment used when handling the product must be grounded. Do not

touch or walk through spilled material. Stop leak if you can do it without risk.
Prevent entry into waterways, sewers, basement or confined areas. A vapor suppressing foam may be used to reduce vaporous. Absorb or cover with dry earth, sand or other non-combustible material and transfer to containers.
Use clean non-sparking tools to collect absorbed material.

IN CASE OF ALARM FOLLOW THE EMERGENCY ACTIONS ON PLANTS RECOMMENDED IN THIS PROCEDURE AND THE EMERGENCY PLAN OF JUNO SITE

7.6. Recommended major safety equipment

- Portable Fire Extinguishers. Number 2 pressurized foam 50 liters fire extinguishers should be provided at strategic locations. Also large foam-type extinguishers are useful. In any case, follow the prescriptions in the emergency plan of JUNO site.
- Minor Equipment. Minor safety equipment typically on hand comprises hard hats, goggles, gloves, etc., should be available in control room. During operations the work areas should be isolated with signs posted

"授权人员只"

"AUTHORIZED PERSONNEL ONLY"

- Other Safety Equipment absorbent cloth, containment "snakes", vacuums liquids cleaners and a containment basin.

7.7. External and Environmental Impact

All the operation will be done in the confined space (Distillation Hall). The Distillation Hall is provided with a fixed foam fire extinguisher plant operated in manual. There are also liquid sensors and sensors to measure smokes and temperature.

The nitrogen will be vented directly in the hall.

The operation implies the production of liquid waste that comes from the bottom tank of the distillation. The waste will be pumped in an outside waste tank and then disposed by an external company.

8. Purification of LAB solvent

This section provides a very detailed description of the general operating procedures for starting, running and stopping the distillation plant. Procedures in brief with checklists are included later in this section. These procedures assume the plant is commissioned and functionally tested. It is also assumed that the system has already at least a minimal inventory of LAB. This procedure refers to Slow Control instructions, by referring to the control loop or equipment, but do not refer to specific graphical pages, which are under constant revision and upgrade. It is assumed here that the operator is familiar with logging into and using the Slow Control System, and has a valid individual operators account.
These instructions will always assume that in the starting condition all process valves are closed, although any valves, which are critical to check, are explicitly written. In all cases, the Distillation Plant is started in internal loop mode, where the output is routed back to the input through V-186. On startup, the system should be run in this mode until the system is stable, before connecting to external systems.

The operation consists of drawing the LAB solvent from the buffer Tank T-101 and pumping it in the Distillation plant.

The solvent is purified by distillation under vacuum. Following purification, the solvent is pumped into T-102 Buffer Tank.

9. Pre-Start Check Out

9.1. Administrative

1. The plant should be operated only with management approval, and only at agreed scheduled times, with authorized personnel, and only for the specific operations planned.
2. Regular operation of the plant requires the minimum of 2 authorized operators. If the operation involves any other JUNO plants then the minimum operators for those plants must also be present.
3. For each shift of operations, the Firemen/Safety Officer must be informed, and have the written instructions in Chinese regarding fire inspection and supervision.
4. For each shift of operations, check with the shift supervisor or operations manager that there are no scheduled access restrictions or planned interruptions in electrical, telephone, ventilation, nitrogen, cooling water or fire services.
5. Check the Plant logbook for entries on the last operation for any special notes, cautions, or instructions that should be considered for subsequent operations.
6. Check that all operating and equipment manuals and P&IDs are available underground and up to date.

9.2. Equipment, utilities and services

1. Check that Distillation Plant area alarms are activated. Acknowledge any alarms and investigate any that remain active. Report unusual alarms to the plant manager and await instructions.
2. Check that a suitable fire extinguisher is available near the plant.
3. Check that the oxygen sensors are working
4. Check that approved solvent spill absorbent material is available in the Distillation hall.
5. In the main electrical power cabinet check that the electrical breakers are energized for all the instruments, motors, solenoid valves and air handler.
6. Check that the Slow Control and the operator terminals are switched on and running.
7. Check that the nitrogen plant is operating, with regular and high purity nitrogen available between 5-7 bar (TP-12). Check that the supply valves to the Distillation Plant are open V-178, PCV-135 with the PCV-135 regulator output set at about 0.5 bar_g (1.1 barg during pumping and purging). Open V-103. Check the pressures on PI-136.
8. Open V-185 (TP-13) and check the pressure in the Air Instrument line.
9. Check the supply pressure in the Air instrument line is higher than 2 barG and lower than 7 barG, then check that there is pressure in the air instrument line for each pneumatic valve.
10. Check that service-cooling water is available and running, which can be checked within the DCS/local thermometers. Check first that the cooling water supply and return valves located in the Distillation Hall are open (V-188, V-191 for E-102, V-133 and V-124 for E-108, V-122 and V-123 for E-103, V-107 and V-108 for E-106 and V-136 and V-137 for E-105).

11. Check water cooling temperature on control system TI-171 for E-102, TI-172 for E-106
12. Check all Drain and Vent Valves closed
13. Check any sign of water/LAB spillage.

9.3. Purging Vacuum/Nitrogen

VACUUM PURGING

1. Check closed all automatic valves: PV-112A, FV-123, FV-104, FV-118, FV-145, PV-144, XV-169, TV-177, PV-151
2. Check closed valves:
   a. on vacuum pump line: V-116, V-127, V-192, V-193, V-197, V-119
   b. on E-105 drain line: V-170
   c. external connection valves: V-159, V-101, V-167, V-139
   d. on nitrogen line: V-128, V-168, V-129, V-113, V-130, V-132, V-105, V-103
   e. connection of tanks to vent line: V-131, V-147, V-141 and V-187, V-368
   f. on product line: V-160, V-194, V-169, V-174, V-196, V-186, V-145
3. Switch on pump VP-101D
4. Check pressure on PI-170
5. Switch on pump VP-101A/B/C
6. Open valves:
   a. on feed line: V-181, V-352, V-353, V-354, V-199, V-112, V-104, V-111
   b. on product line: V-140, V-145, V-158, V-186
   c. on bottom line: V-355, V-151, V-155, V-356
   d. on drain line: V-170
   e. on vacuum line: PV-144
   f. drain valves:
7. Open V-127 on T-104
8. Open V-131 and V-358 on T-101
9. Open V-357 (bypass on T-101 RD)
10. Open V-147 on T-103
11. Open PV-112A
12. Open V-141 on T-102
13. Open V-196
14. Open FV-145
15. Open V-174 and V-169
16. Open V-160 and V-194
17. Open V-187 (on vent line)
18. Open V-362 (bypass on E-108 RD)
19. Open FV-104 (on feed line)
20. Open FV-123 on bottom line
21. Open FV-118 on product line
22. Open V-132, V-105, V-129, V-113, V-128, V-130, XV-169, V-168 (on nitrogen line)
23. Open V-364 (bypass on T-102 RD)
24. Open V-359 (bypass on T-103 RD)
25. Open V-178 and V-103
26. Open PCV-135 and set at 0.5 barg
27. Close V-178 and V-103
28. Open V-116, V-192, V-193 and V-197, V-119, V-368
29. Check pressure on PI-140
30. Check pressure on PI-115, PIC-112
31. Check pressure on PI-143, PIC-151
32. Check pressure on PI-101, PIC-144, PI-126

33. Check DPI-148 > 0
34. All the pumps should be working
35. Check pressure on PIC-112 until it reaches 5 mbar (keep an eye also on all other pressure sensors to check that all values are in agreement)

NITROGEN PUMPING

1. Close V-116, V-197, V-192 and V-193, V-119, V-368
2. Open slowly V-178
3. Open slowly V-103
4. Check the pressure on PIC-112 until it reaches 0.5 barG

VACUUM PURGING

1. Close V-103 and V-178
2. Start VP-101A/D if needed
3. Open Slowly V-116, V-197, V-192 and V-193, V-119, V-368
4. Check the pressure on PIC-112 until it reaches 5 mbar

REPEAT (three) times.

END

1. Close all the automatic valves
2. Close all manual valves
3. Check closed V-357, V-359, V-362, V-364 (RD bypass)

10. Process startup

This section describes the procedures for starting up the plant processes and achieving stable operation in internal loop mode (through V-186). Unless the plant will be then immediately shutdown, then this section will be followed directly by the procedures in section 10.1 for continuous operation. Plant shutdown procedures are in section 16.

1. Start with all process controllers in MAN mode (output to zero).
2. Check hot oil system running.
3. Set Hot Oil System temperature at 45 °C (IMPORTANT SAFETY ISSUE!!!!!!)
4. Check chilled water system running
5. Check at the interconnections panel that the input valve V-101 and the output valve V-159 of the Distillation plant are closed.
6. Open valves of the hot oil system:
   a. open V-135 and V-114 on E-101
   b. open V-175 and V-198 on E-107
7. ALWAYS OPEN CHILLED WATER SLIGHTLY TO AVOID SAFETY ISSUES!
8. Open valves of cooling water circuits:
   a. V-188, V-191 on E-102
   b. V-122 and V-123 on E-103
   c. V-136 and V-137 on E-105
   d. V-107 and V-108 on E-106
   e. V-124 and V-133 on E-108
9. Check closed V-368 and V-119
10. Check all VP running
11. Check pressure on local PI-170
12. Check open V-116, V-197, V-193 and V-192 on vacuum line
13. Check pressure on PI-140
14. Open V-178 and V-103 on N2 line and check the PI-136 < 0.5 barg
15. Check that the level of T-101 is above the LI-103-L. If in excess, operations can start running with higher levels (but less than LI-103-H). If in excess, LAB can be drained through C-101 to the waste tank T-103 by opening FV-123. If the level are less than LI-103-L, then new LAB or scintillator should be obtained by opening V-101, and connecting to the appropriate source at the interconnections (probably the storage area), following the procedures appropriate to the LAB feed.
16. Check that the level of C-101 is BELOW LI-107-H and ABOVE LI-107-L. If needed change the column level manually.
17. Check closed V-128, V-357, V-131 and V-358 on T-101
18. Check closed V-160, V-174 and V-193 (on F-101) with F-101A in service.
19. Check closed V-130, V-364 and V-141 on T-102.
20. Check closed V-129, V-359 and V-147 on T-103.
21. Check closed V-139, V-170, V-127, V-105, V-119 on T-104.
22. Check Closed V-113 to C-101 and V-168, XV-169 and V-132 to the vacuum line.
23. Now continue the procedure in the next sections(s).

10.1. Distillation Startup in Loop Mode

1. **Nitrogen Blanket on T-101**
   a. Check closed V-181 and V-199 on T-101
   b. Open V-128 (on T-101)
   c. Open slightly and partially V-358
   d. Check constant PI-101 at 0.5 barg
   e. Check and register (by V-358) the flux change in FI-142 (around 1 Nm3/h)

2. **Vacuum in C-101, T-102, T-103**
   a. Check the following valves closed:
      I. FV-104, V-112, V-104 on feed line
      II. V-111 (by pass on C-101)
      III. V-159, V-194, V-169, V-160, V-174 on product line
      IV. V-151, V-155, FV-123, V-167, V-356 on bottom line
      V. V-127, V-132, V-131, V-116, V-197, V-192, V-193 and V-105 on vacuum line
      VI. V-141 (on T-102), V-147 (on T-103), PV-112
   b. At T-103, open V-147 and check with PI-126 that pressure decreases
   c. Open V-141 on T-102
   d. Open V-187 and V-168 on C-101
   e. Open slowly PV-112A in order to vacuum C-101
   f. Open slowly PV-144 in order to vacuum T-102
   g. When PIC-112 and PIC-144 are less than 20 mbar, set and open on DCS, PV-112A and PV-144 in automatic regulation in order to keep 5 mbar in the tank and in the column.
   h. Open XV-169 and regulate V-168 to keep 5 mbar in the column C-101 and in the vacuum line. The regulation of V-168 depends on the number of vacuum pumps running. In steady state try to set V-168 and V-358 on T-101 to be stable at 5 mbar with only 2 vacuum pumps running (VP101 A/B/C). VP101D only for services.

3. **LAB Feed and Product**
   a. Open valves:
      I. on feed line: V-181, V-352, V-353 (P-104 bypass), V-354, V-199, V-112, V-104
      II. on distillate line: V-140
   b. If Level in C-101 is below the LSL-146 and/or LI-107-L threshold limit:
      I. Switch on pump P-104
      II. Open FV-104 at 50%
      III. Wait for level in C-101
      IV. Close FV-104
      V. Switch off P-104
   c. Open PV-151 at 100% in order to warm up the liquid in the reboiler and the column.

d. Open TV-177 at 30% in order to warm up the liquid in the E-107 (to be checked at during commissioning)
e. Start to increase the Oil temperature with a rump-up from 25°C to 250°C in 3 h (180 minutes, so 1.25°C/min). Check the oil temperature rise through TI-179 (E-101).
f. Observe the C-101 temperature (TI-105, TI-109, TI-110, TI-180, TI-137) increasing as vapor starts to rise in the column.
g. Check the level in C-101. If the LI-107 goes below the LI-107-L limit threshold, open FV-104 and start P-104 in order to fill the column at the required level
h. When FI-147 (Reflux flow meter) measures 9 m3/h, open FV-104 and FV-118
i. Close V-353 on feed line and start P-104
j. Partially or fully close the by-pass V-199 if the pump P-104 is working properly (to be tested during commissioning)
k. Start the automatic control on FV-104 and FV-118 in order to keep the level in the reboiler constant.
l. Activate automatic control loop on PV-151 (E-101 oil flow) by feedback on PIC-151 (pressure in the column)

4. **Loop Mode**

a. Wait for the level LI-122 in T-102 to be above the LI-122-L limit.
b. Open V-145 on T-102 and V-158 (P-102 bypass)
c. Open V-194 and V-169 (F-101A) or open V-160 and V-174 (F-101B)
d. Open V-186 (internal loop mode valve)
e. Open FV-145 in automatic control mode
f. Start P-102 in order to keep the level in T-102 constant
g. As soon as the pump P-102 is working properly, partially or fully close the by-pass V-158 (to be tested during commissioning)
h. Activate automatic control loop on TV-177 to regulate the LAB inlet temperature in C-101
i. Operate this way until T-101 level and T-102 level are almost constant, as LAB is returned to the input.
j. Start the automatic procedure for draining the column bottom to T-103.

NOTES:

I. Throughout this startup procedure, the operators must closely watch the C-101 pressure and temperature, and all the vessel levels. If the controllers (eg. FIC-104, FIC-118, FIC-123, , PIC-151, PIC-112, TIC-177, PIC-144, FIC-145) are not stabilizing well, the operator must be prepared to switch any controllers to MAN mode and find a suitable output, before switching back to AUTO mode.
II. For continuous running, the C-101 bottoms draining should be enabled, according to the quality control procedures in section 12.1.

III. Check the vent temperature TI-113. If it is excessively hot (greater than 100°C), then the cooling flow should be increased by fully opening V-124 and V-133 on E-108.

IV. Check the temperature TI-110: if below the expected equilibrium temperature, adjust the V-111 manual bypass.

WARNINGS:

I. Do not allow T-101 to reach a low level (LL threshold). If T-101 sucks empty, this will cause C-101 to break vacuum through T-101. This could cause surges in the input flow to T-101 and temporary backflows in the vent. While this is not a safety concern, it could cause contamination due to turbulence and backflows in the vent lines **and would immediately break the magnetic driven pump!**

II. Do not operate the distillation at or above 100 $mbar_a$ unless during the commissioning phase with pure water (check on PIC-151 and check carefully also the temperature in E-101 on TI-180).

11. Process Operation, Controls and Alarm Actions

11.1. Continuous process operation

Following the procedures in section 10.1, the plant process should be running in internal mode and generally stable. In this section, there are basic procedures for bringing the plant on-line for operations, and repetitive procedures for continued operation.

11.2. Placing the purification plant on-line

Putting the plant on-line means connecting the input and output of the plant to external sources, so that it becomes a component of a larger operation. The Distillation Plant is connected to the wider JUNO Purification plants via the interconnection system. This allows the purification plants to be employed in a variety of purification flow paths.
The Distillation Plant cannot be connected to other plants unless specifically authorized by all other task managers and only when authorized operators for the other involved plants are available.

1. Check the levels in T-101 to be lower than 60% and in T-102 to be higher than 30%
2. Co-ordinate with plant operators for the plant connecting to the Distillation Plant **input**, check that all procedures for that plant have been followed, and that the plant is ready for operation. Ensure that the flow path and connected equipment meet JUNO cleanliness requirements and will not contaminate the purification system. Keep in mind that the input plant will probably require a pump.
3. Complete the input flow path, checking first that all valves required to be closed are in fact closed, and then opening other valves in sequence. Leave the final valve V-101 closed, and the source pump switched off.
4. Co-ordinate with plant operators for the plant connecting to the Distillation Plant **output**, check that all procedures for that plant have been followed and that the plant is ready for operation. Ensure that the flow path and connected equipment meet JUNO cleanliness requirements and will not contaminate the purification system. Complete the output flow path, checking first that all valves required to be closed are in fact closed, and then opening other valves in sequence. Leave some final valve (V-159) closed, which is conveniently positioned.
5. When the operator for the output plant is ready, check that the valves on filter are opened (V-194 and V-169 or V-160 and V-174) and open the final valve V-159 in the output line. Then slowly close the skid bypass valve V-186. If the skid output pump (P-102) slows and stalls or FV-145 drop down, then there could be a blockage or restriction in the output line or plant (eg. missed closed valve). Reopen V-186 to restore internal flow and investigate. Try again to close V-186. If it stalls again or is cycling very slowly, then the problem could just be that the line impedance is increased. If so, proper pump operation should be obtained by adjusting P-102 speed.
6. Open V-101 and start the external source pump to initiate the input flow. Verify if there is input flow and that the T-101 level stabilizes. If there is a problem with the input flow, then open V-186 temporarily to allow internal loop flow to maintain the T-101 level until the input flow is started.

7. The input flow and purified output flow must be roughly balanced, at least on average, to maintain the T-101 buffer level. If the input flow is much greater than FT-104, then the input flow can be reduced or throttled back or turned off intermittently to maintain the T-101 level. Alternately, if the input flow is limited, then the FV-104 feed can be throttle to maintain the T-101 level.
8. The Distillation Plant output flow is almost equal to the input feed FIC-104 over the long term when the level controllers are constant and stable. The output flow can be stopped temporarily or intermittently by closing V-159 and opening V-186 to return the flow to T-101. However, the long-term output flow rate should be set via FIC-104.

12. Draining distillation bottoms

For purification, the distillation process works by evaporating higher volatility components, while leaving behind the contaminants, which are typically heavier (heavy metals, suspended particles etc). The liquid remaining in the evaporation column is called “bottoms”, and this becomes more concentrated with these contaminants. In equilibrium, some small fraction of the bottoms contamination will carry over in the distillate, so it is important to maintain the purity of the bottoms. The bottoms purity is maintained by regular or constant discharge of some of the bottoms to waste, so that the bottoms are replaced by liquid from the feed and reflux. Thus, the distillation process concentrates the contaminants in to the bottoms discharge.

An issue is to know what quantity of the product to waste as bottoms discharge. If the discharge is too low, then the bottoms contamination concentration could be too high, and the distillate purity will fall. If the discharge is too high, then valuable product is needlessly wasted. Until the product and bottoms can be analyzed, it is difficult to know the optimal discharge rate. However, a good rule of thumb is 0.5% to 1.5%. In addition, the purification skids is a high purity application of distillation, and by most standards, even the input feed is already pure. Thus, it is unlikely that the bottoms concentration will be the limiting factor for purification, so there is probably no point in discharging more than 1% of the product to waste. For now, we set the target of 0.75%, with the range 0.5%-1.5%.

12.1. Draining C 101 bottoms

The C-101 bottoms are drained in continuous mode or in batch mode through valve FV-123 and through the cooler E-103.

A. Continuous mode
   1. Ensure that the waste tank T-103 is closed (V-151 and V-129 are closed) and that V-147 (connection to vacuum line) is open. The tank should be under vacuum, which can be confirmed by checking the pressure monitor PI-126.
   2. Check the set point of FIC-123 at 60 l/h (1% of the nominal distilled flux)
   3. Activate FIC-123 in AUTO

B. Batch mode
   1. Ensure that the waste tank T-103 is closed (V-151 and V-129 are closed) and that V-147 (connection to vacuum line) is open. The tank should be under vacuum, which can be confirmed by checking the gauge PI-126.
   2. Check the set point of FIC-123 at 600 l/h (must be set in forced output at a xx% in order to give 600 l/h)
   3. Activate the FIC loop for 2 minutes each 20 minutes
   4. Activate FIC-123 in AUTO

NOTE: during bottom draining, check the temperature on TI-124 and eventually adjust the cooling water flux.

The level of the bottoms tank T-103 should be monitored and needs to emptied when 70-80% full. To empty T-103:

1. Check the connection of T-103 with the external waste tank through the interconnection, if you do not want to send back bottom LAB to T-101
2. **ONLY** if the pump P-103 doesn't work under vacuum:
   a. Close in MAN FV-123
   b. Close V-147 and slowly open V-129 to break the Vacuum inside T-103 and re-pressurize the tank with nitrogen. Carefully watching the pressure gauge PI-126, pressurize to about 80 mbarG.
   c. WARNING: do not over pressurize T-103 (eg. do NOT use pressure to empty it) since there is a burst disk at 3.5 barG.
3. **OTHERWISE** go directly to point 4
4. Open V-356, V-151 and V-167 (if you want to end bottoms to external waste tank) or V-155(if you want to send bottom to T101). Start the Pump P-103. At the Slow Control, monitor the T-103 level falling, and the waste tank level (or T-101 level) increasing.
5. If Pump work smoothly close V-356
6. **SKIP THIS POINT IN CASE OF DRAINING UNDER VACUUM:**
   a. Leave V-129 open to add some more nitrogen again through V-129 and prevent forming a vacuum in T-103 as it is pumped out.
7. When the T-103 level is about 10%, stop the pump and close V-151, V-356 and V-167 or V-155.
8. **SKIP THIS POINT IN CASE OF DRAINING UNDER VACUUM:**
   a. Check VP101D running normally
   b. Check close V-116
   c. Close V-129
   d. Open slowly V-368 to re-evacuate T-103 only through VP101D (in order to not perturbing C-101)
   e. Check T103 pressure till nominal value of C-101
   f. Open V-147
   g. Close V-368

13. Drain of the plant

When the Plant will be not operated for a long time, a complete drain of the plant is required.
Following the procedures for a complete drain of the plant, take in mind also all the operations described on paragraph 10.1 regarding valve and pumps sequences. Pumps should always be full of liquid.
Do not run pumps dry!

1. Close FV-104, FV-123, FV-118 and FV-145 and stop P-104, P-102, P-103
2. Close V-101 (LAB feed) and V-159 (distillate LAB outlet)
3. Put the plant in nitrogen atmosphere @ 200 mbarG

4. Check close all the valves at the Terminal Points for Hot Oil (V-135, V-114, V-198, V-175) and Chilled Water (V-191, V-188, V-123, V-122, V-136, V-137, V-108, V-107)
5. Let drain E-102, E-104 and E-106 in T-102 by gravity
6. Open V-186
7. Empty T-102 in T-101 through V-186 starting P-102
8. Pay attention to stop P-102 when T-102 level reaches LI-122-LL: the pump must NOT run dry! (Do not disable interlock on P-102 from LT-122)
9. Empty T-101 in C-101 starting P-104 and opening FV-104
10. Pay attention to stop P-104 when T-101 level reaches LI-103-LL: the pump must NOT run dry! (Do not disable interlock on P-104 from LI-103)
11. Open V-355
12. Empty C-101 and E-101 in T-103 opening FV-123
13. Check close V-155
14. Empty T-103 in external tanks through V-167 starting P-103
15. Pay attention to stop P-103 when T-103 level reaches LI-125-LL: the pump must NOT run dry! (Do not disable interlock on P-103 from LI-125)
16. Check that V-199, V-356 and V-158 (T-101, T-103 and T-102 bypass, respectively) remain open during the drain procedure (they always should be partially open during plant operation mode)
17. Open V-353, V-111, V-155, V-196
18. Drain the remaining LAB through drain valves (V-106, V-180, V-118, V-166, V-182, V-195, V-162, V-184, V-138, V-171, V-150, V-144, V-366, V-367) properly connected to a waste system
19. If needed, drain the remaining LAB through V-167 and/or V-159 properly connected to a waste system
20. Drain E-105 through the dedicated procedure (see section 15)

14. Change output filter

If DPI-148 is greater than 200 mbar, it means that the filters are plugged. In order to replace the filter, follow the following procedure.

If the filter plugged is F-101A:

1. Open V-160 and V-174
2. Close V-194 and V-169
3. Open the cap on V-195
4. Open V-366 (KF25 on filter side)
5. Drain F-101A in a tank by opening V-195
6. Close V-195
7. Open cartridges holder (main flange)
8. Change cartridges
9. Close holder
10. Connect a portable vacuum pump on V-366 (KF25 on filter side) with a protective oil separator before pump inlet
11. Make full vacuum on F-101A filter (pumping and purging)
12. Close V-366
13. Connect N2 temporary line to V-195

14. Open N2 and V-195 until pressure 0.5 barg (few minutes)
15. Close V-195
16. Open V-366
17. Repeat from point 10 two times
18. Close V-366
19. Remove portable pump and close the cap
20. Close the cap on V-195

If the filter plugged is F-101B:

1. Open V-194 and V-169
2. Close V-160 and V-174
3. Open the cap on V-162
4. Open V-367 (KF25 on filter side)
5. Drain F-101B in a tank by opening V-162
6. Close V-162
7. Open cartridges holder (main flange)
8. Change cartridges
9. Close holder
10. Connect a portable vacuum pump on V-367 (KF25 on filter side) with a protective oil separator before pump inlet
11. Make full vacuum on F-101B filter (pumping and purging)
12. Close V-367
13. Connect N2 temporary line to V-162
14. Open N2 and V-162 until pressure 0.5 barg (few minutes)
15. Close V-162
16. Open V-367
17. Repeat from point 10 two times
18. Close V-367
19. Remove portable pump and close the cap
20. Close the cap on V-162

Filter cartridges holder must be opened only by qualified staff. After changing cartridges and closing back holder, make full vacuum from purge port before put it back to service.

15. Drain E-105

If LI-156 is greater than set threshold and/or LSH-119 start to blink, it means that the level in E-105 is too high and it is necessary to drain the condenser in T-104 with the following procedure.

1. Check VP-101D is running
2. Check close V-170 and V-127, V-105
3. Open (slowly) V-119 to vacuum T-104 through F-102
4. After few minute close V-119
5. Open (slowly) V-170 and wait for the E-105 to be drained
6. Close V-170
7. Open V-105 to pressurize T-104
8. Open V-139 to send the discharged LAB to an external storage
9. Close V-139
10. Close V-105

16. Process Stop/Standby and Shutdown

16.1. Process stop/standby

This is the procedure for temporarily interrupt the process, for example to configure something inside or external to the plant, or to investigate a problem. Whenever changing the plant status, plants manager of all interconnected systems must be informed.

16.1.1. Internal loop mode

Whenever possible, switch to internal loop mode, which leaves the plant running as normal with the output redirected back to the input. Open valve V-186 to open the bypass line. Then close the input line (V-101) and close the output line (V-159).

16.1.2. Software Process Shutdown

This is the minimum procedure to simply stop the LAB flow. This is only a temporary standby condition, to leave the plant in safe condition.
This Procedure is partially operated by the Slow Control System and it is triggered by the operator or by the Slow Control itself in response of a critical alarm

1. Shut down E-101 heater (PV-151 fully closed)
2. Shut down E-107 heater (TV-177 fully closed)
3. Wait till temperature at TI-116, TI-105 and TIC-177 start to decrease
4. Close XV-169 (and V-113) on nitrogen line
5. Shut down Pump P-104
6. Close FIC-118 and FV-104
7. Shut down pump P-102
8. Close V-159 (or V-186 in case of internal loop)
9. Close V-101
10. Close PV-112A
11. Close V-119, V-116, V-192, V-193, V-197, V-178
12. Shut down VP-101

WARNING: as soon as the Shutdown happen the operator must close XV-169 (V-113) to not break the vacuum in the column

The LAB flow should be restarted in internal loop mode, by stepping through the regular startup sequence in section 10.1 (obviously omitting steps for the parts already running).

17. Alarms

17.1. Setting the process variable alarms

The complete alarm table is reported in the document:

"Alarms and interlocks list C-367_101 rev.5.xlsx"

See this document to have the whole list of alarm thresholds (LL, L, H, HH, etc.) for each instrument installed on the plant and controlled by the DCS. The alarms in this table must be checked and set as required. Notify the purification Distillation Plant manager of any alarms that are found to be not activated, or have different set points. Check the logbook for notes about any intentional variations.

The interlock functions listed in this table are designed to prevent undesirable process situations resulting from operator error and/or equipment failures. Note the philosophy, that Slow Control interlocks are used only for protection of process quality and to prevent process and equipment problems due to failures or large transients. Interlocks required for safety have either been provided intrinsically (burst disks etc.). For some operations, or for maintenance, the interlocks will need to be overridden, in this case is mandatory a written approval by task managers and actions and modifications should be reported on logbook.

Check at the Slow Control that all these interlocks are set (not overridden). Note that some interlocks require setting choices for the operating mode in order that the interlocked variables are consistent. The interlocks that cannot be overridden have no operator functions, and are listed only for operator information.

17.2. Set of Control

LOOP OR DEVICE		DESCRIPTION	LINE TYPE	SET VALUE
FIC	104	FLOW CONTROLLER FV-104 FROM P-104 TO E-104	LAB	7000 l/h
PIC	112	PRESSURE CONTROLLER PV-112A AFTER E-108 ON VACUUM LINE	VACUUM	5 mbar
FIC	118	FLOW CONTROLLER FV-118 INLET T-102	LAB	7000 l/h
FIC	123	FLOW CONTROLLER FV-123 FROM C-101 BOTTOM TO E-103	LAB	70 l/h ?
PIC	144	T-102 PRESSURE CONTROLLER PV-144 ON VACUUM LINE	VACUUM	5 mbar ?
FIC	145	T-102 OUTLET FLOW CONTROLLER FV-145	LAB	7000 l/h
PIC	151	BOTTOM C-101 PRESSURE CONTROLLER PV-151 ON REBOILER OIL OUTLET	LAB VAPORS	55 mbar ?
TIC	177	BOTTOM E-107 TEMPERATURE CONTROLLER TV-177 ON E-107 OIL OUTLET	LAB	150°C ??

17.3. Alarm Switches

LOOP OR DEVICE		DESCRIPTION	LINE TYPE	SET VALUE
LAH	108	ALARM HIGH LEVEL C-101	LAB	LAH
LAH	119	ALARM HIGH LEVEL E-105	WASTE	LAH
LAL	146	ALARM LOW LEVEL C-101	LAB	LAL
IAL	154	INVERTER P-103	CURRENT	IAL
IAL	155	INVERTER P-102	CURRENT	IAL
LAL	176	ALARM LOW LEVEL C-101	LAB	LAL
IAL	196	INVERTER P-104	CURRENT	IAL

17.4. Hardware Interlock

The main hardware interlock are:

1. Emergency Button
2. Circuit Breaker for motor driven pumps

17.5. Alarms Action

For any alarms that occur, you should call the skids manager, unless the occurrence of the alarm is a very well understood phenomenon that has already occurred previously. Only if an alarm can be trivially understood and/or corrected should you avoid calling the task manager. In any case, all alarm occurrences should be noted in the logbook along with any actions taken. The following actions serve only as a guideline, as the correct response to an alarm requires thoroughly understanding the root cause of it. The general guideline should be that of caution, where the plant is shut down if you cannot understand the problem, and cannot contact the skid manager or other manager in reasonable time.

Device Controller	***Alarm type***	***Reason***	***Cause***
	Actions, checks, notes, and warnings		
LT-103	H,HH	High Level	Input Flow too high, Output Flow too low
	The Flow input to the Distillation Plant is greater than the output flow leaving T-101. Reduce the input flow and check for failure of FV-104 or P-104. ***WARNING: uncorrected this condition will lead to Nitrogen Line flooding an then eventually rupture of Burst Disk***		
LT-103	L,LL	Low Level	Input Flow too low, Output Flow too high
	The flow input to the skid is less than the output flow leaving T-101. Increase the input flow or decrease the output flow acting on FT-104 and/or P-104. If in internal loop mode, then check T-102 Level and P-102 ***WARNING: If feed is to C-101 and T-101 sucks empty, then C-101 will break vacuum through T-101. This will cause surges in input flow and possible contamination due to turbulence and backflows in the vent.***		
FT-104	H,HH	High Level	Flow rate too High
	The flow rate is too high. This can happen in MAN if T-101 output is too high (and V-199 totally or partially closed) or in AUTO if the control valve FV-104 is stuck.		
FT-104	L,LL	Low Level	Flow rate too Low
	The flow rate is too low. This can happen in MAN if T-101 output is too low or V-199 is too open or in AUTO if the control valve FV-104 is stuck.		
DPI-111	H	High DP	C-101 differential pressure High
	This means the vapor generation rate is very high, due to high heat input or a failure in the Vacuum Pumps. Check the hot oil controller valve PV-151 at the local panel and Vacuum Pumps.		
TE-105	H	High Temp	High Temperature in the column

Device Controller	Alarm type	Reason	Cause
	Actions, checks, notes, and warnings		
TE-109 TE-110	The distillation column temperature is high, due to bad regulation of the column pressure (PIC-151) or too high hot oil heat power transferred (PV-151) or poor vacuum regulation (PIC-112). Switch PIC-151 to MAN and turn it off until the condition is corrected. Also, switch PIC-112 to MAN to improve and stabilize vacuum. Some loss of vacuum will increase the temperature due to increase in boiling point at higher pressure.		
TI-137	H,HH	High Temp	High Hot Oil Outlet Temperature
	The temperature of the hot oil exiting from E-101 (reboiler) is too high. Check the hot oil auxiliary system and check Pv-151 and PIC-151 at the local panel. Check also LI-107: if the reboiler E-101 is dry, no heat is being transferred from the hot oil to the primary fluid.		
LT-107	H,HH	High Level	C-101 high level
	The level is high in C-101 due to the feed rate too high, the reboiler (E-101) Control failure or low output flow. Check FV-104, PV-151 and FV-118. In case of bad regulation of the Hot Oil system (PIC-151), put Level Control in MAN and open PV-151.		
LT-107	L,LL	Low Level	C-101 low level
	The Column level is low, due to low input flow or due to excess heat from the E-101 heating system. If the feed flow has stopped, check if FV-104 has stacked. Otherwise, the problem could be bad PV-151 regulation: if so then switch PIC-151 Control to MAN and close PV-151 until level stability in the column is regained.		
PT-112	H,HH	High Pressure	High pressure in the vacuum line (Vacuum Loss)
	The pressure in the Vacuum Line is too high, implying loss of vacuum regulation (during distillation), or pressurization of the distillation column. During distillation this could occur as a controller overshoot due to instabilities in the pressure controller. Switch PIC-112 to MAN and open PV-112, and ensure vacuum is recovered. Otherwise, check that PV-112 actually opened (is not stuck) and that the vacuum pump is running. Check also LAB evaporation parameters in C-101 bottom (PIC-151, temperature and input/output flow)		
LT-122	H,HH	High Level	T-102 Level too High
	The T-102D level has become too high, since P-102 is not pumping product out fast enough compared to the purification rate. This could be a level controller overshoot. Put FV-118 and FV-145 in MAN and turn on P-102. Also, the pump P-102 could have stalled, due to pump instability, blockage of F-101, or the unexpected closure of any downstream valves. If the situation is not corrected quickly, then the purification must be stopped, by closing PV-151 and the feed valve FV-104 and stopping any input source.		
LT-122	L,LL	Low Level	T-102D Level too Low
	The T-102 level has become too low, since P-102 is pumping product out too fast compared to the purification rate. This could be a level controller overshoot. Put FV-118 and FV-145 in MAN and turn off P-102. The FV-118 and FV-145 controllers perhaps were not in AUTO or had an incorrect set point.		

18. Operation and Shift Requirement

The operation will be organized on shifts. There will be at least two person/shift.

The Operations Manager will communicate in advance to the SPP the contact person and her/his emergency contacts.

Leading personnel involved in the operation and contact numbers:

Name	Cellphone	E-mail
Paolo Lombardi	+393473771723	Paolo.lombardi@mi.infn.it
Michele Montuschi	+393928496592	Michele.montuschi@lngs.infn.it
Augusto Brigatti		Augusto.Brigatti@mi.infn.it
Sergio Parmeggiano		Sergio.Parmeggiano@mi.infn.it
Cecilia Landini		Cecilia.landini@mi.infn.it

19. Equipment List

NAME	TYPE	FLOOR	DESCRIPTION	FLUID
C-101	Distillation column	1st to 3rd	DISTILLATION COLUMN	LAB
E-101	Heat exchanger (reboiler)	1st	REBOILER FOR LAB EVAPORATION	Tubes: HOT OIL Shell: LAB
E-102	Heat exchanger	4th	DISTILLATION CONDENSER	Tubes: LAB Shell: CHILLED WATER
E-103	Heat exchanger	Ground	BOTTOM COOLER	Tubes: LAB Shell: HOT OIL
E-104	Heat exchanger	3rd	DISTILLATION HEAT RECOVERY	Tubes: DISTILLED LAB Shell: LAB BEFORE DISTILLATION
E-105	Heat exchanger	2nd to 3rd	VENT CONDENSER FOR VACUUM LINE	Tubes: VAPORS, N2 Shell: CHILLED WATER
E-106	Heat exchanger	2nd	LAB DISTILLATE COOLER	Tubes: LAB Shell: CHILLED WATER
E-107	Heat exchanger	2nd	FEED PRE-HEATER	Tubes: LAB Shell: HOT OIL
E-108	Heat exchanger	4th	VENT PRE-COOLER	Tubes: VAPORS Shell: CHILLED WATER
F-101A/B	Filters	Ground	LAB PRODUCT FILTERS (F-101B AS SPARE)	LAB
P-102	Magnetic driven pump	Ground	LAB PRODUCT PUMP	LAB
P-103	Magnetic driven pump	Ground	DISTILLATION BOTTOM PUMP	LAB

P-104	Magnetic driven pump	Ground	LAB FEED PUMP	LAB
T-101	Tank	Ground to 3rd	LAB FEED TANK	LAB
T-102	Horizontal tank	Ground	LAB PRODUCT TANK	LAB
T-103	Tank	Ground	DISTILLATION BOTTOM TANK	WASTE LAB
T-104	Tank	1st	DRAIN TANK (WASTE CONDENSATE)	CONDENSED VAPORS, LAB
VP-101A/B/C/D	Vacuum pumps	3rd	VACUUM PUMPS	VAPORS, N2, WATER

To understand the arrangement of Distillation plant floors, see section 22.

20. Instrument List

LOOP OR DEVICE		FLOOR	LINE TYPE	DESCRIPTION	NOMINAL OPERATING VALUE	DCS SIGN. TRANSM.	DCS INDIC. CONTR.
PI	101	3rd, top of tank T-101	NITROGEN	T-101 PRESSURE INDICATOR	0.5 barg ?	Yes	No
LI	103	3rd, top of tank T-101	LAB	T-101 LEVEL INDICATOR	50% ?	Yes	No
FIC	104	1st ?	LAB	FLOW INDICATOR AND CONTROLLER FROM P-104 TO E-104	7000 l/h	Yes	Yes
TI	105	1st ?	LAB	C-101 BOTTOM TEMPERATURE INDICATOR	220°C	Yes	No
TI	106	3rd ?	LAB	TEMPERATURE INDICATOR AFTER E-102	145°C ?	Yes	No
LI	107	1st ?	LAB	C-101 LEVEL INDICATOR	??	Yes	No
LSH	108	1st ?	LAB	HIGH LEVEL SWITCH FOR C-101	??	Yes	No
TI	109	2nd ?	LAB VAPORS	C-101 MIDDLE TEMPERATURE INDICATOR	210°C ?	Yes	No
TI	110	3rd ?	LAB VAPORS	C-101 TOP TEMPERATURE INDICATOR	200°C ?	Yes	No
DPI	111	2nd ??	LAB VAPORS	C-101 DELTA P INDICATOR	30 mbar	Yes	No
PIC	112	4th	VACUUM	PRESSURE INDICATOR AND CONTROLLER AFTER E-108	5 mbar ??	Yes	Yes
TI	113	4th	VACUUM	TEMPERATURE INDICATOR FROM E-108 TO E-105	??	Yes	No
PI	115	3rd ?	VACUUM	PRESSURE INDICATOR BEFORE E-105	5 mbar ?	Yes	No
TI	116	2nd	LAB	TEMPERATURE INDICATOR FOR C-101 INLET FROM E-107	150°C ??	Yes	No
TI	117	2nd	LAB	TEMPERATURE INDICATOR AFTER E-106	25°C ?	Yes	No
FIC	118	1st	LAB	FLOW INDICATOR AND CONTROLLER FROM E-106 TO T-102	7000 l/h	Yes	Yes
LSH	119	2nd	WASTE CONDENSATE	HIGH LEVEL SWITCH FOR E-105 BOTTOM LEVEL	??	Yes	No
LI	122	3rd, top of tank T-102	LAB	T-102 LEVEL INDICATOR	50% ?	Yes	No

LOOP OR DEVICE		FLOOR	LINE TYPE	DESCRIPTION	NOMINAL OPERATING VALUE	DCS SIGN. TRANSM.	DCS INDIC. CONTR.
FIC	123	Ground	LAB WASTE	FLOW INDICATOR AND CONTROLLER FROM E-103 TO T-103	70 l/h ?	Yes	Yes
TI	124	Ground	LAB WASTE	TEMPERATURE INDICATOR FOR T-103 INLET	??	Yes	No
LI	125	Ground	LAB WASTE	T-103 LEVEL INDICATOR	50% ?	Yes	No
PI	126	Ground	NITROGEN	T-103 PRESSURE INDICATOR	5 mbar ??	Yes	No
PI	128	Ground ?	LAB	P-103 DELIVERY PRESSURE INDICATOR	2.5 bar ??	No	No
PI	129	Ground	LAB	P-104 DELIVERY PRESSURE INDICATOR	2.5 bar ??	No	No
PI	130	Ground	LAB	PRESSURE INDICATOR AFTER F-101	??	No	No
TI	131	4^{th}	VACUUM	TEMPERATURE INDICATOR BEFORE VACUUM PUMPS (VP-101)	40°C ??	Yes	No
PI	132	Ground ?	LAB	P-102 DELIVERY PRESSURE INDICATOR	2.5 bar ??	No	No
PI	136	Ground	NITROGEN	NITROGEN FEED PRESSURE INDICATOR	0.5 barg ??	No	No
TI	137	1^{st}	LAB	TEMPERATURE INDICATOR FOR E-101 OUTLET	225°C ?	Yes	No
PI	140	4^{th}	VACUUM	PRESSURE INDICATOR BEFORE VACUUM PUMPS (VP-101)	3 mbar ?	Yes	No
FI	142	Ground	NITROGEN	NITROGEN FEED FLOW INDICATOR	3 Nm^3/h ?	Yes	No
PI	143	3^{rd} ?	LAB VAPORS	TOP C-101 PRESSURE INDICATOR	15 mbar ?	Yes	No
PIC	144	1^{st}	NITROGEN	T-102 PRESSURE INDICATOR AND CONTROLLER	5 mbar ?	Yes	Yes
FIC	145	Ground	LAB	FLOW INDICATOR AND CONTROLLER FROM P-102 TO F-101A/B	7000 l/h	Yes	Yes
LSL	146	1^{st} ?	LAB	LOW LEVEL SWITCH FOR C-101 BOTTOM LEVEL	??	Yes	No
FI	147	3^{rd} ?	LAB	FLOW INDICATOR FOR C-101 REFLUX FROM E-102	2000 l/h	Yes	No
DPI	148	Ground	LAB	F-101 DELTA P INDICATOR	500 mbar ?	Yes	No
PIC	151	1^{st}	LAB VAPORS	C-101 BOTTOM PRESSURE INDICATOR AND CONTROLLER	55 mbar ?	Yes	Yes
TI	152	3^{rd} ?	LAB	TEMPERATURE INDICATOR AFTER E-104	65°C ?	Yes	No

LOOP OR DEVICE		FLOOR	LINE TYPE	DESCRIPTION	NOMINAL OPERATING VALUE	DCS SIGN. TRANSM.	DCS INDIC. CONTR.
LI	156	2nd	WASTE CONDENSATE	E-105 LEVEL INDICATOR	50% ?	Yes	No
PI	170	4th	VACUUM	PRESSURE INDICATOR BEFORE VP-101D	3 mbar ?	No	No
TI	171	4th	COOLING	TEMPERATURE INDICATOR FOR E-102 COOLING OUTLET	??	Yes	No
TI	172	2nd	COOLING	TEMPERATURE INDICATOR FOR E-106 COOLING OUTLET	??	No	No
TI	173	1st	HEATING	TEMPERATURE INDICATOR FOR E-101 (REBOILER) HEATING OUTLET	240°C ?	No	No
TI	174	2nd	HEATING	TEMPERATURE INDICATOR FOR E-107 HEATING OUTLET	??	No	No
TI	175	4th	VACUUM	TEMPERATURE INDICATOR BEFORE VP-101D	40°C ?	Yes	No
LSL	176	1st ?	LAB	LOW LEVEL SWITCH FOR C-101 BOTTOM LEVEL	??	Yes	No
TIC	177	2nd	LAB	TEMPERATURE INDICATOR AND CONTROLLER FOR E-107 OUTLET	150°C ?	Yes	Yes
TI	179	1st	HEATING	TEMPERATURE INDICATOR FOR E-101 (REBOILER) HEATING INLET	250°C	Yes	No
TI	180	1st	LAB	SHELL-SIDE E-101 TEMPERATURE INDICATOR	220°C ?	Yes	No
LT	195	1st ?	LAB	C-101 LEVEL TRANSMITTER	??	Yes	No

To understand the arrangement of Distillation plant floors, see section 22.

21. Valves List

TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	100	2nd	HEATING	1″	DRAIN VALVE FOR HOT OIL LINE E-107B INLET	MANUAL
V	101	3rd, top of tank T-101	LAB	DN50	LAB FEED INLET T-101	MANUAL
V	103	Ground	NITROGEN	DN25	FEED INLET VALVE AFTER PCV-135	MANUAL
FV	104	1st	LAB	DN50	FROM P-104 TO E-104L	AUTO
V	104	?	LAB	DN50	FROM E-107B TO C-101	MANUAL
V	105	1st ??	NITROGEN	DN25	T-104 NITROGEN INLET LINE	MANUAL
V	106	Ground	LAB	DN25	DRAIN VALVE BETWEEN T-101 AND P-104	MANUAL
V	107	2nd	COOLING	DN50	E-106H WATER COOLING INLET VALVE	MANUAL
V	108	2nd	COOLING	DN50	E-106A WATER COOLING OUTLET VALVE	MANUAL
V	109	2nd	COOLING	1″	VENT VALVE FOR E-106A OUTLET WATER LINE	MANUAL
V	110	2nd	COOLING	1″	DRAIN VALVE FOR E-106H INLET WATER LINE	MANUAL
V	111	?	LAB	DN50	E-104 AND E-107 BYPASS FROM P-104 TO C-101	MANUAL
V	112	?	LAB	DN50	FROM P-104 TO E-104L	MANUAL
EV	112	4th	VACUUM	-	SOLENOID VALVE FROM E-108 TO E-105 (IT OPERATES ON PV-112A)	AUTO
PV	112A	4th	VACUUM	DN25	VACUUM LINE VALVE FROM E-108 TO E-105	AUTO
V	113	2nd	NITROGEN	DN25	C-101 NITROGEN INLET VALVE	MANUAL
V	114	1st	HEATING	DN150	E-101 OIL HEATING OUTLET VALVE	MANUAL
V	115	1st	HEATING	1″	VENT VALVE FOR E-101 OUTLET HEATING LINE	MANUAL
V	116	4th	VACUUM	DN50	VACUUM PUMP VP-101D INLET VALVE	MANUAL
V	117	1st	HEATING	1″	DRAIN VALVE FOR E-101 INLET HEATING LINE	MANUAL
FV	118	1st	LAB	DN50	FROM E-106H TO T-102	AUTO
V	118	Ground	LAB	DN25	DRAIN VALVE BETWEEN E-103B AND T-103	MANUAL
V	119	1ST	VACUUM	DN25	VALVE FROM T-104 BEFORE F-102	MANUAL
V	120	Ground	COOLING	1/2″	DRAIN VALVE FOR E-103B INLET WATER LINE	MANUAL
V	121	Ground	COOLING	1/2″	VENT VALVE FOR E-103A OUTLET WATER LINE	MANUAL
V	122	Ground	COOLING	DN32	E-103B WATER COOLING INLET VALVE	MANUAL

TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	123	Ground	COOLING	DN32	E-103A WATER COOLING OUTLET VALVE	MANUAL
FV	123	Ground ?, bottom of C-101	LAB	DN25	REGULATING VALVE FROM C-101 TO E-103A	AUTO
V	124	4th	COOLING	DN15	E-108 WATER COOLING OUTLET VALVE	MANUAL
V	127	1st ???	VACUUM	DN25	FROM T-104 TO VP-101 LINE	MANUAL
V	128	3rd, top of tank T-101	NITROGEN	DN25	T-101 NITROGEN INLET VALVE	MANUAL
V	129	Ground	NITROGEN	DN25	T-103 NITROGEN INLET VALVE	MANUAL
V	130	1st ?	NITROGEN	DN25	T-102 NITROGEN INLET VALVE	MANUAL
V	131	3rd	VACUUM	DN50	FROM T-101 TO VACUUM LINE	MANUAL
V	132	2nd ??	NITROGEN	1/4″	NEEDLE VALVE FROM NITROGEN INLET TO VACUUM LINE	MANUAL
V	133	4th	COOLING	DN15	E-108 WATER COOLING INLET VALVE	MANUAL
CV	134	??	NITROGEN	DN25	CHECK VALVE FROM NITROGEN INLET TO VACUUM LINE (BEFORE V-132 AND V-105)	ONE WAY
PCV	135	Ground	NITROGEN	1/2″	NITROGEN FEED REGULATING VALVE	AUTO
V	135	1st	HEATING	DN150	E-101 HOT OIL INLET VALVE	MANUAL
V	136	3rd	COOLING	DN25	E-105 WATER COOLING OUTLET VALVE	MANUAL
V	137	3rd	COOLING	DN25	E-105 WATER COOLING INLET VALVE	MANUAL
V	138	Ground	LAB	1/4″	SAMPLE PORT FOR DISTILLATED PRODUCT AFTER F-101	MANUAL
V	139	1st	WASTE	DN25	LAST VALVE FROM T-104 TO WASTE	MANUAL
V	140	1st	LAB	DN50	FROM E-106H TO T-102	MANUAL
V	141	1st	VACUUM	DN50	FROM T-102 TO VACUUM LINE	MANUAL
V	144	Ground, bottom of tank T-102	LAB	1/4″	T-102 SAMPLE PORT	MANUAL
PV	144	1st	VACUUM	DN25	REGULATING VALVE FROM T-102 TO VACUUM LINE	AUTO
V	145	Ground, bottom of tank T-102	LAB	DN50	FROM T-102 TO P-102	MANUAL
FV	145	Ground	LAB	DN50	FROM P-102 TO F-101	AUTO
V	147	2nd ??	VACUUM	DN50	FROM T-103 TO VACUUM LINE	MANUAL
V	150	Ground	LAB	1/4″	T-103 SAMPLE PORT	MANUAL
EV	151	1st	HEATING	-	SOLENOID VALVE FOR E-101 HOT OIL OUTLET (IT OPERATES ON PV-151)	AUTO
PV	151	1st	HEATING	DN150	REGULATING VALVE FOR E-101 HOT OIL OUTLET	AUTO

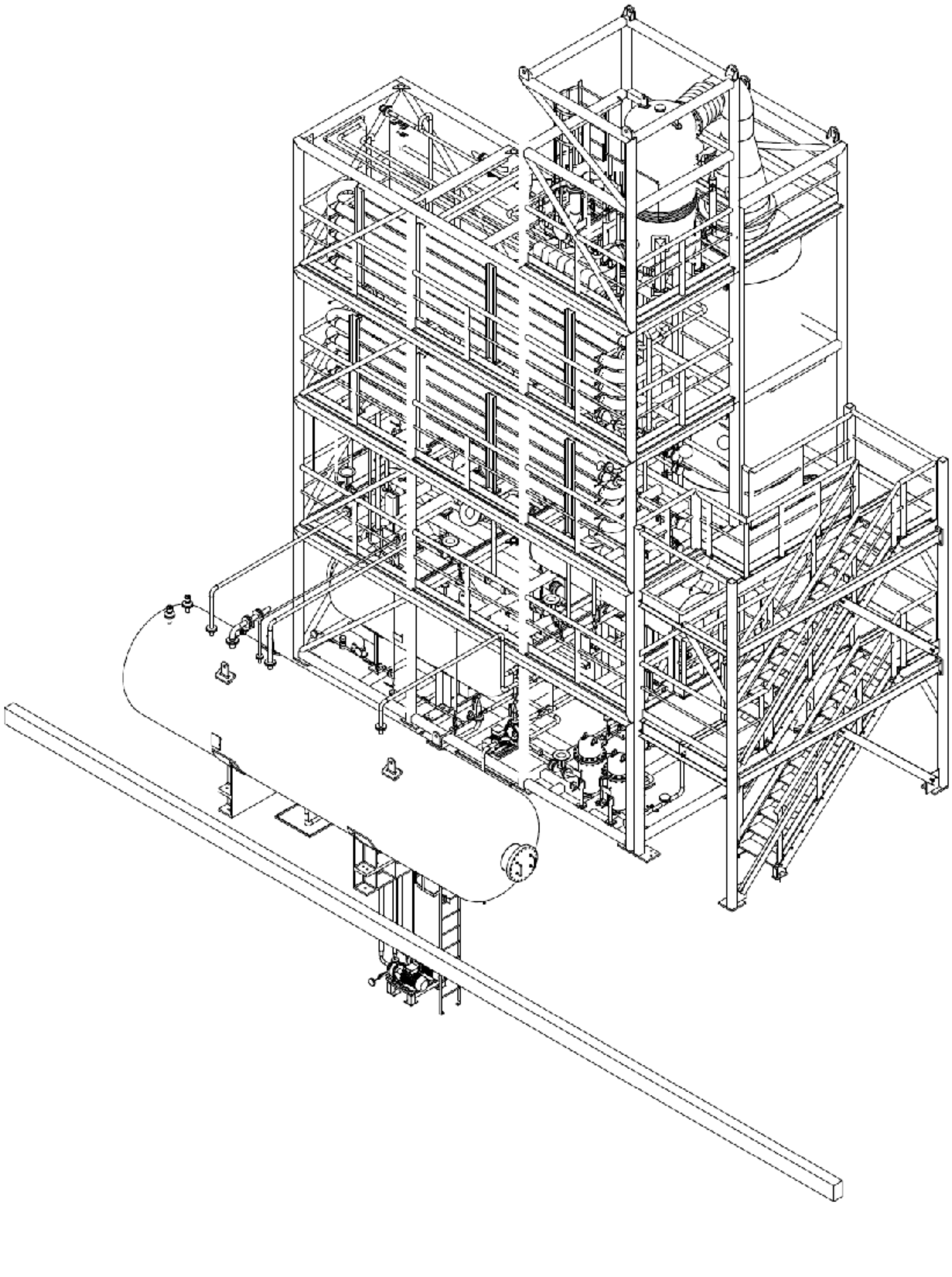
TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	151	Ground, bottom of tank T-103	LAB	DN50	FROM T-103 TO P-103	MANUAL
CV	154	3rd ??, top of tank T-101	LAB	DN50	CHECK VALVE FOR LAB RETURN TO T-101 IN LOOP MODE	ONE WAY
V	155	Ground ?	LAB	DN25	FROM P-103 TO T-101	MANUAL
CV	156	Ground	LAB	DN50	CHECK VALVE FROM F-101 TO T-101	ONE WAY
V	158	Ground ?	LAB	DN50	RETURN FROM P-102 TO T-102	MANUAL
V	159	Ground	LAB	DN50	LAB DISTILLATE PRODUCT OUTLET (LAST VALVE)	MANUAL
V	160	Ground	LAB	DN50	FROM P-102 TO F-101B	MANUAL
CV	161	Ground	NITROGEN	DN25	T-103 NITROGEN INLET CHECK VALVE	ONE WAY
V	162	Ground	LAB	DN25	F-101B DRAIN VALVE	MANUAL
V	164	2nd ??	VACUUM	DN25	DRAIN VALVE FROM E-105 TO VP-101 LINE	MANUAL
V	166	Well ??	LAB	DN25	DRAIN VALVE FROM T-103 TO P-103	MANUAL
V	167	Ground	LAB	DN25	LAST LAB BOTTOM OUTLET T-103	MANUAL
V	168	4th ??	NITROGEN	1/4″	NEEDLE VALVE FROM NITROGEN INLET TO VACUUM LINE BEFORE XV-169	MANUAL
V	169	Ground	LAB	DN50	FROM F-101A TO LAB PRODUCT OUTLET	MANUAL
EV	169	4th ??	NITROGEN	-	SOLENOID VALVE OPERATING ON XV-169	AUTO
XV	169	4th ??	NITROGEN	1/4″	FROM NITROGEN INLET LINE TO VACUUM LINE AFTER E-108	SOLENOID
V	170	1st	WASTE	DN25	FROM E-105 TO T-104	MANUAL
V	171	Ground, bottom of tank T-101	LAB	1/4″	T-101 SAMPLE PORT VALVE	MANUAL
V	172	3rd	COOLING	1/2″	E-105 VENT WATER VALVE	MANUAL
V	173	3rd ?	COOLING	1/2″	E-105 DRAIN WATER VALVE	MANUAL
V	174	Ground	LAB	DN50	FROM F-101B TO LAB PRODUCT OUTLET	MANUAL
V	175	2nd	HEATING	DN80	E-107B HOT OIL INLET VALVE	MANUAL
CV	176	4th ?	VACUUM	DN50	LAST VALVE AFTER PUMPS VP-101	ONE WAY
TV	177	2nd	HEATING	DN80	REGULATING VALVE FOR E-107 HOT OIL OUTLET	AUTO
PSV	178	Ground	NITROGEN	DN25	NITROGEN INLET PRESSURE RELIEF VALVE	AUTO
V	178	Ground	NITROGEN	DN25	NITROGEN FEED VALVE BEFORE PCV-135	MANUAL
V	179	Ground	NITROGEN	DN25	NITROGEN LINE PORT VALVE AFTER FT-142	MANUAL
V	180	1st	LAB	DN25	DRAIN VALVE FROM T-101 TO E-104	MANUAL

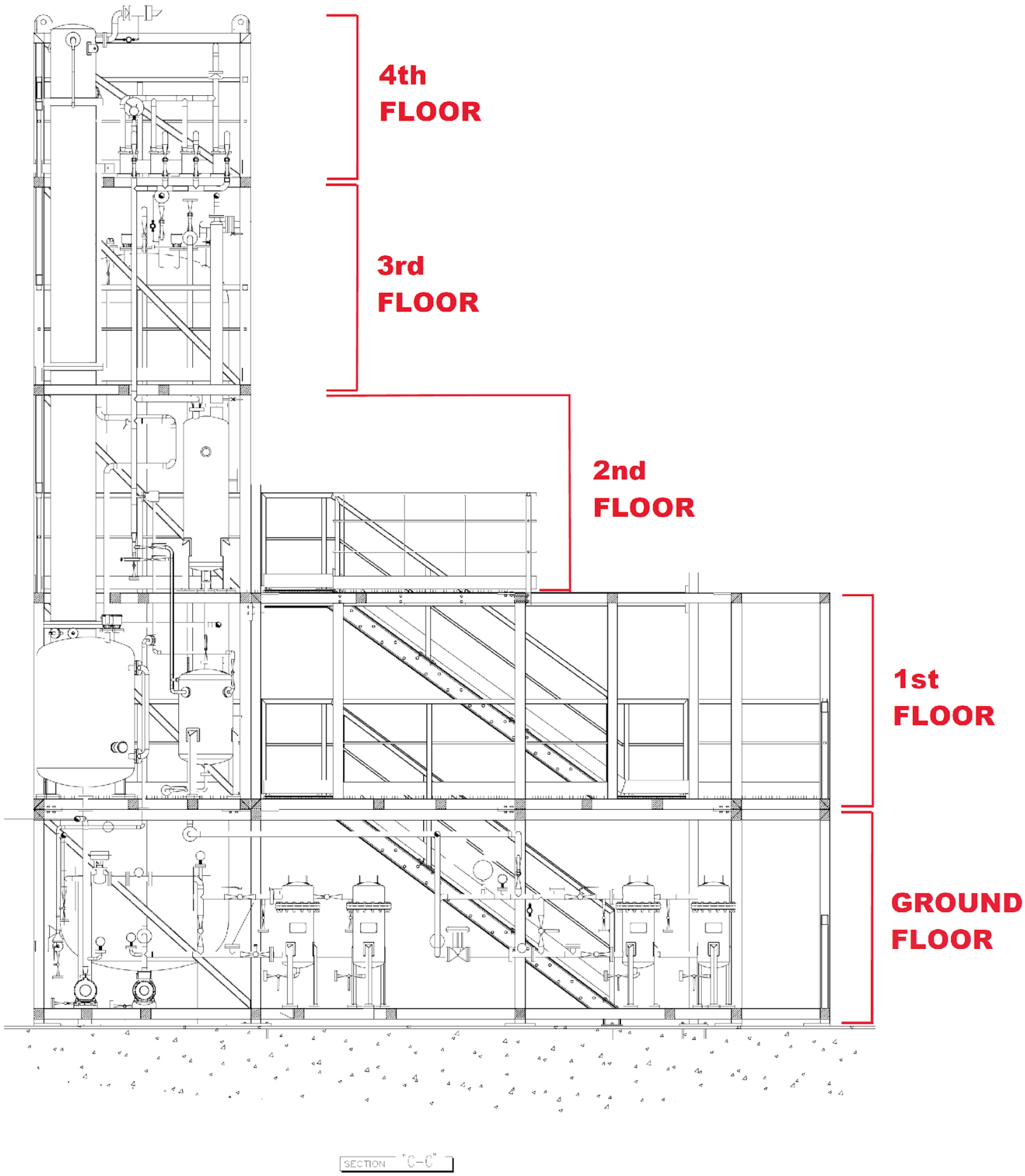
TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATIO N
V	181	Ground, bottom of tank T-101	LAB	DN50	T-101 OUTLET	MANUAL
V	182	Well ???	LAB	DN25	DRAIN VALVE FROM T-102 TO P-102	MANUAL
V	184	1st	LAB	DN25	DRAIN VALVE FROM E-106H TO T-102	MANUAL
V	185	*	AIR	1/2”	COMPRESSED AIR FEED INLET ON TP-13	MANUAL
V	186	Ground	LAB	DN50	FROM F-101 TO T-101 (LOOP MODE LINE)	MANUAL
V	187	4th	VACUUM	DN50	VACUUM LINE VALVE FROM E-108 TO E-105	MANUAL
V	188	4th	COOLING	DN150	E-102 COOLING WATER INLET VALVE	MANUAL
V	189	4th	COOLING	1”	DRAIN VALVE FOR E-102 INLET WATER LINE	MANUAL
V	190	4th	COOLING	1”	VENT VALVE FOR E-102 OUTLET WATER LINE	MANUAL
V	191	4th	COOLING	DN150	E-102 COOLING WATER OUTLET VALVE	MANUAL
V	192	4th	VACUUM	DN50	VACUUM PUMP VP-101A INLET VALVE	MANUAL
V	193	4th	VACUUM	DN50	VACUUM PUMP VP-101B INLET VALVE	MANUAL
V	194	Ground	LAB	DN50	FROM P-102 TO F-101A	MANUAL
V	195	Ground	LAB	DN25	F-101A DRAIN VALVE	MANUAL
V	196	Ground	LAB	DN50	F-101A/B BYPASS	MANUAL
V	197	4th	VACUUM	DN50	VACUUM PUMP VP-101C INLET VALVE	MANUAL
V	198	2nd	HEATING	DN80	E-107A HOT OIL OUTLET VALVE	MANUAL
V	199	3rd, top of tank T-101	LAB	DN50	FROM P-104 TO T-101 (RETURN)	MANUAL
V	350	2nd	HEATING	1”	VENT VALVE FOR E-107A OUTLET HEATING LINE	MANUAL
CV	351	3rd ??, top of tank T-101	NITROGEN	DN25	T-101 NITROGEN INLET CHECK VALVE	ONE WAY
V	352	Ground ?	LAB	DN50	FROM T-101 TO P-104	MANUAL
V	353	Ground	LAB	DN50	P-104 BYPASS	MANUAL
V	354	Ground	LAB	DN50	FROM P-104 TO E-104L	MANUAL
V	355	???	LAB	DN25	FROM E-101 TO E-103A	MANUAL
V	356	Ground ?	LAB	DN25	RETURN FROM P-103 TO T-103	MANUAL
V	357	3rd, top of tank T-101	NITROGEN	1/4”	BYPASS ON T-101 RUPTURE DISK	MANUAL
V	358	3rd	VACUUM	1/4”	T-101 VACUUM LINE BYPASS	MANUAL

TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	359	Ground, top of tank T-103	NITROGEN	1/4”	BYPASS ON T-103 RUPTURE DISK	MANUAL
CV	360	Ground, top of tank T-103	NITROGEN	DN50	CHECK VALVE TO T-103 RUPTURE DISK	ONE-WAY
CV	361	4^{th}	NITROGEN	DN50	CHECK VALVE TO C-101 RUPTURE DISK	ONE-WAY
V	362	4^{th}	NITROGEN	1/4”	BYPASS ON C-101 RUPTURE DISK	MANUAL
CV	363	Ground, top of tank T-102	NITROGEN	DN65	CHECK VALVE TO T-102 RUPTURE DISK	ONE-WAY
V	364	Ground, top of tank T-102	NITROGEN	1/4”	BYPASS ON T-102 RUPTURE DISK	MANUAL
CV	365	3^{rd}, top of tank T-101	NITROGEN	DN65	CHECK VALVE ON T-101 RUPTURE DISK	ONE-WAY
V	366	Ground	VACUUM	DN25	F-101A VACUUM PORT	MANUAL
V	367	Ground	VACUUM	DN25	F-101B VACUUM PORT	MANUAL
V	368	???	VACUUM	DN50	FROM T-103 TO VP-101D	MANUAL

To understand the arrangement of Distillation plant floors, see section 22.

22. Distillation Plant Layout




4th
FLOOR
3rd
FLOOR
2nd
FLOOR
1st
FLOOR
GROUND
FLOOR
SECTION "C-C"

APPENDIX B.
Stripping plant operation procedure

Istituto Nazionale di Fisica Nucleare

JUNO Liquid Scintillator Plant Procedure

Stripping Plant

Process Procedure Number: Stripping Rev. 6

Last Revision Date: **May 2020**

Procedure Author(s):

Michele Montuschi ________________________

Reviewed by:

Paolo Lombardi ________________________

Augusto Brigatti ________________________

Cecilia Landini ________________________

Last Revised and Approved by:

Paolo Lombardi ________________________

Procedure validity: from Revision Date to End of Project

1. Table of Contents

2. Revision History

Revision #	Date	Author(s)	Rationale	Sections Updated
0	15-02-2019	Michele Montuschi	First Version	All
1	18-02-2019	Paolo Lombardi	General revision	8-19
2	19-02-2019	Paolo Lombardi Augusto Brigatti	General revision	8-19
3	03-04-2019	Paolo Lombardi	Insertion of water Extraction bypass E201	10-15
4	09-2019	Cecilia Landini	Valves update and general revision	8-19
5	01-10-2019	Michele Montuschi	Deleted second Table in 17.1, updated table in 17.5, minor spelling corrections	All
6	08-05-2020	Cecilia Landini	Valve List updated. Equipment List and Instrument List added. Plant layout drawings added.	All

The last revision of this document refers to the revision n.11 of the Stripping P&Id Diagram (C-367-102 Rev.11.pdf, see Document List).

3. Description

The JUNO (Jiangmen Underground Neutrino Observatory) Liquid Scintillator (LS) will be composed by Linear AlkylBenzene (LAB, $C_6H_5C_nH_{2n+1}$) and several solute, in particular DyPhenylOxazole (PPO) and 1,4-bis(2-metil) benzene (bis-MSB).

Following the experience gained from the design and operations done at the Daya Bay site with the stripping plant, the JUNO collaboration has realized an industrial scale stripping plant as one of the purification systems for the JUNO LS. Stripping plant will remove the lightest and more volatile radioactive impurities, mainly Ar, Kr, and Rn.
This procedure covers the stripping operations of the JUNO LS that has to be accomplished in order to guarantee the better performances in terms of contaminant removal and safety.

The LS will be pumped in the Input buffer tank of the Stripping Plant and then to the Stripping Column after being filtered and pre-heated.
After the Purification inside the column the LAB will be stored in the Output Buffer Tank waiting to be sent to the detector or tested for its property.

4. Plants in Use and Reference Documents

The plants in use are: JUNO Stripping Plant, Nitrogen purification plant, Hot oil System and Chilling water plant.

Reference documents:

- FDR report (JUNO-doc-3534-3538)
- HAZOP: Distillation and Stripping Plant (JUNO-doc-3772-v1)
- Procedure & technical documents (JUNOEng-doc-13-v7)
- Manufacture certificates and operating manuals (JUNOEng-doc-13-v7)
- P&Id (JUNOEng-doc-13-v7)

The flow diagram are in DocDB JUNOEng-doc-13-v7:

- Pre-start checkout.pdf
- Stripping startup.pdf
- Stop & shutdown.pdf

5. Distribution list

- JUNO Collaboration through the database http://JUNO.ihep.ac.cn/cgi-bin/Dev_DocDB/DocumentDatabase.
- JUNO Chief Engineer (CE)
- JUNO Local Installation Manager (LIM)
- JUNO Local Safety Officers (LSOs)

6. References

- D. Lgs. 81/08 and later modifications.
- D. Lgs. 334/99 and later modifications.
- Directive 2014/68/UE (PED)
- Directive 2014/34/UE (ATEX)

7. Hazards of Unit Operations & Safety Instructions

7.1. Introduction

The plants of the Experiment should be operated only with management approval, and only at agreed scheduled times, with authorized personnel, and only for the specific operations planned.

Regular operation of the plants (i.e. using Heaters and/or any pumps) requires the minimum of 2 authorized persons. Authorized personnel are the operators that have been trained for technical specific purpose and safety. For each shift of operations, check with the shift supervisor or operations manager, that there are no scheduled access restrictions or planned interruptions in electrical, telephone, ventilation, nitrogen, cooling water or fire services. All operations, in progress in each shift or daily, and notes must be recorded (date and signature) in the Operations Logbook.

Check that all operating and equipment manuals and P&IDs are available underground and up to date.

Check that the safety manual, underground site evacuation plan and emergency contact telephone numbers are available underground.

7.2. Chemical Safety

Process hydrocarbons, chemicals and utilities used, or wastes produced in the process are as follows: LS (a solution of LAB, PPO and bisMSB), Mineral Oil, Cooling Water, and Nitrogen. A summary of the hazards, precautions and first aid to be used for each of these chemicals is listed below.

7.2.1. Exposure limits and definitions

- **PEL.** U.S. Government OSHA Permissible Exposure Limits. PEL and TLV refers to airborne concentrations measured in the breathing zone by appropriate sampling techniques.
- **ACGIH.** American Conference of Governmental Industrial Hygienists.
- **TLV-TWA.** The time-weighted average concentrations for a normal 8-hour workday or 40 hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.
- **TLV-STEL.** The short term exposure limit (TLV-STEL) is the maximum concentration to which workers can be exposed for a period of up to 15 minutes continuously without suffering from (1) irritation, (2) chronic or irreversible tissue change, or (3) narcosis of sufficient

degree to increase accident proneness, impair self-rescue, or materially reduce work efficiency, provided that no more than four excursions per day are permitted, with at least 60 minutes between exposure periods, and provided that the daily TLV-TWA also is not exceeded. The STEL should be considered a maximum allowable concentration or absolute ceiling not to be exceeded at any time during the 15-minute excursion period.

- **TLV-C**. The threshold limit value - ceiling concentration that should not be exceeded even instantaneously. For most substances, e.g., irritant gases, only one category, the TLV-Ceiling, may be relevant. For other substances, either two or three categories may be relevant depending upon their physiologic action. It is important to observe that if any one of these three TLV's is exceeded, a potential hazard from that substance is presumed to exist. The TWA-STEL should not be used as engineering design criterion or considered as an emergency control of health hazards and should not be used as fine lines between safe and dangerous concentrations.

7.2.2. Definition of Species

- **Linear AlkylBenzene** (LAB, $C_6H_5C_nH_{2n+1}$, CAS 68890-99-3**).** LAB is a liquid at ambient conditions. It boils in a temperature range of 278°C - 316°C and freezes at a temperature below -50 °C. It is not considerable flammable at ambient temperature because its flash point is 140°C, so well above the ambient temperature and even above the maximum temperature expected in the plant. LAB is slightly toxic. Its properties are detailed in the MSDS available on the Document DataBase.

- **Mineral OIL (ENI ALARIA 3 - CAS: 101316-72-7).** Mineral oil is used in order to provide heat for the stripping process. It is grant through a closed loop. It is not considered a hazard. Its properties are detailed in the MSDS available on the Document DataBase.

- **Water (CAS: 7732-18-5).** Chilled water for cooling is provided through a closed loop. This water is non-potable. It is not considered a hazard. Its properties are detailed in the MSDS available on the Document DataBase.

- **Nitrogen (CAS: 7727-37-9).** Nitrogen gas is used for internal gas blanketing, and instrument control. In LAB-5 is not considered a hazard, except in confined areas where it could displace air and suffocate the inhabitants. Its properties are detailed in the MSDS available on the Document DataBase.

7.3. First Aid

In case of contact with the substances written in the last paragraph, act as below:

- **If inhaled:** Move person to fresh air. If breathing has stopped, administer artificial respiration, oxygen or cardiopulmonary resuscitation if needed. Seek medical attention
- **In case of skin contact:** Remove contaminated clothing and wash it before reuse. Flush affected areas with large amounts of water for at least 20 minutes. Wash area with mild soap and water. If irritation occurs, seek medical attention.
- **In case of eye contact:** Flush thoroughly with water for at least 20 minutes. Seek medical attention.
- **If swallowed:** Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

7.4. Firefighting Measure

LAB

- **Small Fire:** Use a dry chemical, CO_2, water spray or AFFF foam.

- **Large Fires:** Water spray, fog or AFFF foam. Use water spray or fog; do not use straight streams. Move containers from fire area if you can do it without risk.

- **Fire involving Tanks or Car/Trailer Loads:** fight fire from maximum distance, use unmanned hose holders, or monitor nozzles. Cool containers with flooding quantities of water until well after fire is out. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. ALWAYS stay away from tanks engulfed in fire. For massive fire, use unmanned hose holders or monitor nozzles; if this is impossible, withdraw from area and let fire burn.

- Self-contained breathing apparatus should be worn during fires in confined spaces.

7.5. LAB Leaking from Pipes or Equipment

ELIMINATE all ignition sources (no smoking sparks or flames in immediate area). All equipment used when handling the product must be grounded. Do not touch or walk through spilled material. Stop leak if you can do it without risk. Prevent entry into waterways, sewers, basement or confined areas. A vapor suppressing foam may be used to reduce vaporous. Absorb or cover with dry earth, sand or other non-combustible material and transfer to containers.
Use clean non-sparking tools to collect absorbed material.

IN CASE OF ALARM FOLLOW THE EMERGENCY ACTIONS ON PLANTS RECOMMENDED IN THIS PROCEDURE AND THE EMERGENCY PLAN OF JUNO SITE

7.6. Recommended major safety equipment

- **Portable Fire Extinguishers.** Number 2 pressurized foam 50 liters fire extinguishers should be provided at strategic locations. Also useful are large foam-type extinguishers.

- **Minor Equipment.** Minor safety equipment typically on hand comprises hard hats, goggles, gloves, etc., should be available in control room. During operations the work areas should be isolated with signs posted

"授权人员只"

"AUTHORIZED PERSONNEL ONLY"

- **Other Safety Equipment** absorbent cloth, containment "snakes", two vacuums liquids cleaners and a containment basin.

7.7. External and Environmental Impact

All the operation will be done in the confined space (LAB-5). The LAB-5 is provided with a fixed foam fire extinguisher plant operated in manual. There are also liquid sensor and sensor to measure smokes and temperature.

The nitrogen will be vented directly in the LAB.

The operation implies the production of liquid waste (LAB + PPO + bisMSB) that comes from the plant. The waste will be disposed by an external company.

8. Purification of Liquid Scintillator

This section provides a very detailed description of the general operating procedures for starting, running and stopping the JUNO stripping plant. Procedures in brief with checklists are included later in this section. These procedures assume the plant is commissioned and functionally tested, following additional specific procedures. In addition, it is assumed that the system has already at least a minimal inventory of scintillator or LAB. This procedure refers to Slow Control instructions, by referring to the control loop or equipment, but do not refer to specific graphical pages, which are under constant revision and upgrade. It is assumed here that the operator is familiar with logging into and using the Slow Control System, and has a valid individual operators account.
These instructions will always assume that in the starting condition all process valves are closed, although any valves, which are critical to check, are explicitly written. In all cases, the Stripping Plant is started in internal loop mode, where the output is routed back to the input through V-253. On startup, the system should be run in this mode until the system is stable, before connecting to external systems.

The operation consists of drawing the LS from the buffer Tank T-201 and pumping it in the Stripping column. The LS is purified by steam stripping under vacuum. Following purification, the LS is pumped to T-202 Buffer Tank.

9. Pre-Start Check Out

9.1. Administrative

1. The skids should be operated only with management approval, and only at agreed scheduled times, with authorized personnel, and only for the specific operations planned.
2. Regular operation of the skids requires the minimum of 2 authorized operators. If the operation involves any other JUNO purification plants then the minimum operators for those plants must also be present.
3. For each shift of operations, the Firemen/Safety Officer must be informed, and have the written instructions in Chinese regarding fire inspection and supervision.
4. For each shift of operations, check with the shift supervisor or operations manager, that there are no scheduled access restrictions, or planned interruptions in electrical, telephone, ventilation, nitrogen, cooling water or fire services.
5. Check the Plant logbook for entries on the last operation for any special notes, cautions, or instructions that should be considered for subsequent operations.
6. Check that all operating and equipment manuals and P&IDs are available underground and up to date.

9.2. Equipment, utilities and services

1. Check that only Stripping Plants area alarms are activated. Acknowledge any alarms and investigate any that remain active. Report unusual alarms to the purifications skids manager and await instructions.
2. Check that a suitable fire extinguisher is available near the plant.
3. Check that the oxygen sensors are working
4. Check that approved solvent spill absorbent material is available in the Liquid Scintillator Hall.
5. In the main electrical power cabinet check that the electrical breakers are energized for all the instruments, motors, solenoid valves and air handler.
6. Check that the Slow Control and the operator terminals are switched on and running.
7. Check that the nitrogen plant is operating, with regular and high purity nitrogen available between 5-7 bar (TP-23). Check that the supply valves to the Stripping Plant are open V-238, PCV-228 with the PCV-228 regulator output set at about 0.5 bar_g (1.1 barg during pumping and purging). Open V-211. Check the pressures on PI-227.
8. Open V-306 (TP-35) and check the pressure in the Air Instrument line
9. Check the supply pressure in the Air instrument line is higher than 2 barG and lower than 7 barG, then check that there is pressure in the air instrument line for each pneumatic valve.
10. Check that service-cooling water is available and running, which can be checked within the DCS/local thermometers. Check first that the

cooling water supply and return valves located in the Liquid Scintillator Hall are open (V-217, V-218 for E204, V-245 and V-246 for E-203). Check temperatures TI-253 and TIC-272 for E-204

11. Check water cooling temperature and flow rate on the chilling plant
12. Check all Drain and Vent Valves closed
13. Check any sign of water/LAB spillage

9.3. Purging Vacuum/Nitrogen

VACUUM PURGING

1. Check closed all pneumatic valves on the process lines: FV-238, LV-215, FV-250, PV-219, FV-239
2. Check closed all pneumatic valves on the auxiliary lines:TV-208, TV-201
3. Check closed valves
   a. on process: V-256, V-260, V-290, V-209, V-232, V-253, V-220, V-298, V-258, V-304, V-328
   b. on nitrogen line: V-238, V-211, V-206, V-255, V-237, V-242, V-278, V-243, V-251
   c. on steam line: V-284, V-205, V-303
   d. on vacuum line: V-264, V-252, V-288, V-289, V-227, V-248, V-301, V-276, V-279
   e. on E-201 Water Extraction by-pass: V-326, V-327
4. Switch on pump VP-201D
5. Check pressure on PI-264
6. Switch on pumps VP-201A/B/C
7. Check open valves
   a. on process: V-204, V-291, V-292, V-275, V-280, V-261, V-231, V-296, V-297, V-258, V-260, V-290, V-220, V-298, V-232, V-253, V-209, V-210, V-202, V-328
   b. on nitrogen line: V-206, V-243, V-251, V-255, V-242, V-237
   c. on steam line: V-205, V-303
   d. on vacuum line: V-281, V-247, V-301, V-276, V-315, V-314, V-279, V-316, V-319, V-321
8. Open V-238 and V-211
9. Open PCV-228 and set at 0.5 barg
10. Close V-238 and V-211
11. Open PV-219
12. Open FV-238
13. Open FV-250, LV-215, FV-239
14. Open V-264, V-252, V-288, V-289, V-227
15. Check pressure on PI-224
16. Check pressure on PI-229 and PI-233
17. Check pressure on PIC-219, PI-216
18. Check pressure on PI-222
19. Check DPI-237 > 0
20. Check DPI-266 > 0
21. Check pressure on PIC-219 until it reaches 5 mbar (keep an eye also on all other pressure sensors to check that all values are in agreement)

NITROGEN PURGING

1. Close V-264, V-252, V-288, V-289, V-227
2. Open slowly V-238
3. Open slowly V-211
4. Check the pressure on PIC-219 until it reaches 0.5 barg

VACUUM PURGING

1. Close V-238, V-211
2. Start VP-201A/D if needed
3. Open Slowly V-264, V-252, V-288, V-289, V-227
4. Check the pressure on PT-219 until it reaches 5 mbar

REPEAT (three) times

END

1. Close all the automatic valves
2. Close all manual valves
3. Check closed V-314, V-319, V-321 (RD bypass)

10. Process startup

This section describes the procedures for starting up the plant processes and achieving stable operation in internal loop mode (through V-253). Unless the plant will be then immediately shutdown, then this section will be followed directly by the procedures in section 10.1 for continuous operation. Plant shutdown procedures are in section 16, and emergency shutdown response is described in section 16.1.2

1. Start with all process controllers in MAN mode.
2. Check hot oil system running
3. Set Hot Oil System temperature at 45 °C (IMPORTANT SAFETY ISSUE!)
4. Check chilled water system running
5. Check at the interconnections panel that the input valve V-256 and output valve V-304 of the Stripping Plant are closed.
6. Check open V-272 and V-271 and TV-208 set at 50% on hot oil line (E-202) to start the hot oil flow for the E-202. Verify there is flow and temperature increase.
7. Check open V-201, V-282 and TV-201 at 20% (Hot oil on steam producer) to start the hot oil flow for the E-205. Verify there is flow and temperature increase TI-252.
8. ALWAYS OPEN CHILLED WATER SLIGHTLY TO AVOID SAFETY ISSUES!
9. Open V-217, V-218 and TV-272 on Chilled Water line to start the cooling water for the E-204.
10. Open V-245 and V-246 to start the Chilled cooling water for the E-203 condenser. Verify flow.
11. Open TV-272 at 90%, to start Chilled-cooling water in E-204. Verify flow
12. Check all VP running
13. Check pressure on local PI-264
14. Check open V-264, V-252, V-289 and V-288 on Vacuum line
15. Check pressure on PI-224
16. Open V-211 and V-238 on N2 line and check the PI-227 < 0.5 barg
17. Check that the level of T-201 is above the LI-223-L. If in excess, operations can start running with higher levels (but less than LI-223-HH). If in excess, LAB can be drained through C-201 to T-202. If the level are less than LI-223-L, then new LAB or scintillator should be obtained by opening V-256, and connecting to the appropriate source at the interconnections. Following procedures appropriate to the source (e.g. storage area), flow LAB into T-201 while monitoring the level LI-223. When the desired level is reached, close V-256.
18. Check closed V-276, V-314 and V-315 (on T-201)
19. Check closed V-204, V-290 and V-292 (on F-202) with F-202A in service
20. Check closed V-326 and V-327 (on E-201)
21. Check closed V-279, V-316 and V-319 (on T-202)
22. Check closed V-231, V-298 and V-297 (on F-201) with F-201A in service
23. Check closed V-304 (output product line TP-24)
24. Check closed V-251, V-247, V-248, V-281, V-227 (on T-203)
25. Now continue the procedure in the next sections(s).

Stripping Startup in Loop Mode

1. **N2 Blanket in T-201**
   a. Open V-255
   b. Open slightly and partially V-315 (see point 1d.)
   c. Check constant PI-229 at 0.5 barg
   d. Check and register (by V-315) the flux change in FI-236 (around 1-2 Nm3/h)

2. **N2 Blanket in T-202**
   a. Open V-242
   b. Open slightly and partially V-316 (see point 2d.)
   c. Check constant PI-222 at 0.5 barg
   d. Check and register (by V-316) the flux change in FI-236 (around 1-2 Nm3/h)

3. **N2 Blanket in C-201**
   a. Open PV-219 by setting PIC-219 regulation at 250 mbar
   b. Open slightly and partially V-237 (see point 3c.)
   c. Check and register (by V-237) the flux change in FI-211 (around 2-4 Nm3/h)
   d. Check constant PIC-219 at 250 mbar

4. **LAB Feed**
   a. Open V-258 under T-201
   b. Open V-260 and V-291 on F-202A
   c. Open V-202 (P-202 by pass)
   d. Open V-261 and V-280 (on line E-201 after filter) **[in case of energy recovery on Water Extraction close V-261 and V-280 and open V-326, V-327 on E-201 by pass]**
   e. Check close V-275 (E-201 by pass) **[in case of energy recovery on Water Extraction open V-275]**
   f. Open FV-238 at 100%
   g. Start P-202 (slowly from 0 to 10 m3/h) (Speed rate to be checked during the first startup)
   h. Set FIC-238 in order to reach the desired value of flow rate (3000 L/h)
   i. Partially or fully close V-202 if the pump is running well **(if flow rate on FIC-238 is less than 5000 L/h V-202 must be partially open to keep enough flux inside the pump)**
   j. Keep watching LIC-215 level in C-201!!!
   k. Open TV-208 at 100%
   l. Set TIC-208 in order to reach the desired first value of temperature (45 °C)

5. **Product**
   a. Open V-209 (T-202 input)
   b. Set TIC-272 in order to reach the desired value of temperature (21 °C)
   c. When LIC-215 > 60% , open LV-215 at 90%
   d. Open V-328 (P-201 bypass)
   e. Start P-201 (slowly from 0 to 10 m3/h) (Speed rate to be checked during the first startup)

f. Set LIC-215 in order to keep constant the level in the column (50%)
g. Partially or fully close V-328 if the pump is running well **(if flow rate on LIC-215 is less than 5000 L/h V-328 must be partially open to keep enough flux inside the pump)**
h. Fill T-202

6. **Loop Mode**

When the level in T-202>30% (check LI-231):

a. Open V-232 on T-202 and V-210 (P-203 by pass)
b. Open V-220 and V-296 an F-201A
c. Open V-253 (internal loop valve)
d. Start P-203 (slowly from 0 to 10 m3/h) (Speed rate to be checked during the first startup)
e. Open FV-250 at 90%
f. Set FIC-250 equal to FIC-238 in order to keep the inlet and outlet flowrate constant
g. Partially or fully close V-210 if the pump is running well **(if flow rate on FIC-250 is less than 5000 L/h V-210 must be partially open to keep enough flux inside the pump)**
h. Check that LS is going back to T-201
i. Slightly increase Hot Oil temperature from 45 °C up to 120 °C
j. Set TIC-208 in order to reach the desired final value of temperature (90 °C)
k. Slowly increase the plant flow rate from 3000 L/h to 7000 L/h by changing both P-201, P-202, P-203 speed and FIC-238 and FIC-250 flow rate. **In case adjust also the pumps bypass.**

7. **Steam Production**

a. Start electrical resistance on steam line
b. Check close FV-239
c. Check TI-240 increase up to 90 °C
d. Check open V-201 and V-282 (E-205 Hot oil)
e. Check closed V-205
f. Open TV-201 at 50% and set TI-252 at 90 °C (if not done before)
g. Check hot oil flow by TI-252 and that temperature increase until 90 °C
h. Open V-284
i. Open V-303
j. Set FIC-239 in order to keep FT-239 at 5 l/h (just for startup)
k. Open FV-239
l. Check TI-218 close to 90 °C
m. Wait until PIC-219 stabilize at 250 mbar
n. Start to increase FT-239 up to 20 – 30 L/h by 5 L/h steps
o. Wait until PIC-219 stabilize at 250 mbar

If everything stable:

p. Open V-205
q. Close V-303
r. Check TIC-201 and TI-240 around 90 °C
s. Check column pressure PIC-219 stable at 250 mbar
t. Control V-237 to diminish or increase the nitrogen flow to the column at the desired value (nominal 2 – 3 Nm3/h)

NOTES:

a. Throughout this procedure, the operators must closely watch the C-201 pressure, temperature, and T-201 Pressure to avoid the breaking of Rupture Disk, and all the vessel levels.

WARNINGS:

a. Do not operate the stripping above 450 mbar.

11. Process Operation, Controls and Alarm Actions

11.1. Continuous process operation

Following the procedures in section 10.1, the plant process should be running in internal loop mode and generally stable. In this section are basic procedures for bringing the plant on-line for operations and repetitive procedures for continued operation.

11.2. Placing the purification plant on-line

Putting the plant on-line means connecting the input and output of the plant to external sources, so that it becomes a component of a larger operation. The Stripping Plant is connected to the wider JUNO Purification plans via the interconnection system. This allows the purification plants to be employed in a variety of purification flow paths.
The Stripping Plant cannot be connected to other plants unless specifically authorized and only when authorized operators for the other plants involved are available.

1. Co-ordinate with plant operators for the plant connecting to the Stripping Plant **input**, check that all procedures for that plant have been followed and that the plant is ready for operation. Ensure that the flow path and connected equipment meet JUNO cleanliness requirements and will not contaminate the purification system. Keep in mind that the input plant will probably require a pump. Complete the input flow path, checking first that all valves required to be closed are in fact closed and then opening other valves in sequence. Leave the final valve V-304 closed and the source pump switched off.
2. Coordinate with plant operators for the plant connecting to the Stripping Plant **output**, check that all procedures for that plant have been followed and that the plant is ready for operation. Ensure that the flow path and connected equipment meet JUNO cleanliness requirements and will not contaminate the purification system. Complete the output flow path, checking first that all valves required to be closed are in fact closed and then opening other valves in sequence. Leave the final valve closed (V-304 – TP-24).
3. When the operator for the output plant is ready, open the final valve (V-304 – TP-24) in the output line. Then slowly close the skid bypass valve V-253. If the level in T-202 keep increasing then there could be a blockage or restriction in the output line or plant (e.g. undesired closed valve). Reopen V-253 to restore internal flow and investigate. Then try again to close V-253. If it stalls again or is cycling very slowly, then the problem could just be that the line impedance is increased.
4. Open V-256 and start the external source pump to initiate the input flow. Verify input flow and that the T-203 level stabilizes.

5. Next the input flow and purification skid feed rate must be roughly balanced, at least on average, to maintain the T-201 buffer level. If the input flow is much greater than FIC-238, then the input flow can be reduced or throttled back or turned off intermittently to maintain the T-201 level. Alternately, if the input flow is limited, then the P-202 feed can be throttle to maintain the T-201 level.
6. The Stripping Plant output flow is equal to the input feed FT-238 over the long term when the level controllers are constant and stable. The output flow can be stopped temporarily or intermittently by closing V-304 and opening V-253.

12. Drain of the plant

When the Plant will be not operated for a long time, a complete drain of the plant is required.
Following the procedures for a complete drain of the plant, take in mind also all the operations described in section 10.1 regarding valve and pumps sequences. Pumps should always be full of liquid when running.
Do not run pumps dry!

1. Put the plant at nitrogen atmosphere (0.5 barg)
2. Check close all the valves at the Terminal Points for Hot Oil (V-271, V-272, V-282, V-201) and Chilled Water (V-217, V-218, V-245, V-246)
3. Close V-256 (LAB feed) and V-304 (LAB outlet)
4. Empty T-201 in C-201 through E-202 starting P-202
5. Pay attention to stop P-202 when T-202 level reaches LT-223-LL: the pump must NOT run dry! (Do not disable interlock on P-202 from LT-223)
6. Check that V-328 (P-201 bypass) remains open during the drain procedure (it always should be partially open during plant operation mode)
7. Empty C-201 in T-202 starting P-201
8. Pay attention to stop P-201 when C-201 level reaches LT-215-LL: the pump must NOT run dry! (Do not disable interlock on P-201 from LT-215)
9. Empty T-202 in external tanks through V-304 starting P-203
10. Pay attention to stop P-203 when T-202 level reaches LT-231-LL: the pump must NOT run dry! (Do not disable interlock on P-203 from LT-231)
11. Open V-204 (F-202 bypass)
12. Close V-326 and V-327 (Water Extraction LAB inlet and outlet)
13. To allow the drain of E-201 and E-202, open V-261, V-280 and V-275
14. Check that V-202 and V-210 (T-201 and T-202 bypass, respectively) remain open during the drain procedure (they always should be partially open during plant operation mode)
15. Connect a temporary pump (e.g. DEBEM diaphragm pump) to V-259: drain all the LS and discharge it to an external waste system
16. Close V-259
17. Drain the remaining LS through drain valves (V-294, V-295, V-213, V-228, V-235, V-299, V-300, V-222, V-214, V-317, V-259, V-324, V-325, V-305, V-322, V-323) properly connected to a waste system

Drain of E-205 (Water Boiler)

1. Check Plant under Nitrogen Atmosphere (0.5 barg)
2. Open V-206
3. Connect V-285 to a proper drain system
4. Open V-285
5. Drain water from V-285
6. Close V-285

13. Drain E-203

If LI-271 is greater than set threshold (80%) and/or LSH220 start to blink, it means that the level in E-203 is too high and it is necessary to drain the condenser in T-203 with the following procedure.

1. Check VP-201D is running and PI-264 less than few mbar
2. Check close V-227, V-247, V-251, V-281, V-248, V-264 (on T-203)
3. Check F-203 status (LAB presence on bottom) and drain if needed (VP-201D off before)
4. Open (slowly) V-227 to vacuum T-203 through F-203
5. After few minute close V-227, check PI-264
6. Open (slowly) V-247 and wait for E-203 to be drained (check LI-271 level)
7. Close V-247
8. Open V-251 to pressurize T-203
9. Close V-251
10. Open V-248 to send the discharged LS to an external storage
11. During discharge it could be that V-251 should be open temporary to avoid vacuum in T-203 due to liquid drain
12. Close V-248

14. Change input filter (F-202)

If DPI-237 is greater than 700 mbar, it means that the filters are plugged. In order to replace the filter, follow the following procedure.

If the filter plugged is F-202A:

1. Open V-290 and V-292
2. Close V-260 and V-291
3. Open the cap on V-294
4. Open V-324 (KF25 on filter side)
5. Drain F-202A in a tank by opening V-294
6. Close V-294
7. Open cartridges holder (main flange)
8. Change cartridges
9. Close holder
10. Connect a portable vacuum pump on V-324 (KF25 on filter side) with a protective oil separator before pump inlet
11. Make full vacuum on F-202A filter
12. Close V-324
13. Connect N2 temporary line to V-294
14. Open N2 and V-294 until pressure 0.5 barg (few minutes)
15. Close V-294
16. Open V-324
17. Repeat from point 10 two times
18. Close V-324
19. Remove the portable vacuum pump and close the cap
20. Close the cap on V-294

If the filter plugged is F-202B:

1. Open V-260 and V-291
2. Close V-290 and V-292
3. Open the cap on V-295
4. Open V-325 (KF25 on filter side)
5. Drain in a tank F-202B by opening V-295
6. Close V-295
7. Open cartridges holder (main flange)
8. Change cartridges
9. Close holder
10. Connect a portable vacuum pump on V-325 (KF25 on filter side) with a protective oil separator before pump inlet
11. Make full vacuum on F-202B filter
12. Close V-325
13. Connect N2 temporary line to V-295
14. Open N2 and V-295 until pressure 0.5 barg (few minutes)
15. Close V-295
16. Open V-325
17. Repeat from point 10 two times
18. Close V-325
19. Remove the portable vacuum pump and close the cap
20. Close the cap on V-295

15. Change output filter (F-201)

If DPI-266 is greater than 700 mbar, it means that the filters are plugged. In order to replace the filter follow the following procedure.

If the filter plugged is F-201A:

1. Open V-298 and V-297
2. Close V-220 and V-296
3. Open the cap on V-299
4. Open V-322 (KF25 on filter side)
5. Drain in a tank F-201A by opening V-299
6. Close V-299
7. Open cartridges holder (main flange)
8. Change cartridges
9. Close holder
10. Connect a portable vacuum pump on V-322 (KF25 on filter side) with a protective oil separator before pump inlet
11. Make full vacuum on F-201A filter
12. Close V-322
13. Connect N2 temporary line to V-299
14. Open N2 and V-299 until pressure 0.5 barg (few minutes)
15. Close V-299
16. Open V-322
17. Repeat from point 11 two times
18. Close V-322
19. Remove portable pump and close the cap
20. Close the cap on V-299

If the filter plugged is F-201B:

1. Open V-220 and V-296
2. Close V-298 and V-297
3. Open the cap on V-300
4. Open V-323 (KF25 on filter side)
5. Drain in a tank F-201B by opening V-300
6. Close V-300
7. Open cartridges holder (main flange)
8. Change cartridges
9. Close holder
10. Connect a portable vacuum pump on V-323 (KF25 on filter side) with a protective oil separator before pump inlet
11. Make full vacuum on F-201B filter
12. Close V-323
13. Connect N2 temporary line to V-300
14. Open N2 and V-300 until pressure 0.5 barg (few minutes)
15. Close V-300
16. Open V-323
17. Repeat from point 11 two times
18. Close V-323
19. Remove portable pump and close the cap
20. Close the cap on V-300

16. Process Stop and Shutdown

16.1. Process stop/standby

This is the procedure for temporarily interrupt the process, for example to configure something inside or external to the plant, or to investigate a problem. Whenever changing the plant status, plants manager of all interconnected systems must be informed.

16.1.1. Internal loop mode

Whenever possible, the best standby mode is internal loop mode, which leaves the plant running as normal with the output redirected back to the input. Open valve V-253 to open the bypass line. Then close the input line (V-256), and close the output line (V-304).

16.1.2. Software Process Shutdown

This is the minimum procedure to simply stop the LAB flow. This is only a temporary standby condition, to leave the plant in safe condition. This Procedure is partially operated by the Slow Control System and it is triggered by the operator or by the Slow Control itself in response of an alarm.

1. Shutdown E-202 heater (TV-208 fully closed)
2. Shutdown E-205 heater (TV-201 and FV-239 fully closed)
3. Shutdown Heat resistance stripes
4. Disable (set manually closed on DCS) FIC-238 and LIC-215
5. Shut down the pumps P-203, P-202 and P-201
6. Close V-304
7. Close V-256

The LS flow should be restarted in internal loop mode, by stepping through the regular startup sequence in section 10.1 (obviously omitting steps for the parts already running).

17. Alarms

17.1. Setting the process variable alarms

The complete alarm table is reported in the document:

"Alarms and interlocks list C-367_102 rev.5.xlsx"

See this document to have the whole list of alarm thresholds (LL, L, H, HH, etc.) for each instrument installed on the plant and controlled by the DCS. The alarms in this table must be checked and set as required. Notify the purification Stripping Plant manager of any alarms that are found to be not activated or have different set points. Check the logbook for notes about any intentional variation.

The interlock functions listed in this table are designed to prevent undesirable process situations resulting from operator error and/or equipment failures. Note the philosophy, that Slow Control interlocks are used only for protection of process quality and to prevent process and equipment problems due to failures or large transients. Interlocks required for safety have either been provided intrinsically (rupture disks etc.). For some operations, or for maintenance, the interlocks will need to be overridden: in this case is mandatory a written approval by task managers and actions and modifications should be reported on logbook.

Check at the Slow Control that all these interlocks are set (not overridden). Note that some interlocks require setting choices for the operating mode in order that the interlocked variables are consistent. The interlocks that cannot be overridden have no operator functions and are listed only for operator information.

17.2. Set of Control

LOOP OR DEVICE		DESCRIPTION	LINE TYPE	SET VALUE
TIC	201	TEMPERATURE CONTROLLER (THROUGH TV-201) FOR E-205 OUTLET	PURE WATER SUPPLY	90°C ?
TIC	208	TEMPERATURE CONTROLLER (THROUGH TV-208) FOR C-201 INLET	LAB	90°C ?
LIC	215	LEVEL CONTROLLER (THROUGH LV-215) FOR C-201 OUTLET	LAB	50% ?
PIC	219	PRESSURE CONTROLLER (THROUGH PV-219) FOR C-201 STEAM OUTLET	NITROGEN / WATER STEAM	250 mbar ?
FIC	238	FLOW CONTROLLER (THROUGH FV-238) FOR E-201 INLET	LAB	7000 l/h
FIC	239	FLOW CONTROLLER (THROUGH FV-239) FOR E-205 INLET	PURE WATER SUPPLY	20 l/h
FIC	250	FLOW CONTROLLER (THROUGH FV-250) FOR T-202 OUTLET	LAB	7000 l/h
TIC	272	TEMPERATURE CONTROLLER (THROUGH TV-272) FOR E-204 OUTLET	LAB	20-30°C ?

17.3. Alarm Switches

LOOP OR DEVICE		DESCRIPTION	LINE TYPE	SET VALUE
LAH	213	ALARM HIGH LEVEL C-201	LAB	LAH
LAH	220	ALARM HIGH LEVEL E-203	LAB	LAH
IAL	254	P-202 INVERTER	CURRENT	IAL

IAL	255	P-201 INVERTER	CURRENT	IAL
LAL	267	ALARM LOW LEVEL C-201	LAB	LAL
IAL	274	P-203 INVERTER	CURRENT	IAL

17.4. Hardware Interlock

The main hardware interlock are:

1. Emergency Button
2. Circuit Breaker for motor driven pumps

17.5. Alarms Action

For any alarms that occur, you should call the skids manager, unless the occurrence of the alarm is a very well understood phenomenon that has already occurred previously. Only if an alarm can be trivially understood and/or corrected should you avoid calling the skids manager. In any case, all alarm occurrences should be noted in the logbook along with any actions taken. The following actions serve only as a guideline, as the correct response to an alarm requires thoroughly understanding the root cause of it. The general guideline should be that of caution, where the plant is shut down if you cannot understand the problem, and cannot contact the skid manager or other manager in reasonable time.

<table>
<tr><th rowspan="2">Device Controller</th><th>Alarm type</th><th>Reason</th><th>Cause</th></tr>
<tr><th colspan="3">Actions, checks, notes, and warnings</th></tr>
<tr><td rowspan="2">LT-223</td><td>H, HH</td><td>High Level</td><td>Input Flow too high, Output Flow too low</td></tr>
<tr><td colspan="3">The Flow input to the Stripping Plant is greater than the output flow leaving T-201. Reduce the input flow and check for failure of P-202.
WARNING: if uncorrected, this condition will lead to Nitrogen Line flooding an then eventually rupture of Burst Disk</td></tr>
<tr><td rowspan="2">LT-223</td><td>L,LL</td><td>Low Level</td><td>Input Flow too low, Output Flow too high</td></tr>
<tr><td colspan="3">The input flow to the skid is less than the output flow leaving T-201. Increase the input flow or stop P-202. WARNING: If feed is to C-201 and T-201 is empty, then C-201 can break vacuum through T-201 if it is non under vacuum. This will cause surges in input flow and possible contamination due to turbulence and backflows in the vent.</td></tr>
<tr><td rowspan="2">TT-208</td><td>H, HH</td><td>High Temp</td><td>High temperature in E-202</td></tr>
<tr><td colspan="3">The Temperature after E-202 is too high. This could happen if there is no flow to C-201 or TV-208 not regulating in the proper way. Check P-202 and TV-208</td></tr>
<tr><td rowspan="2">PT-219</td><td>H, HH</td><td>High Pressure</td><td>High Pressure in the column</td></tr>
<tr><td colspan="3">The pressure in the Vacuum Line is too high, implying loss of vacuum regulation (during stripping) or pressurization of the stripping column. During stripping this could occur if the production of steam is too high or due to instabilities in the pressure controller PV-219. Check the level TT-252 (temperature in E-205), the integrity of the rupture disks, PT-219 and that VP-201A/D are working properly.</td></tr>
<tr><td rowspan="2">LT-215</td><td>H, HH, L, LL</td><td>High/Low Level</td><td>High Level in the column</td></tr>
<tr><td colspan="3">The level is high/low in C-201 due to instabilities in the feed rate to the column or exiting form the column. Check the regulation of FV-238 (INPUT) and LV-215 (OUTPUT). To recover the level, set FIC-238 and LIC-215 in MAN regulating manually the flows to re-establish the correct level of LT-215.</td></tr>
<tr><td>TT-272</td><td>H, HH</td><td>High Temp</td><td>T-202 Inlet High Temperature</td></tr>
</table>

Device Controller	***Alarm type***	***Reason***	***Cause***
	Actions, checks, notes, and warnings		
	The temperature in T-202 is High: this could be due to a lack of flow to the column through E-201 or malfunctioning of the cooler E-204.		
DPT-237/ DPT-266	H, HH	High pressure difference	High pressure on the filters
	If DPT-237 (DPT-266) is too high the filter F-202 (F-201) is clogged. Proceed with the procedure described in chapter 15.		
TT-252	H, HH	High temperature	High Temperature in E-205 (Steam Producer)
	If TT-252 is too high, check the regulation FIC-239 or the valve FV-239 are not closed and the temperature of the hot-oil (check also TV-201).		

18. Operation and Shift Requirement

The operation will be organized on shifts.

There will be at least two person per shift.

The Operations Manager will communicate in advance to the SPP the contact person and her/his emergency contacts.

Leading personnel involved in the operation and contact numbers:

Name	**Cellphone**	**E-mail**
Paolo Lombardi	+393473771723	Paolo.lombardi@mi.infn.it
Michele Montuschi	+393928496592	Michele.montuschi@lngs.infn.it
Augusto Brigatti		Augusto.Brigatti@mi.infn.it
Sergio Parmeggiano		Sergio.Parmeggiano@mi.infn.it
Cecilia Landini		Cecilia.landini@mi.infn.it

19. Equipment List

NAME	TYPE	FLOOR	DESCRIPTION	FLUID
C-201	Stripping column	1st to 4th	GAS STRIPPING COLUMN	LAB
E-201	Heat exchanger	1st	HEAT RECOVERY FOR LAB FROM WATER EXTRACTION PLANT	Tubes: LAB FROM COLUMN Shell: LAB FROM W.E. PLANT
E-202	Heat exchanger	1st	STRIPPING COLUMN INLET HEATER	Tubes: LAB Shell: HOT OIL
E-203	Heat exchanger	2nd to 3rd	VENT CONDENSER FOR VACUUM LINE	Tubes: VAPORS, N2 Shell: CHILLED WATER
E-204	Heat exchanger	Ground	STRIPPED LAB COOLER	Tubes: LAB Shell: CHILLED WATER
E-205	Heat exchanger	2nd	UPW EVAPORATOR	Tubes: UPW Shell: HOT OIL
F-201A/B	Filters	Ground	LAB PRODUCT FILTERS (F-201B AS SPARE)	LAB
F-202A/B	Filters	Ground	LAB FEED FILTERS (F-202B AS SPARE)	LAB
P-201	Magnetic driven pump	Ground	PUMP AFTER STRIPPING COLUMN	LAB
P-202	Magnetic driven pump	Ground	LAB FEED PUMP	LAB
P-203	Magnetic driven pump	Ground	LAB PRODUCT PUMP	LAB
T-201	Tank	Ground to 3rd	LAB FEED TANK	LAB
T-202	Tank	Ground to 3rd	LAB PRODUCT TANK	LAB
T-203	Tank	1st	DRAIN TANK (WASTE CONDENSATE)	CONDENSED VAPORS, LAB
VP-201A/B/C/D	Vacuum pumps	4th	VACUUM PUMPS	VAPORS, N2, WATER

To understand the arrangement of Stripping plant floors, see section 22.

20. Instrument List

LOOP OR DEVICE		FLOOR	LINE TYPE	DESCRIPTION	NOMINAL OPERATING VALUE	DCS SIGN. TRANSM.	DCS INDIC. CONTR.
TIC	201	2^{nd}	PURE WATER SUPPLY	TEMPERATURE INDICATOR AND CONTROLLER FOR E-205 OUTLET	90°C ?	Yes	Yes
TIC	208	1^{st}	LAB	TEMPERATURE INDICATOR AND CONTROLLER FOR C-201 LAB INLET	90°C ?	Yes	Yes
FI	211	1^{st} ?	NITROGEN	C-201 INLET NITROGEN FLOW INDICATOR	2 Nm^3/h ?	Yes	No
LSH	213	1^{st}	LAB	HIGH LEVEL SWITCH FOR C-201 BOTTOM LEVEL	?	Yes ??	No
TI	214	1^{st}	LAB	C-201 BOTTOM TEMPERATURE INDICATOR	90°C ?	Yes	No
LIC	215	Ground	LAB	C-201 LEVEL INDICATOR AND CONTROLLER (DELTA P GAUGE)	50% ?	Yes	Yes
PI	216	1^{st}	NITROGEN	C-201 MIDDLE PRESSURE INDICATOR	250 mbar ?	Yes	No
TI	218	4^{th}	NITROGEN / WATER STEAM	TEMPERATURE INDICATOR FOR C-201 GAS OUTLET	90°C ?	Yes	No
PIC	219	4^{th}	NITROGEN / WATER STEAM	C-201 GAS OUTLET PRESSURE INDICATOR AND CONTROLLER	250 mbar ?	Yes	Yes
LSH	220	2^{nd}	WASTE CONDENSATE	HIGH LEVEL SWITCH FOR E-203 BOTTOM LEVEL	?	Yes	No
PI	222	3^{rd}, top of tank T-202	NITROGEN	T-202 PRESSURE INDICATOR	0.5 barg ?	Yes	No
LI	223	3^{rd}, top of tank T-201	LAB	T-201 LEVEL INDICATOR	50% ?	Yes	No
PI	224	2^{nd}	VACUUM	PRESSURE INDICATOR FOR VP-201 INLET	?	Yes	No
TI	225	4^{th} ?	VACUUM	TEMPERATURE INDICATOR FOR VP-201 INLET	25°C ?	Yes	No
PI	226	Ground	LAB	P-201 DELIVERY PRESSURE INDICATOR	2.5 bar ??	No	No
PI	227	Ground	NITROGEN	PRESSURE INDICATOR FOR GAS NITROGEN FEED	0.5 barg ??	No	No
PI	229	3^{rd}, top of tank T-201	NITROGEN	T-201 PRESSURE INDICATOR	0.5 barg ?	Yes	No
LI	231	3^{rd}, top of tank T-202	LAB	T-202 LEVEL INDICATOR	50% ?	Yes	No
PI	232	Ground	LAB	P-202 DELIVERY PRESSURE INDICATOR	2.5 bar ??	No	No
PI	233	Ground	LAB	F-202 LAB OUTLET PRESSURE INDICATOR	??	No	No

LOOP OR DEVICE		FLOOR	LINE TYPE	DESCRIPTION	NOMINAL OPERATING VALUE	DCS SIGN. TRANSM.	DCS INDIC. CONTR.
FI	236	Ground	NITROGEN	GAS NITROGEN FEED FLOW INDICATOR	3 Nm^3/h ?	Yes	No
DPI	237	Ground	LAB	F-202 DELTA P INDICATOR	500 mbar ?	Yes	No
FIC	238	Ground	LAB	E-201 INLET FLOW INDICATOR AND CONTROLLER	7000 l/h	Yes	Yes
FIC	239	2nd ?	PURE WATER SUPPLY	E-205 PURE WATER INLET FLOW INDICATOR AND CONTORLLER	20 l/h ?	Yes	Yes
TI	240	1st ?	PURE WATER SUPPLY	TEMPERATURE INDICATOR FOR C-201 PURE WATER INLET	90°C ?	Yes	No
FIC	250	Ground	LAB	F-201 INLET FLOW INDICATOR AND CONTROLLER	7000 l/h	Yes	Yes
TI	251	1st	LAB	TEMPERATURE INDICATOR FOR E-202 INLET	50-60°C ?	Yes	No
TI	252	2nd	HEATING	TEMPERATURE INDICATOR FOR E-205 HEATING FLUID OUTLET	?	Yes	No
TI	253	1st ??	LAB	TEMPERATURE INDICATOR FOR E-204 INLET	55°C ??	Yes	No
TI	262	Ground	LAB	T-202 TEMPERATURE INDICATOR	20°C ?	Yes	No
TI	263	Ground	LAB	TEMPERATURE INDICATOR FOR LAB OUTLET	20°C ?	Yes	No
PI	264	4th	VACUUM	PRESSURE INDICATOR FOR VP-201D INLET	1 mbar ?	No	No
PI	265	Ground	LAB	PRESSURE INDICATOR FOR LAB OUTLET	??	No	No
DPI	266	Ground	LAB	F-201 DELTA P INDICATOR	500 mbar ?	Yes	No
LSL	267	1st	LAB	LOW LEVEL SWITCH FOR C-201 BOTTOM LEVEL	?	Yes ?	No
LI	268	1st ?	LAB	C-201 LEVEL INDICATOR	50% ?	Yes	No
PI	270	Ground	LAB	P-203 DELIVERY PRESSURE INDICATOR	2.5 bar ?	No	No
LI	271	2nd	WASTE CONDENSATE	E-203 LEVEL INDICATOR	50% ?	Yes	No
TIC	272	Ground	LAB	TEMPERATURE INDICATOR AND CONTROLLER FOR E-204 OUTLET	20-30°C ?	Yes	Yes
TI	273	4th ?	VACUUM	TEMPERATURE INDICATOR FOR VP-201D INLET	?	Yes	No

Legend:

DCS SIGN. TRANSM. = DCS Signal Transmitter (the instrument measure is automatically transmitted to the DCS)

DCS INDIC. CONTR. = DCS Indicator Controller (depending on the value measured by the instrument, the DCS can automatically operate and control the related valve to reach the set nominal operating value)

To understand the arrangement of Stripping plant floors, see section 22.

21. Valves List

TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	201	2nd	HEATING	DN25	E-205 HEATING FLUID OUTLET	MANUAL
TV	201	2nd	HEATING	DN25	REGULATING VALVE FOR E-205 HEATING FLUID OUTLET	AUTO
V	202	3rd, top of tank T-201	LAB	DN50	RETURN FROM P-202 TO T-201	MANUAL
V	203	2nd	PURE WATER	1/4"	PURE WATER FEED SAMPLE PORT	MANUAL
V	204	Ground	LAB	DN50	F-202 BY-PASS	MANUAL
V	205	3rd (?)	PURE WATER	DN25	FROM E-205 TO C-101	MANUAL
V	206	1st	NITROGEN	DN25	FROM NITROGEN INLET TO E-205	MANUAL
TV	208	1st	HEATING	DN50	REGULATING VALVE FOR E-202 HEATING FLUID INLET	AUTO
V	209	Ground (?)	LAB	DN50	FROM E-204 TO T-202	MANUAL
V	210	Ground (?)	LAB	DN50	FROM P-203 TO T-202	MANUAL
V	211	Ground	NITROGEN	DN25	NITROGEN FEED VALVE AFTER PCV-228	MANUAL
V	213	Ground (?)	LAB	DN25	C-201 DRAIN	MANUAL
V	214	Ground	LAB	1/4"	STRIPPING PRODUCT SAMPLE PORT	MANUAL
LV	215	Ground	LAB	DN50	FROM E-204 TO T-202	AUTO
V	215	Ground	COOLING	1"	E-204 COOLING FLUID VENT	MANUAL
V	216	Ground	COOLING	1"	E-204 COOLING FLUID DRAIN	MANUAL
V	217	Ground	COOLING	DN50	E-204 COOLING FLUID OUTLET	MANUAL
V	218	Ground	COOLING	DN50	E-204 COOLING FLUID INLET	MANUAL
CV	219	4th (?)	VACUUM	DN50	CHECK VALVE AFTER VP-201	ONE-WAY
EV	219	4th (?)	VACUUM / STEAM	-	SOLENOID VALVE FROM C-201 TO E-203 (IT OPERATES ON PV-219)	AUTO
PV	219	4th	VACUUM / STEAM	DN50	FROM C-201 TO E-203	AUTO
V	220	Ground	LAB	DN50	FROM P-203 TO F-201A	MANUAL
V	222	Ground, bottom of tank T-201	LAB	1/4"	T-201 SAMPLE PORT	MANUAL
V	227	2nd	VACUUM	DN25	FROM T-203 TO F-203	MANUAL
PCV	228	Ground	NITROGEN	1/2"	NITROGEN FEED REGULATING VALVE	AUTO

TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	228	Ground, bottom of tank T-202	LAB	1/4″	T-202 SAMPLE PORT	MANUAL
CV	229	3rd, top of tank T-201	LAB	DN50	CHECK VALVE FROM F-201 TO T-201 (RETURN LINE)	ONE-WAY
V	231	Ground	LAB	DN50	F-201 BY-PASS	MANUAL
V	232	Ground, bottom of tank T-202	LAB	DN50	FROM T-202 TO P-203	MANUAL
V	235	Ground, bottom of tank T-202	LAB	DN25	T-202 DRAIN	MANUAL
V	237	1st (?)	NITROGEN	DN25	FROM NITROGEN INLET TO C-201	MANUAL
V	238	Ground	NITROGEN	DN25	NITROGEN INLET VALVE	MANUAL
FV	238	Ground	LAB	DN50	FROM F-202 TO E-201	AUTO
FV	239	2nd	PURE WATER	1/4″	FROM PURE WATER INLET TO E-205	AUTO
V	240	3rd	COOLING	1/2″	E-203 COOLING FLUID VENT	MANUAL
PSV	241	Ground	NITROGEN	DN25	NITROGEN INLET RELIEF VALVE	AUTO
V	241	3rd	COOLING	1/2″	E-203 COOLING FLUID DRAIN	MANUAL
V	242	Ground, near T-202 (?)	NITROGEN	DN25	FROM NITROGEN INLET TO T-202	MANUAL
V	243	2nd	NITROGEN	1/4″	FROM NITROGEN INLET TO VACUUM LINE	MANUAL
V	245	3rd	COOLING	DN25	E-203 COOLING FLUID INLET	MANUAL
V	246	3rd	COOLING	DN25	E-203 COOLING FLUID OUTLET	MANUAL
V	247	1st	WASTE CONDENSATE	DN25	FROM E-203 TO T-203	MANUAL
V	248	1st	WASTE CONDENSATE	DN25	LAST WASTE VALVE	MANUAL
CV	249	2nd (???)	NITROGEN	DN25	CHECK VALVE FROM NITROGEN INLET TO VACUUM LINE	ONE-WAY
FV	250	Ground	LAB	DN50	FROM P-203 TO F-201	AUTO
V	250	2nd	VACUUM	DN25	E-203 TO VP-201 DRAIN	MANUAL
V	251	1st	NITROGEN	DN25	FROM NITROGEN INLET T-203	MANUAL
V	252	4th	VACUUM	DN50	FROM E-203 TO VP-201C	MANUAL
V	253	Ground (?)	LAB	DN50	FROM F-201 TO T-201	MANUAL

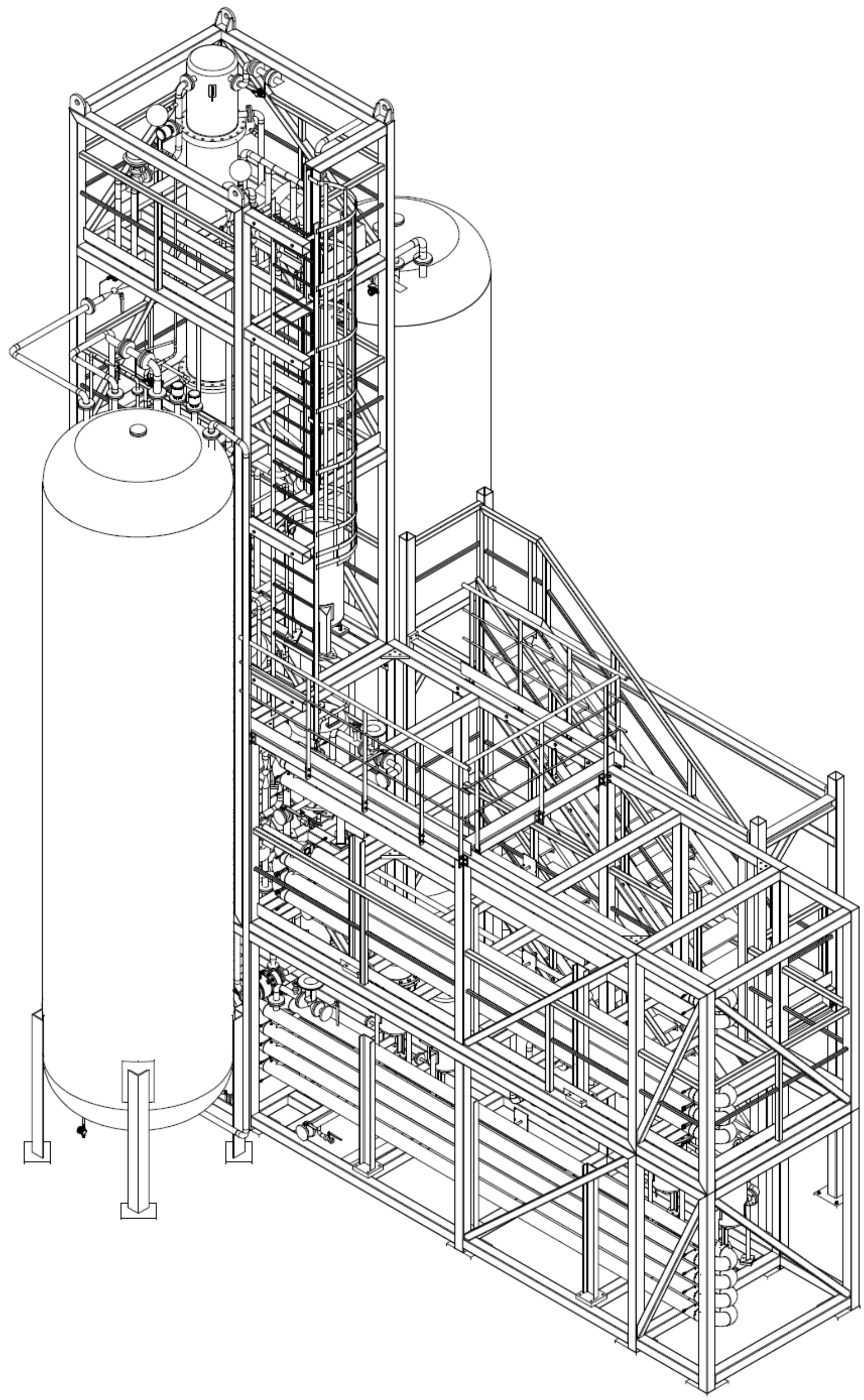
TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	255	3^{rd}, top of tank T-201	NITROGEN	DN25	FROM NITROGEN INLET TO T-201	MANUAL
V	256	3^{rd}, top of tank T-201	LAB	DN50	LAB INLET TO T-201	MANUAL
V	258	Ground, bottom of tank T-201	LAB	DN50	FROM T-201 TO P-202	MANUAL
V	259	Ground, bottom of tank T-201	LAB	DN25	T-201 DRAIN	MANUAL
V	260	Ground	LAB	DN50	FROM P-202 TO F-202A	MANUAL
V	261	1^{st}	LAB	DN50	FROM F-202 TO E-201	MANUAL
V	264	4^{th}	VACUUM	DN50	FROM E-203 TO VP-201D	MANUAL
V	270	2^{nd}	HEATING	1”	E-202 HEATING FLUID VENT	MANUAL
V	271	2^{nd}	HEATING	DN50	E-202 HEATING FLUID INLET	MANUAL
TV	272	Ground	COOLING	DN50	REGULATING VALVE FOR E-204 COOLING FLUID OUTLET	AUTO
V	272	1^{st}	HEATING	DN50	E-202 HEATING FLUID OUTLET	MANUAL
V	273	1^{st}	HEATING	1”	E-202 HEATING FLUID DRAIN	MANUAL
PSV	274	??	PURE WATER / NITROGEN	DN25	E-205 PRESSURE RELIEF VALVE	AUTO
V	274	Ground	NITROGEN	DN25	NITROGEN LINE DRAIN	MANUAL
V	275	1^{st}	LAB	DN50	E-201 BY-PASS FROM F-202 TO E-202	MANUAL
V	276	3^{rd}, top of tank T-201	VACUUM	DN50	FROM T-201 TO VACUUM LINE	MANUAL
V	279	3^{rd}	VACUUM	DN50	FROM T-202 TO VACUUM LINE	MANUAL
V	280	1^{st}	LAB	DN50	FROM E-201 TO E-202	MANUAL
V	281	2^{nd}	VACUUM	DN25	FROM T-203 TO VP-201	MANUAL
V	282	2^{nd}	HEATING	DN25	E-205 HEATING FLUID INLET	MANUAL
V	283	2^{nd}	HEATING	1/2”	E-205 HEATING FLUID VENT	MANUAL
V	284	2^{nd}	PURE WATER	DN25	FROM PURE WATER INLET TO E-205	MANUAL
V	285	2^{nd}	PURE WATER	DN25	E-205 PURE WATER SUPPLY DRAIN	MANUAL
V	288	4^{th}	VACUUM	DN50	FROM E-203 TO VP-201A	MANUAL
V	289	4^{th}	VACUUM	DN50	FROM E-203 TO VP-201B	MANUAL
V	290	Ground	LAB	DN50	FROM P-202 TO F-202B	MANUAL

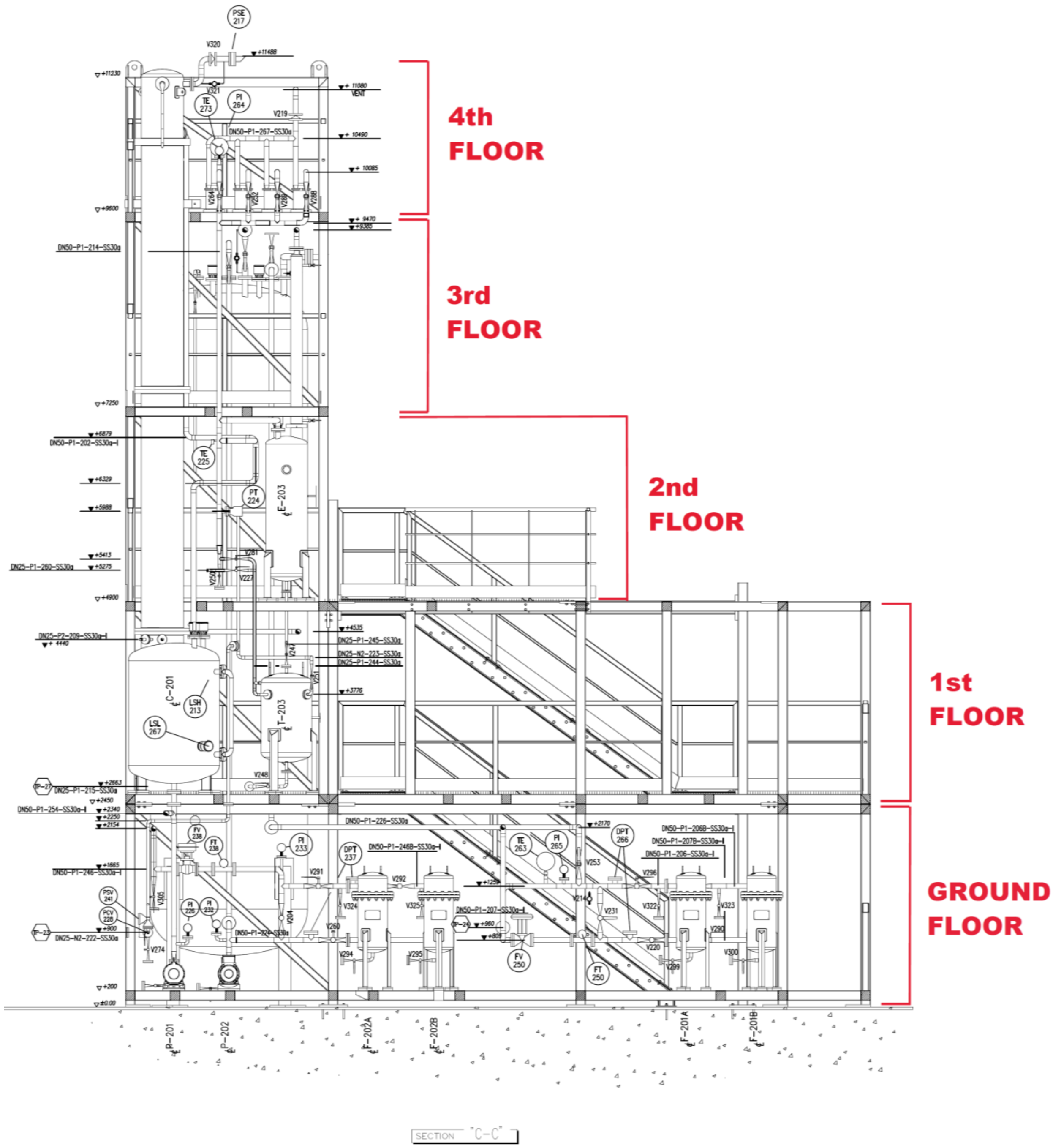
TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	291	Ground	LAB	DN50	FROM F-202A TO E-201	MANUAL
V	292	Ground	LAB	DN50	FROM F-202B TO E-201	MANUAL
V	294	Ground	LAB	DN25	F-202A DRAIN	MANUAL
V	295	Ground	LAB	DN25	F-202B DRAIN	MANUAL
V	296	Ground	LAB	DN50	FROM F-201A TO LAB OUTLET	MANUAL
V	297	Ground	LAB	DN50	FROM F-201B TO LAB OUTLET	MANUAL
V	298	Ground	LAB	DN50	FROM P-203 TO F-201B	MANUAL
V	299	Ground	LAB	DN25	F-201A DRAIN	MANUAL
V	300	Ground	LAB	DN25	F-201B DRAIN	MANUAL
V	301	3rd (?)	VACUUM	DN25	VACUUM LINE TO E-205	MANUAL
V	303	3rd	VACUUM	DN25	STEAM BYPASS FROM E-205 TO VACUUM	MANUAL
V	304	Ground	LAB	DN50	LAST VALVE FOR LAB OUTLET	MANUAL
V	305	Ground	LAB	DN25	E-201 DRAIN	MANUAL
V	306	*	AIR	1/2"	INSTRUMENT AIR INLET	MANUAL
V	312	2nd	HEATING	1/2"	E-205 HEATING FLUID DRAIN	MANUAL
CV	313	3rd, top of tank T-201	NITROGEN	DN65	CHECK VALVE ON T-201 RUPTURE DISK	ONE-WAY
V	314	3rd, top of tank T-201	NITROGEN	1/4"	T-201 RUPTURE DISK BY-PASS	MANUAL
V	315	3rd, top of tank T-201	VACUUM	1/4"	T-201 VACUUM LINE BY-PASS	MANUAL
V	316	3rd	VACUUM	1/4"	T-202 VACUUM LINE BY-PASS	MANUAL
V	317	Ground	LAB	DN25	E-204 DRAIN CLOSE T-202	MANUAL
CV	318	3rd (?), Top of tank T-202	NITROGEN	DN65	CHECK VALVE ON T-202 RUPTURE DISK	ONE-WAY
V	319	3rd (?), Top of tank T-202	NITROGEN	1/4"	T-202 RUPTURE DISK BY-PASS	MANUAL
CV	320	4th	NITROGEN	DN50	CHECK VALVE ON C-201 RUPTURE DISK	ONE-WAY
V	321	4th	NITROGEN	1/4"	C-201 RUPTURE DISK BY-PASS	MANUAL
V	322	Ground	VACUUM	DN25	F-201A VACUUM PORT	MANUAL
V	323	Ground	VACUUM	DN25	F-201B VACUUM PORT	MANUAL

TYPE	VALVE N°	FLOOR	LINE TYPE	DN	DESCRIPTION	OPERATION
V	324	Ground	VACUUM	DN25	F-202A VACUUM PORT	MANUAL
V	325	Ground	VACUUM	DN25	F-202B VACUUM PORT	MANUAL
V	326	MUST BE INSTALLED BY THE CHINESE	LAB	DN50	E-204 WATER EXTRACTION LAB INLET FOR HEAT RECOVERY	MANUAL
V	327	MUST BE INSTALLED BY THE CHINESE	LAB	DN50	E-204 LAB RETURN TO WATER EXTRACTION AFTER HEAT RECOVERY	MANUAL
V	328	Ground	LAB	DN25	P-201 BYPASS	MANUAL

To understand the arrangement of Stripping plant floors, see section 22.

22. Stripping Plant Layout




4th FLOOR
3rd FLOOR
2nd FLOOR
1st FLOOR
GROUND FLOOR
SECTION "C-C"

APPENDIX C.

Distillation plant erection works description

INFN - Sezione di Milano

Polaris company srl

Project: C-367 – LAB distillation unit – INFN

Rev.3 19/10/2021

Distillation Plant

ERECTION WORKS DESCRIPTION

1. SUMMARY

- REFERENCE DOCUMENTS

- Layout: C367-401 Rev.5 AS BUILT (Doc #: JUNOEng-doc-11-v12, Distillation Plant Layout)
- P&ID: C367-101 Rev.12 (Doc #: JUNOEng-doc-11-v12, P&Id)
- Lifting diagram: C367-421 (Doc #: JUNOEng-doc-11-v12, Lifting Diagram)
- Civil Load Diagram: C367-411 Rev.2 (Doc #: JUNOEng-doc-11-v12, Civil Load Diagram)
- Ground Hall layout – Rev.14 (Doc #: JUNOEng-doc-11-v12, Distillation Building layout)
- Equipment list - Rev.6 (Doc #: JUNOEng-doc-11-v12, Equipment List)
- Instrument list - Rev.4 (Doc #: JUNOEng-doc-11-v12, Instrument List)
- Line list – Rev.1 (Doc #: JUNOEng-doc-11-v12, Line List)
- Valve list – Rev.3 (Doc #: JUNOEng-doc-11-v12, Valve List)
- TP information (Doc #: JUNOEng-doc-11-v12, Battery limits and terminal points TP)
- Packing list (Document #: JUNOEng-doc-11-v12, Detailed packing list)
- Electrical panel diagram
- Appendix A of the Distillation Plant installation procedure
- Appendix B of the Distillation Plant installation procedure

- REVISION HISTORY

Revision #	Date	Author(s)	Rationale	Sections Updated
0	21-07-2020	Eleonora Canesi (Polaris)	First Version	All
1	24-07-2020	Paolo Lombardi Cecilia Landini	General revision	All
2	18-03-2021	Michele Montuschi Cecilia Landini	General revision	All
2.1	25-03-21	Michele Montuschi	Add spool instrument and valve lists	10
2.2	26-04-21	Michele Montuschi	Final Check	All
2.3	30-04-21	Michele Montuschi	Correction on pump rack positioning	9.2.3
2.4	03-05-21	Michele Montuschi e Cecilia Landini	Correction on pump rack positioning	9.2.3
3	19-10-21	Cecilia Landini	Cleaning procedure section, appendices	All

- INTRODUCTION

The present specification describes the activities required for the erection of the LAB distillation unit to be installed at the JUNO laboratory (China). The specification includes several references to other engineering documents, all contractors involved for the required works are supposed to carry out a deep analysis of all documents and adequate site survey. All activities to be carried out at site shall be executed in compliance with any applicable local safety and quality standard as well as specific customer requirements.

Each unit is prefabricated and skid-mounted. The general arrangement of each unit is shown in the Layout drawing. All the main equipment, including piping, insulation, instrumentation, etc., are pre-installed on theskids, excluding the interconnecting piping lines already pre-fabricated and to be connected on site. Most of the instruments are pre-wired up to junction boxes provided on skids; the motors are not pre-wired, sincea direct connection from the electrical panel is required. Some other materials, which are part of the supply, are delivered loose.

Please note that all the information regarding procedures and resources recommended for the works described in the present document are based on Polaris experience and expectations, but they shall be adequately checked and adapted to local requirements and safety procedures (LIM, LSO's), in collaboration and agreement with INFN representative.

Please note that some drawing and pictures in this document are for reference only, and do not represent the final assembly.

- **DESCRIPTION OF THE PLANT**

The plant includes 1 distillation column C-101, with relevant accessories (heat exchangers, pumps, tanks, piping, instruments, etc.). Please refer to P&ID and Equipment List for details.

The plant is almost completely prefabricated and delivered in form of skids. Each skid includes the relevantequipment, piping, insulation, instruments, etc. Most instruments are pre-wired to junction boxes inside theskids.

From assembly point of view, the plant is composed of the following main parts (see ***Figure 1***):

- N. 6 prefabricated skids: n° 1 to 4 are horizontal skids, 5 and 6 are vertical skids
- N. 1 stair
- N. 2 external tanks (one vertical and one horizontal)
- N. 1 pump skid

Interconnecting piping between skids and tanks, and other small parts, are delivered loose.

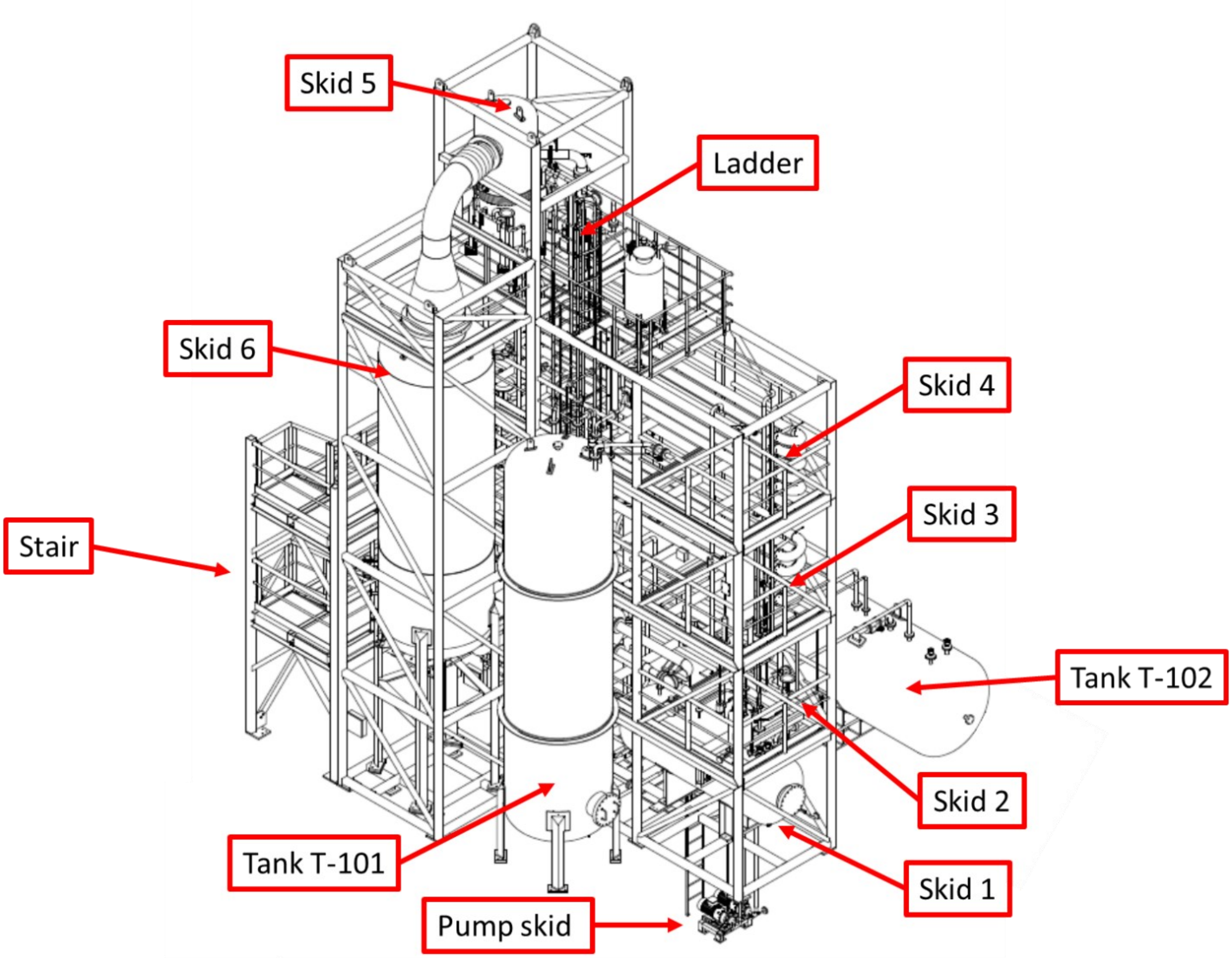


Figure 1: *General layout of the Distillation Plant*

The plant was shipped from Genova port to Shekou port in 5 trucks (flat racks for naval transport) and 3containers (40' HC), specifically:

Table 15: *Containers dimensions and weight*

PACKAGE NO.	Container No./Seal No. Marks and Numbers	DESCRIPTION (GOODS)	DESC. (VEHICLE)	GROSS WEIGHT (GOODS) [kgs]	APPROX. DIMENSIONS (GOODS) [cm]		
					LENGHT	WIDTH	HEIGHT
1	**YMLU7009554**	SKID n.1 (ground floor)	N/A	5,500	750	240	261
2	**YMLU7020168**	SKID n.6 (C-101) included pipe line N. 123	N/A	10,545	1,145	240	261
3	**YMLU7014740**	SKID n.2 (first floor) included LT-122 sensor, LT-195 sensor, spacing plates, positioning template, pipe line N. 166	N/A	5,990	750	240	261
		SKID n.5 (E-102)	N/A	3,500	400	240	261
4	**YMLU7017863**	SKID n.3 (second floor) included pipes line N. 121-106-107-122-140-150-101-143-169-126-141-102-139	N/A	6,645	750	240	261
5	**YMLU7011042**	SKID n.4 (third floor) included pipes line N. 183 - 173 - 174 - 175 - Bolts and nuts	N/A	4,780	750	240	261
6	**CAIU 4281504 seal N. 36483**	Upstairs and handrails, ladder	N/A	3,500	740	150	150
		pallet electrical cables (F)	PALLET	250	120	80	130
		pallet INFN with installation tools (A)	PALLET	200	120	80	130
		pallet INFN with installation tools (B)	PALLET	300	120	80	130
7	**TEMU 7017989 seal N. 091244**	Tank T-102	N/A	5,000	880	215	240
		pipe line N. 163 + Tank legs	PALLET	1,400	320	230	160
8	**TCNU 3092650 seal N. 39064**	Tank T-101	N/A	5,000	880	215	240
		Electrical panel	N/A	240	100	60	210
		pumps skid		300	80	70	100
		pallet with spare parts (E)	PALLET	250	120	80	80
		pallet INFN with installation tools (C)	PALLET	250	80	80	60
		pallet INFN with installation tools (D)	PALLET	125	100	80	80
		pallet with spare pump	PALLET	125	120	80	80

A detailed list of the partition of smaller parts into the packages can be found in the packing list document.

The plant will be afterwards transported and delivered to JUNO site by flat racks or containers.

- ERECTION SCOPE OF WORK

The required scope of supply for the erection of the system only includes the following:

- Manpower
- Tools
- Lifting devices

Based on Polaris and INFN experience with similar projects, it is expected that the erection of main equipment (Section 8 and 9) should be completed in approximately 8-9 days, excluding the first phase of unloading from trucks (Section 7) and transportation to JUNO site.

Please, note that the present document deals with the whole erection, mounting and installation procedurefor Distillation purification plant, but its transportation to the over ground LS (Liquid Scintillator) Hall will be borne by the Chinese group.

During all erection activities, both Polaris and INFN operator are strongly recommended to be on site. Unfortunately, due to Covid-19 pandemic, travelling from and to foreign countries will not be allowed until global Covid-19situation will be under control. To avoid a complete stop of the installation operations, some activities (chapters 7, 8 and 9) could be done in advance by the Chinese LS group or by dedicated installation company. Following the instructions of this manual, the aim is at least to complete the plant positioning intothe distillation room of the over ground hall and stack the skids as in the final plant layout. In this case, at least one INFN manager must be remotely connected to follow, manage, and guide the Distillation plant positioning operations.

Skid interconnections, piping and instrument mounting, mechanical and electrical works (chapters 10 and 11) will be later realized and finalized by INFN and Polaris personnel as soon as they can go to JUNO site.

So, to summarize, the whole installation procedure could be divided in 3 different phases:

1) **Phase 1:**
it includes the transportation of plant components to JUNO site near the LS ground hall, the erection of all the main plant components and finally the ground anchoring with chemical bolts (chapters 8 and 9). These operations will be done by an external installation company, with the supervision of 1 or 2 INFN managers onsite (possibly) and the rest of INFN personnel remotely connected.

2) **Phase 2:**
It includes the following operations: interconnecting pipelines mounting and coupling, installation of instruments and sensors, cleaning of flange surfaces and flange sealing, leak test, installation of the electric cabinet, electric connections, cabling of pumps, instruments and other devices (chapters 10 and 11).

To perform these operations, it is recommended for INFN personnel to be present onsite (accordingly to Covid-19 situation).

3) **Phase 3:**
It includes the first start-up and the early commissioning of the plant.
During this phase, INFN personnel must be present onsite.

- UNLOADING, HANDLING AND STORAGE OPERATIONS

7.1. HANDLING

Both skids and tanks must be handled with care and protected from accidental bumps and damages, otherwise fragile components could break. Special yellow slides have been mounted on skids and tanks to facilitate loading, unloading, and handling operations.

It is important to remember that skids must <u>always be kept in horizontal position</u>. <u>Do not rotate nor pile up in random order</u>.

The Lifting Diagram document shows graphically how to handle and lift the equipment.

Please, handle all the equipment carefully during any operation, especially during loading and unloading from containers or any other transport device.

7.2. STORAGE CONDITIONS

Before installation into the LS Hall, any possible long-term or short-term storage of plant equipment should comply with the following requirements:

- The storage hall must have a roof cover against rain.
- No air conditioning is required.
- In case the hall is open to air and dust (from open walls), a plastic protection foil is suggested to be placed over and around skids/tanks.
- The storage hall should have a flat floor with a lower load capability of 1000 kg/m2.
- The storage hall should be high enough to move skids/tank inside in horizontal position with proper crane truck or forklift.
- Skids/tanks must be protected from damages, occasional bumps, and hits.

Long-term storage could be done in the SAB Hall (Surface Assembly Building) or similar.

7.3. UNLOADING AND TEMPORARY STORAGE

7.3.1. UNLOADING OF SKIDS

For this activity, two cranes (or one crane with two hooks) are required. The crane capacity shall be selected by the contractor based on weights and position. Lifting beams or slings are required to avoid the risk of damaging the skid during the erection with lifting chains. If available, lifting beams are strongly recommended and preferred rather than slings, for safety reasons.

This activity will be executed for skids n° 1 to 6.

The procedure for unloading and temporary storage of the skids shall be defined on site, depending on thespace and size of cranes available; anyway, an example is shown graphically in the lifting diagram and in the description below:

1) connect the two hooks at the two sides of the skid, taking advantage of the wooden beams below the skids.

2) Lift the skid, remove the skid from the truck (or flat rack) and place it on the ground. (See drawing at page 1 of the lifting diagram)

Figure 2: *Unloading of a skid*

7.3.2. UNLOADING OF CONTAINER

For this activity one crane, one forklift and a lifting beam (or slings) are required. The crane capacity shall be selected by the contractor based on weights and position. The lifting beam or slings are required to avoidthe risk of damaging the skid during the erection with lifting chains. If available, lifting beams are strongly recommended and preferred rather than slings, for safety reasons.

This activity will be executed for tanks T-101 and T-102.

The procedure for unloading and temporary storage the tanks shall be defined on site, depending on the space and size of cranes available; anyway, an example is shown graphically in the lifting diagram and in the description below:

1) Connect the forklift to the bottom of the tank (access side) and pull the tank out from the container(see ***Figure 3*** and see drawing at page 5 of the lifting diagram).

Figure 3: *Connection of the forklift to the tank*

2) Keep the access side slightly suspended and slide the opposite side on the container floor (special slides have been provided by Polaris to facilitate loading and unloading, see ***Figure 4***).

Figure 4: *temporary yellow slides, provided on skid and tanks. They shall be removed before positioning operations into the laboratory hall*

3) When the equipment is almost completely pulled out from the container (while the forklift is keepingthe external part supported), join the crane to the top of the tank to hold the equipment and completethe unloading.

4) When the tank is completely out from the container, it can be laid down on the ground and the craneand the forklift can be disconnected. The yellow-coloured slides will be removed before to start the positioning and erection activities.

The prefabricated skids, the tanks and the other ancillary items must be pulled out from the containers assoon as the trucks arrive, since each container will remain on its truck and leave with it.

All the items must be kept in an environment protected from water and occasional bumps, during the phases of unloading, transport, storage, as well as in the waiting times between subsequent activities.

Long-term storage could be done in the SAB Hall (Surface Assembly Building) or similar.

- TRANSPORT AND PREPARATION FOR INSTALLATION

The expected time required for plant transportation from the temporary repository to JUNO site is foreseen to be approximately 2 working days. This operation should be done using flat racks or containers.

The plant will be installed in the LS Ground Hall. The Distillation Hall is not serviced by any crane or fixed lifting device. Therefore, the distillation plant needsto be installed completely removing the roof and inserting all the main components from the top of the building, using rented temporary lifting devices. The cranes should be booked in advance and rented before to start the installation operations.
Since the installation will be done removing the roof of the building and leaving the top opened for the whole phase 1 of the installation (about 9 working days), it's important to verify the weather forecast for the entire period and plan accordingly the start of installation operations.

The preparation of the Distillation Hall needs the following steps:

1) Remove the roof of the Distillation Hall over the final plant position with the first truck crane (min weight: 25 tons)

2) Positioning of the truck crane for skids and tank handling (min weight: 120 tons and min arm length:44.6 m; suggested: KATO NK-1200)

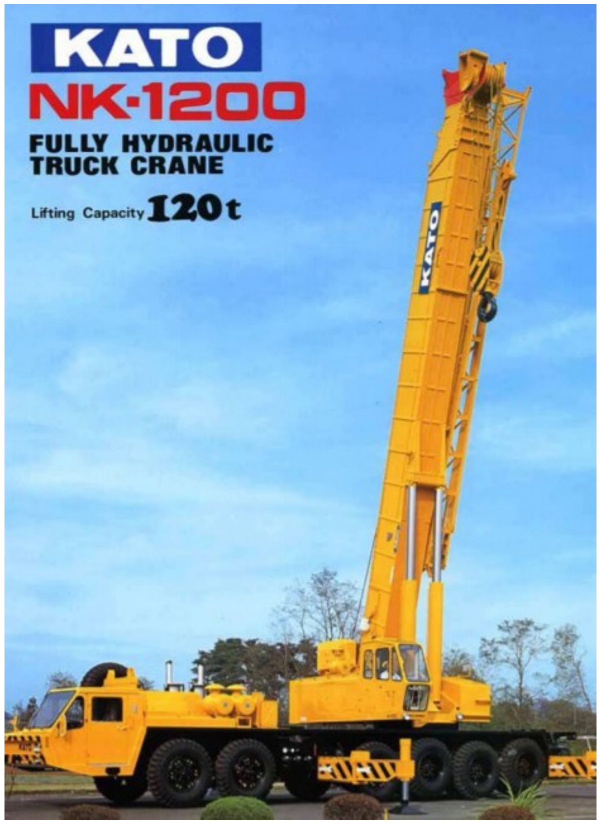


Figure 5: *KATO NK-1200 truck crane*

3) Draw on the hall ground floor the shape of edges and corners of Skid 1 (laid horizontally) (see ***Figure 6*** to have a reference for the theorical final position of the assembled plant into the hall). Distances from walls shall be checked from the LS hall layout drawings.
   It is very important to carefully check the positioning of skid 1 with respect to the well for the pumps, because it will determine also the position of all the other skids.

The distillation plant layout and precise position into the LS hall should be carefully examined from thecorresponding documents. These operations could help the initial positioning of the elements of the plant; then, the precise alignment of each component shall be carefully done using dedicated tools (alignment pins, spacers, bubble level, …), as described in chapter 9.

If available, a forklift and other useful tools can be used to facilitate handling and positioning operations.

Temporary supports for skids and tanks are painted in yellow for easier recognition (see ***Figure 4***). These supports must be removed before positioning and erection activities start. They can be afterwards disposed.

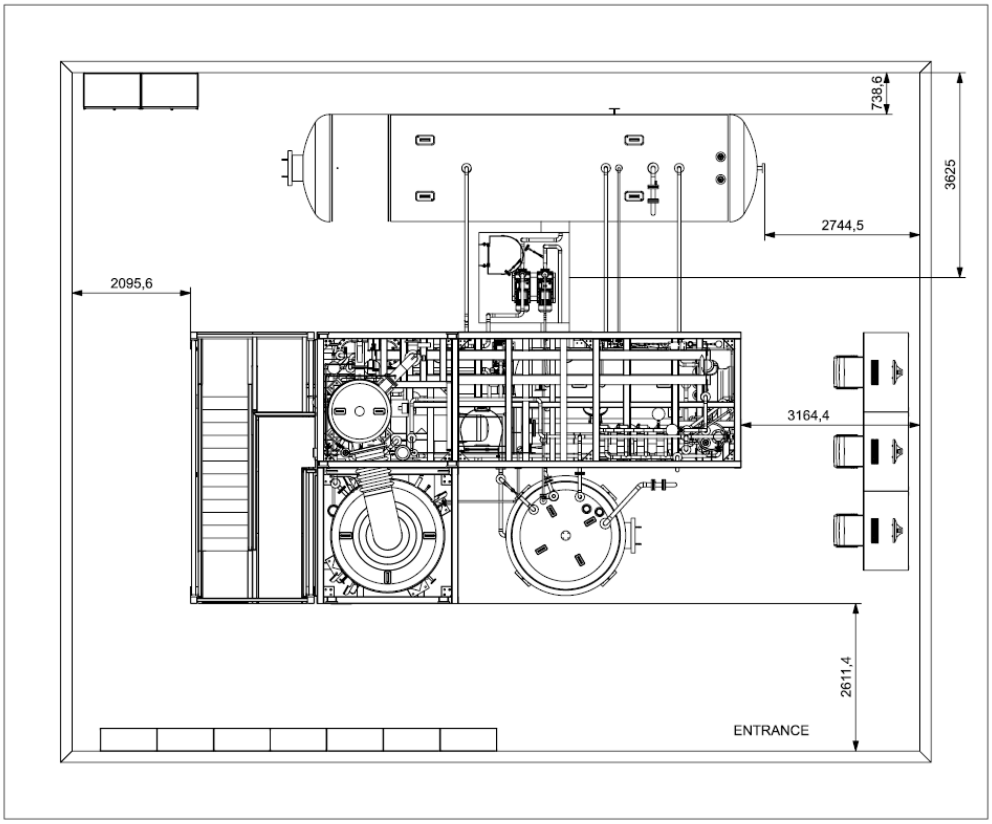


Figure 6: *Distillation Hall layout*

- **ERECTION**

Erection sequence has been supposed based on the information received from INFN related to the dimensions of the external building and open area in the rooftop, specifically:

- INFN drawing “External Building. Dwg” rev.14
- Capacity of the truck cranes to be rented (min weight: 120 tons and min height arm length: 44.6 m for skids and tanks handling).

The procedure can be further optimized on site, depending on available space and tools.

During the erection operations of the skids, it is advisable to use lifting beams if available, to avoid the riskof damaging the skid during the erection with lifting chains.

Some long interconnecting piping are inserted into the main skids for transport: before the erection of the skid, remove all these pieces.
For a detailed list of the items present on each truck, please refer to the packing list that will be provided after trucks loading.

In the following sections, it will be provided a general introductory description of the erection sequence andsubsequently a detailed description for each step.

9.1. ERECTION SEQUENCE: INTRODUCTION AND GENERAL DESCRIPTION

The optimal sequence considered by Polaris and agreed with INFN is the following:

Foreseen on 1st day:

1. Removal of the roof of the building.

Foreseen on 2nd day:

2. Positioning of T-102 horizontal tank into the building in the theoretical position.
3. Positioning of pump skid (P-102 and P-103).
4. Positioning of line 121, 122, 106 and 107 in the pump well.

Foreseen on 3rd day:

5. Positioning of Skid 1 (based on the position of the well).
6. Check the positioning of T-102 with the provided metal template between T-102 and Skid-1 andbetween T-102 and pump well and adjust their position accordingly.

Foreseen on 4th day:

7. Anchor Skid 1 and T-102 to the ground (*Important*: **drytime = at least 1 night**).

Foreseen on 5th day:

8. Positioning of skid 2 on skid 1.
9. Positioning of skid 3 on skid 2.

Foreseen on 6th day:

10. Positioning of skid 4 on skid 3.
11. Erection and positioning of skid 6 (vertical skid).

Foreseen on 7th day:

12. Erection and positioning of skid 5 on skid 4.
13. Mounting of line 163 from C-101 to E-102 (a crane is required).

Foreseen on 8th day:

14. Positioning of T-101 vertical tank.
15. Mounting and installation of stairs.

Foreseen on 9th day:

16. Mounting of the internal ladder.
17. Anchoring of skid 6, tanks T-101 and stairs.
18. Close the roof of the building.

The positioning of the first skid must be done carefully and precisely, because it will determine the position of all other equipment and of the whole plant.The position of the well for pumps must be taken as reference to position correctly skid 1. For this purpose, the prefabricated pipes connecting the pumps with the skid shall be used.

It must be carefully considered that, before placing two skids side by side, it is necessary to remove protective blind flanges from the flanges of the interconnecting pipes (see ***Figure 7***). Please note that this operation cannot be done once the skids are aligned, because there would not be enough space and/or pipes would not be enough flexible.

Figure 7: *Interconnecting pipeline sealed with a protective blind flange*

When removing a protective blind flange, the flange that has been opened must be immediately sealed witha clean plastic sheet to prevent dust from entering and dirtying the plant. In fact, all the internal surfaces of the plant have undergone a complete cleaning process, as required from the cleanliness standards for JUNO experiment.

Moreover, these uncovered flanges must be carefully protected from hits and bumps that could occur whenapproaching and positioning two skid side by side. Even slight scratches, engravings or dents on the flange surface could compromise the leak tightness of the flange.

To protect a flange from both dust and surface damages, one of these two solutions should be adopted:

- A clean plastic sheet and one dedicated cap to close the flange.
  Some yellow caps of different dimensions (see ***Figure 8***) have been inserted into the shipping packages (but not enough to close all interconnection flanges of all skids).

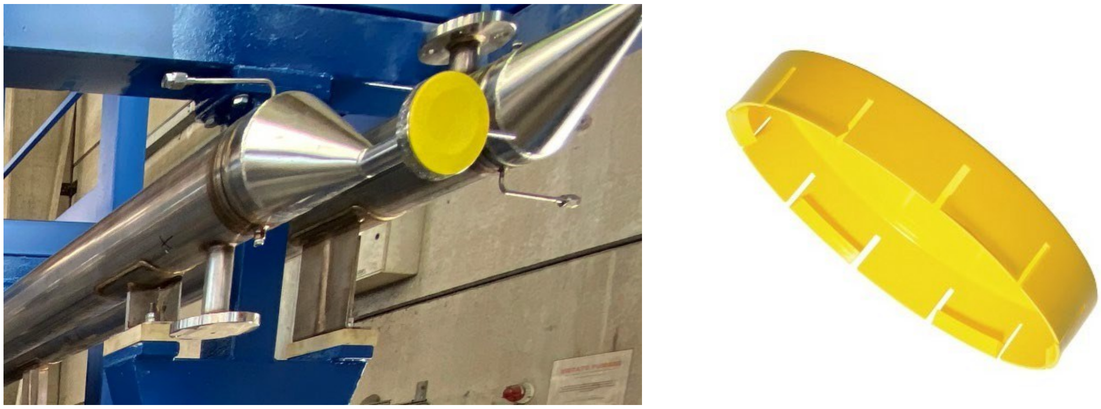


Figure 8: *Plastic cap to be used for protecting the opened flange after the removal of the blind flange*

- A clean plastic sheet and a cardboard sheet (or similar, to protect the flange surface).

Please, remember to protect immediately and accurately each flange as soon as it is opened.

During erection activities, the structures shall be aligned using a bubble level (to “centre the bubble”) and if necessary adequate shims shall be used. All skids shall be aligned and installed so that the internal piping connections will fit. Once positioned the first skid, the alignment of the subsequent skids shall be verified so that the connection flanges match.

After erection of vertical items, it will be necessary to unfix the crane from the lifting lugs at an elevation of max 14 m. For this activity, an independent access system (e.g., a mobile platform or scaffold) shall be required. (See drawing at page 7 of the lifting diagram).

At the end of the first phase of plant installation, the structures will be fixed to ground with chemical bolts (e.g., “Hilti” type) in accordance to the ‘Civil LoadDiagram document’. The foundation bolts are supplied by INFN (see section 9.2.17).

The following pictures represent an example of sequence of erection of a skid. Please note the use of liftingbeam, shackles (both top and bottom, see panel 8 of ***Figure 9***).

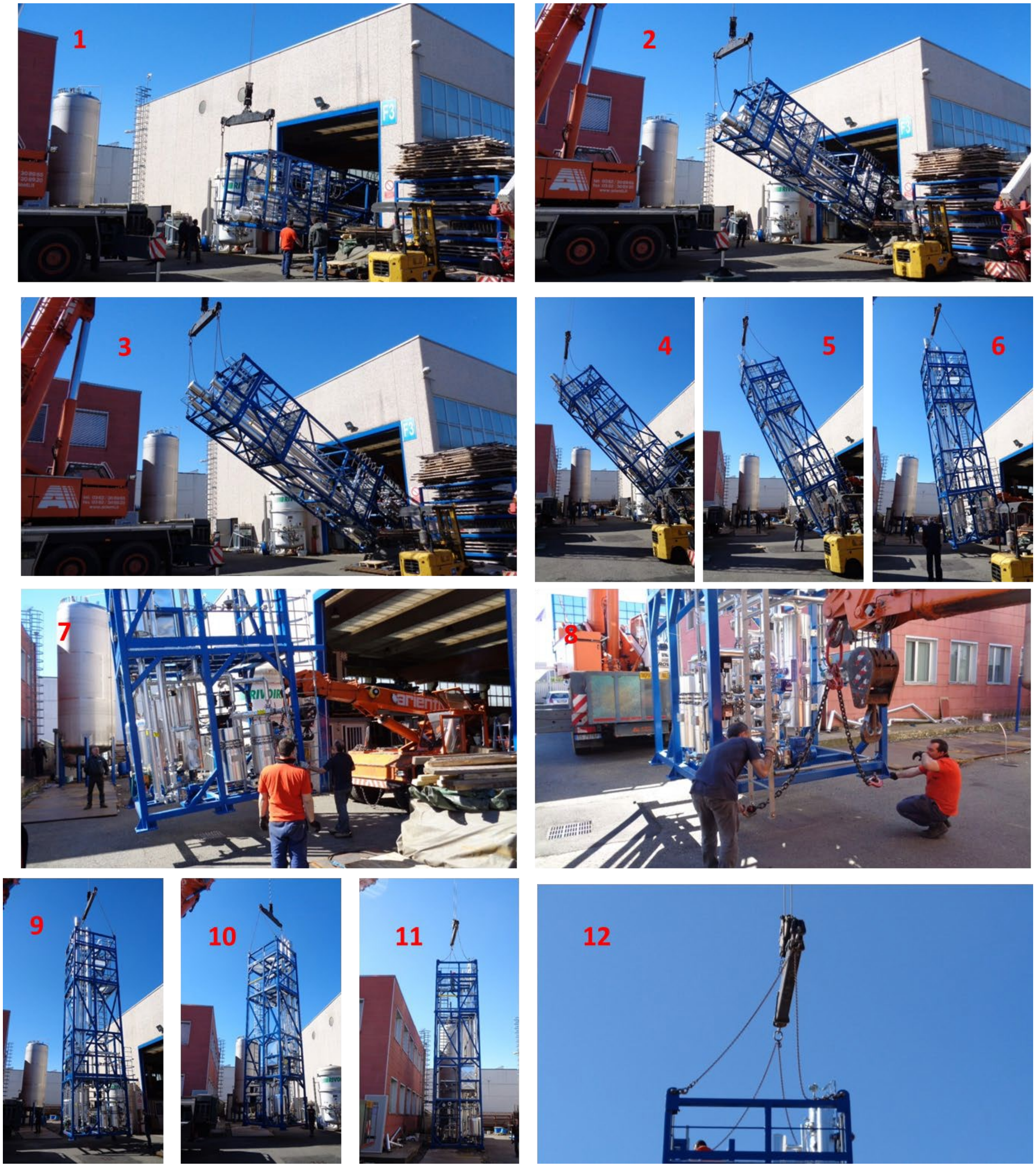


Figure 9: *Erection sequence for a vertical skid*

9.2. DETAILED DESCRIPTION OF ERECTION SEQUENCE

9.2.1. REMOVAL OF THE ROOF OF THE BUILDING

In order to start the installation of skids and tanks, the roof of the LS ground building must be removed. For this purpose, the 25-ton truck crane is required to lift and handle the roof panel. During this operation, at least one Chinese manager of the LS ground hall should be present onsite to guide the removal operation.

9.2.2. INSERTION OF TANK T-102 INTO THE BUILDING

Before moving the tank into the building, it is necessary to mount the legs on it (see ***Figure 10***).

Figure 11 shows graphically how to hook and handle the tank.

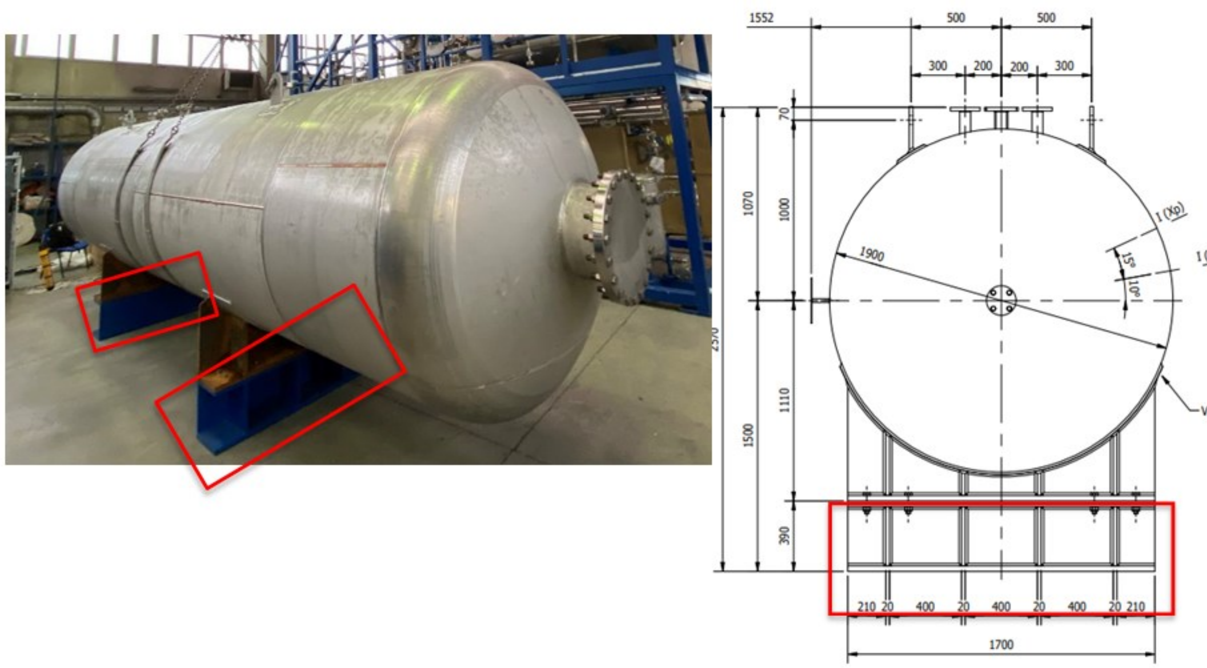


Figure 10: *T-102 tank legs to be mounted*

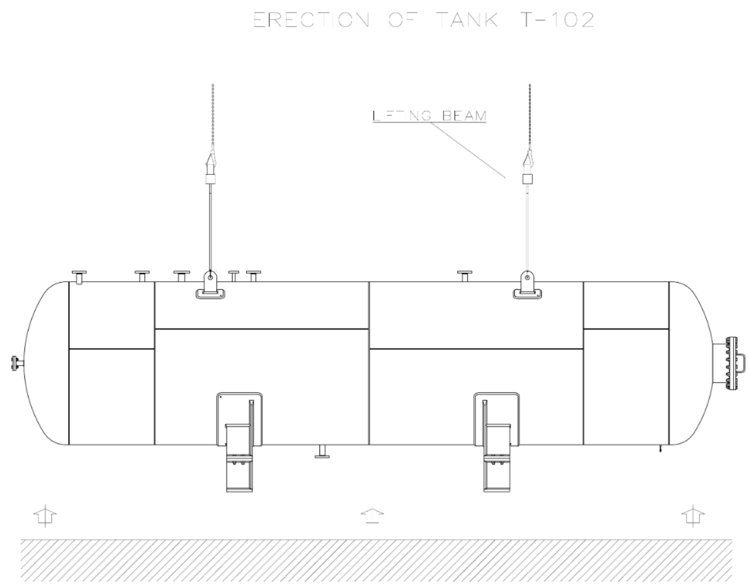


Figure 11: *T-102 tank erection scheme*

For T-102, connect the chain winch to the lifting ears. It is advisable to use lifting beams, if available.

Lift the tank from both sides at the same time and bring it over the roof in the correct position inside the Distillator building. Choose the correct position leaving enough space for inserting in the hall the skid 1 and permitting the later final adjustments of the tank T-102 in the final position.

9.2.3. POSITIONING OF THE PUMPS INSIDE THE WELL

Position the pump skid into the pump well inside the Liquid Scintillator Hall passing through the roof.Check the correct position of the skid inside the well using the following figures and all dedicated documents (see Distillation Building layout drawings).

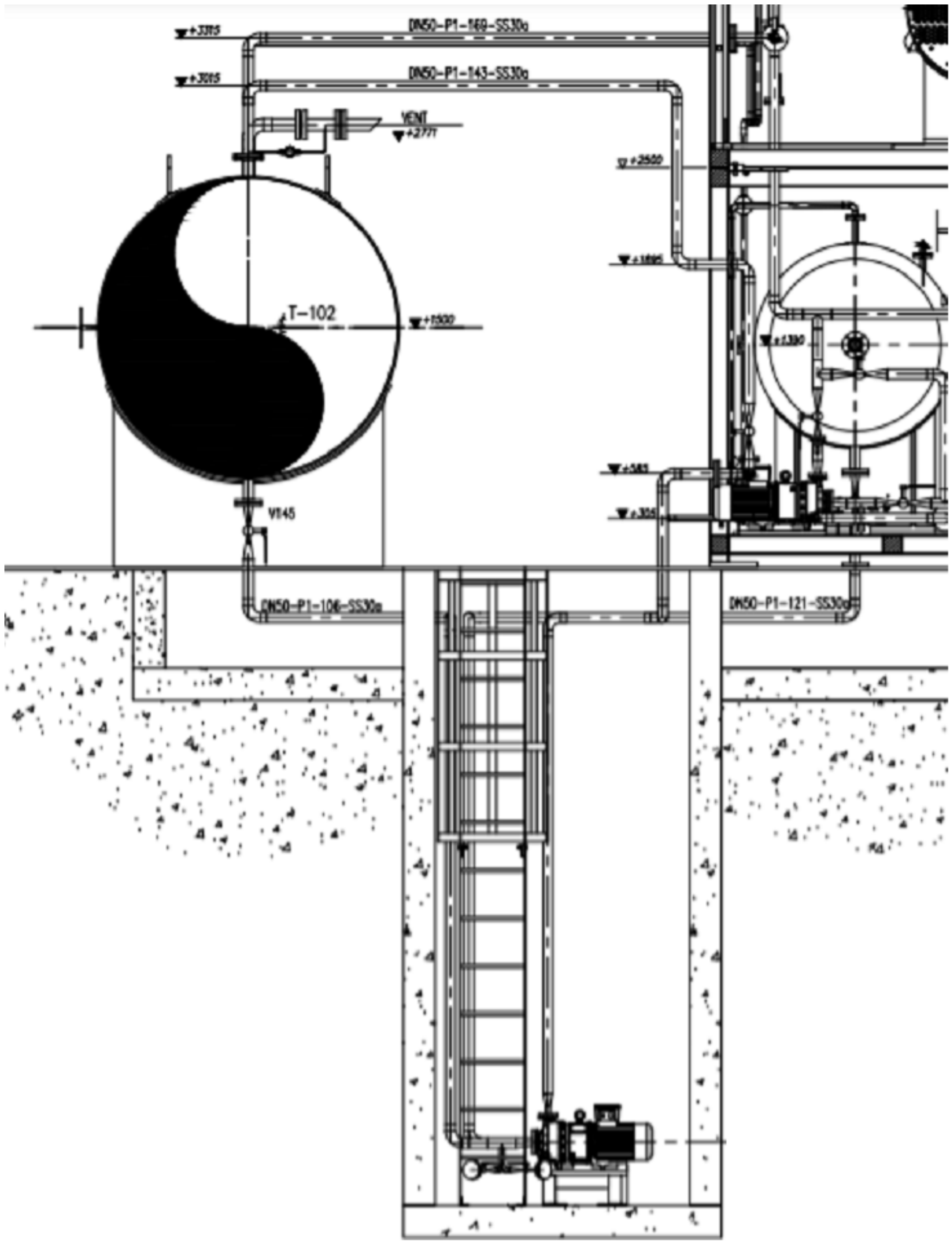


Figure 12: *Final location of the pump skid inside the well*

9.2.4. INSERTION OF THE LINE 121, 122, 106 AND 127 INSIDE THE PUMP WELL

Insert pipelines 121, 122, 106 and 107 (see Line list) in the pump well, in order to make it easier the following connection with Skid 1.

The depth of the pump well is -4250 mm while the position of the pumps is -4000 mm. In orderto keep stable the pump rack, a 200 mm distancer will be bolted under the pump legs. Few plates, built by Polaris and shipped with the plant, will cover the 50 mm left.

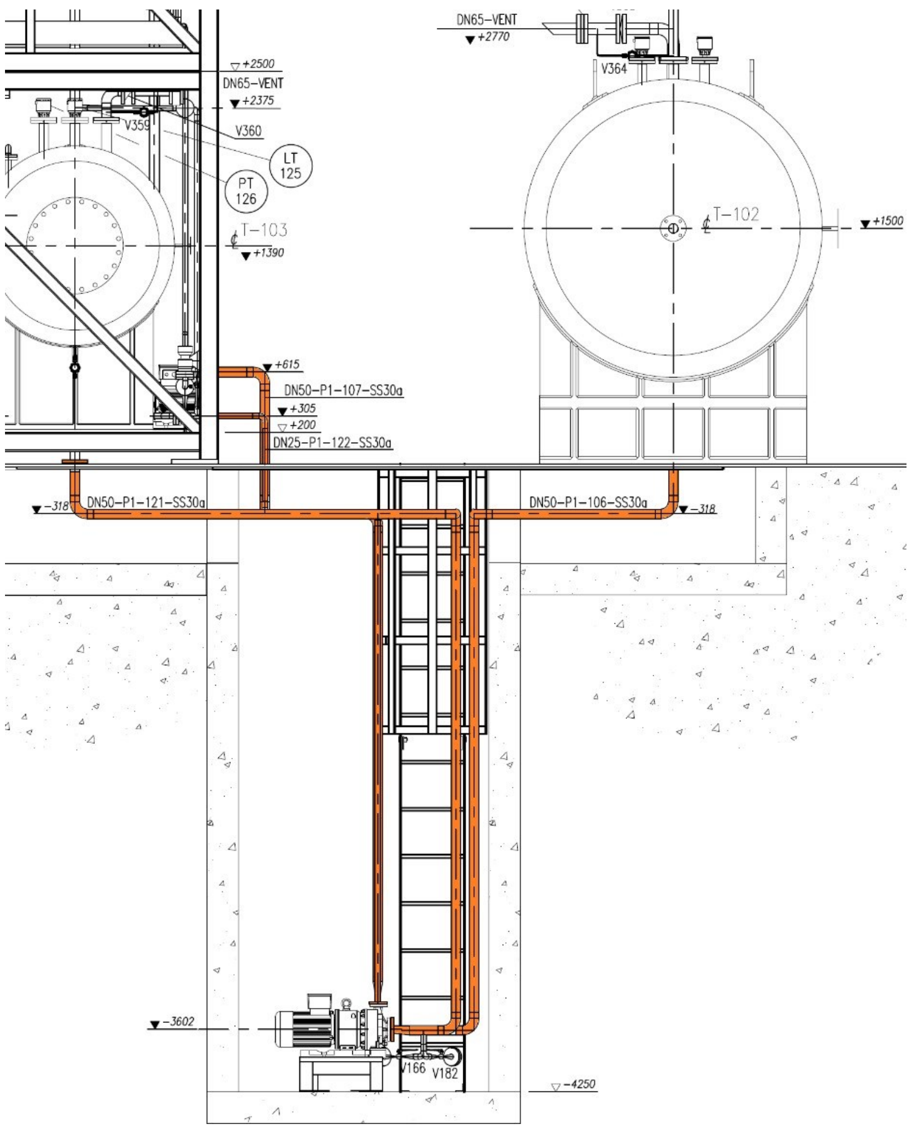


Figure 13: *Exploit of lines 121, 122, 106 and 107 to be inserted into the pump well. The depth of the well is -4250mm.*

9.2.5. POSITIONING OF SKID 1

After removing the plastic foil wrapping the skid 1, lift it as shown in ***Figure 14*** (see also drawing at page 4 of the lifting diagram).

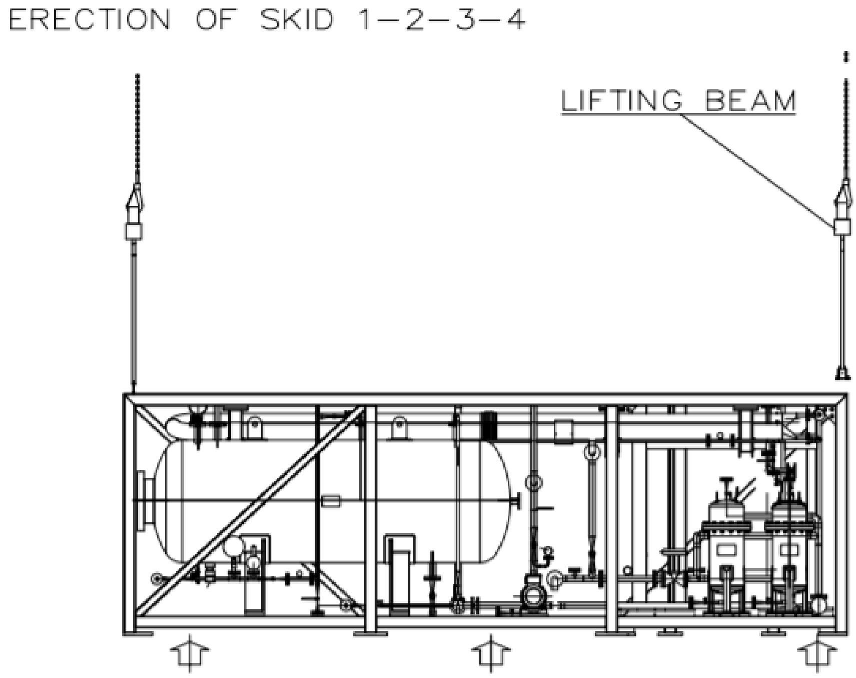


Figure 14: *Erection scheme of skid 1*

Insert skid 1 into the building from the top and place it on the ground of the Liquid Scintillator Hall in correspondence of the line drawn on the floor.

The positioning of the first skid must be done carefully and precisely, because it will determine the position of all other equipment and of the whole plant. The position of the well for pumps must be taken as reference to position correctly skid 1. For this purpose, the prefabricated pipes connecting the pumps with the skid shall be used.

The distances from walls can be carefully checked from the 'Hall Layout' drawings, while the skid orientationinto the hall can be understood from the plant layout drawings.

Please, remove the yellow-coloured slides,if present, before positioning the skid.

9.2.6. CHECK RELATIVE POSITION OF T-102 TANK, SKID 1 AND PUMP SKID

T-102 position should now be checked and adjusted, if needed. For this purpose, two dedicated metallic templates have been provided from Polaris as spacers to help find the correct position of T-102 (see ***Figure 15***).

Correct alignment and accurate positioning are the major issues for tank position. Once it will be fixed to the ground, it would be impossible to change and correct its position if inaccurate; so, please, check carefully both the orientation of nozzles on tank dome and the legs accurate positioning before fixing to ground.

Place on the ground the provided metal template to fix the final position of T-102 tank.

Connect the chain winch to the tank lifting ears and lift the tank from both sides at the same time and bring it in the final position inside the Liquid Scintillator hall.

Lower slowly the tank in correspondence of the installation position.

Figure 15: *Metal template between T-102 tank and skid 1 for T-102 correct positioning*

T-102 must be positioned so that the metallic templates fit perfectly on the tank legs, as shown in ***Figure 15***. Please, note that the templates are custom made for each tank (T-101 and T-102), so be sure to do not swap them and use the correct ones.

As further check, the position of T-102, both in plane and in vertical direction, must be verified taking as a reference the prefabricated pipes connecting the tanks with the skids (if necessary, adequate shims shall be used). Check the correct relative position of T-102, Skid 1 and pumps inside the well, mounting few test lines between them. For example, mount line 106 between T-102 and P-102, the line 121 between P-103 and Skid 1 and line 126 between T-102 and Skid 1.

9.2.7. ANCHORING OF SKID 1 AND T-102 TANK TO THE GROUND

Skid 1 and T-102 shall be fixed to ground with chemical anchors in accordance with the 'Civil Load Diagram' document.

All the tools and items required for ground anchoring ('Hilti' hammer drill, bits of different length and diameter for the hammer drill, 'Hilti' chemical bolts, …) have been supplied by INFN. See the packing list for more details.

Drill the concrete floor with 'Hilti' hammer drilling machine in correspondence of the holes of each plate of skid 1 and T-102 tank.

During drilling operations, it's important to use a dust extractor/aspirator to remove all the drilling powder and prevent it from spreading into the environment and/or entering the plant.

After drilling, place the chemical anchors and **let them dry for at least one night (very important!!)** before to seal the anchors with bolts.

9.2.8. POSITIONING OF SKID 2 ON SKID 1

Before positioning skid 2 on skid 1, protective blind flanges of the interconnecting lines must be removed.

Interconnecting flanges between skids 1 and 2

The list of interconnecting pipes, where blind flanges must be removed, is reported in ***Table 16***. The pipeshave been identified with the corresponding line number indicated on the P&Id. Please, refer to the line list and the P&Id for details.

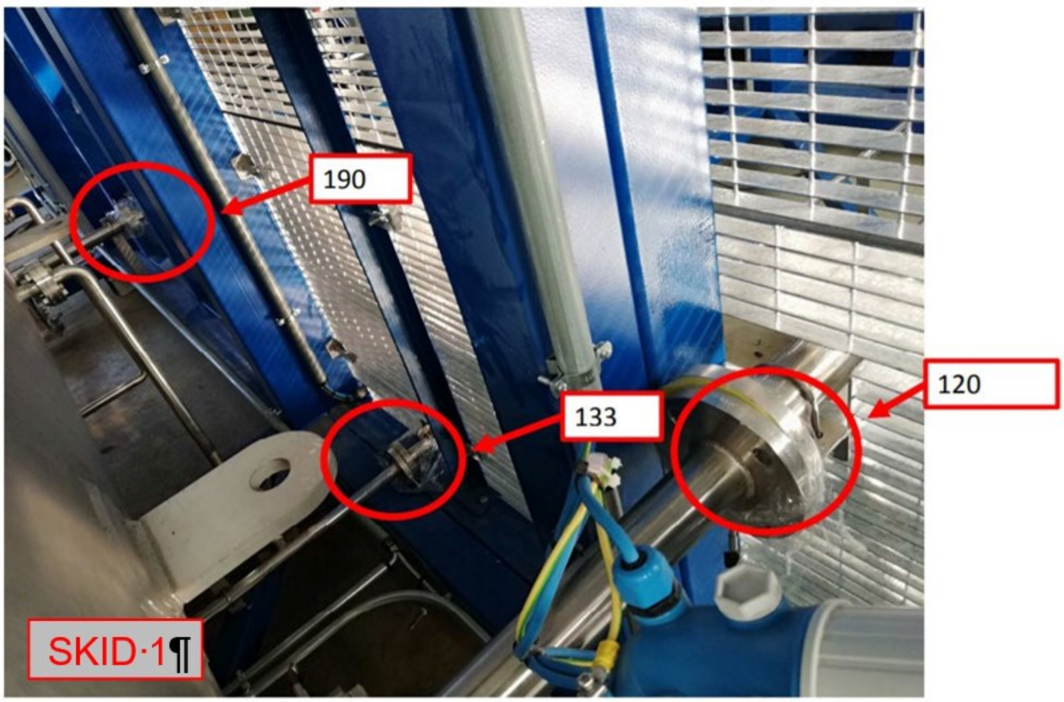


Figure 16: *Blind flanges of skid 1 to be removed before the installation of skid 2 on skid 1.*

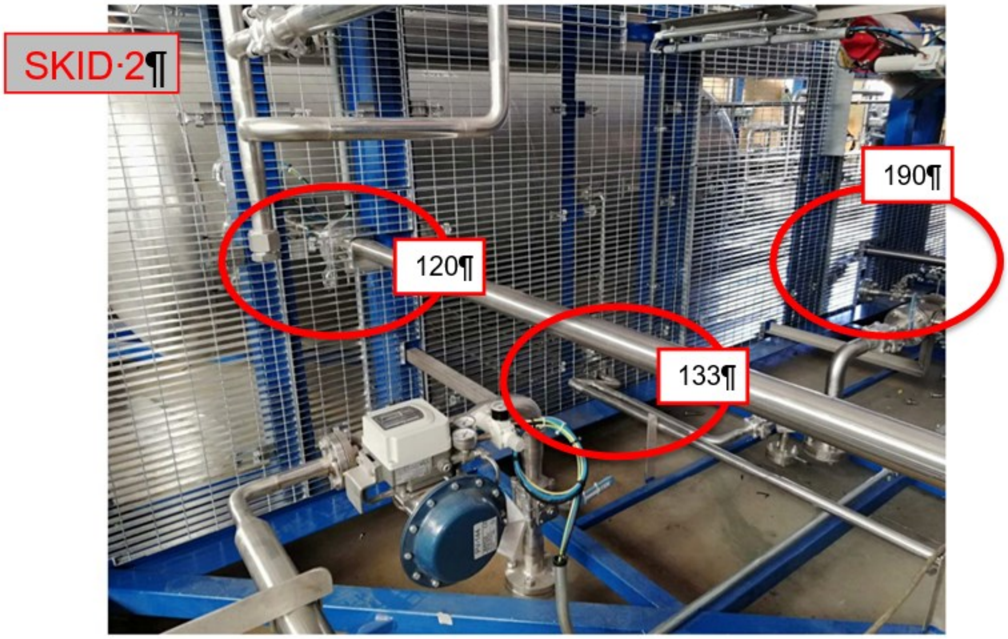


Figure 17: *Blind flanges of skid 2 to be removed before the installation of skid 2 on skid 1.*

Table 16: *Skid 1 & skid 2: interconnecting pipelines list*

SKID 1 & SKID 2: INTERCONNECTION PIPES LIST		
Line number	DN	Operations
Line 120	50	Remove blind flanges both on skid 1 and skid 2
Line 133	25	Remove blind flanges both on skid 1 and skid 2
Line 190	50	Remove blind flanges both on skid 1 and skid 2

For each line, remove the corresponding blind flange both on side of skid 1 and on side of skid 2, so thatthe two bare sides of the interconnecting pipe will face when the two skids will be in the final position.

For easier recognition, the pictures show the position of all the lines of interest.

When removing a protective blind flange, please remember to immediately protect the flange that has beenopened, as described in section 9.1.

Interconnecting flanges between skids 2 and 3.

The list of interconnecting pipes, where blind flanges must be removed, is reported in ***Table 17***. The pipeshave been identified with the corresponding line number indicated on the P&Id.

Please, refer to the P&Id, line list and layout drawings for details.

Table 17: *Skid 2 & skid 3: interconnecting pipelines list*

SKID 2 & SKID 3: INTERCONNECTION PIPES LIST		
Line number	DN	Operations
Line 120	50	Remove blind flanges on skid 2
Line 199	50	Remove blind flanges on skid 2
Line 133	25	Remove blind flanges on skid 2
Line 182	25	Remove blind flanges on skid 2
Line 156	25	Remove blind flanges on skid 2
Line 157	25	Remove blind flanges on skid 2
Line 142	25	Remove blind flanges on skid 2
Line 126	50	Remove blind flanges on skid 2
Line 169	50	Remove blind flanges on skid 2 (remove pipe stub)
Line 190	50	Remove blind flanges on skid 2

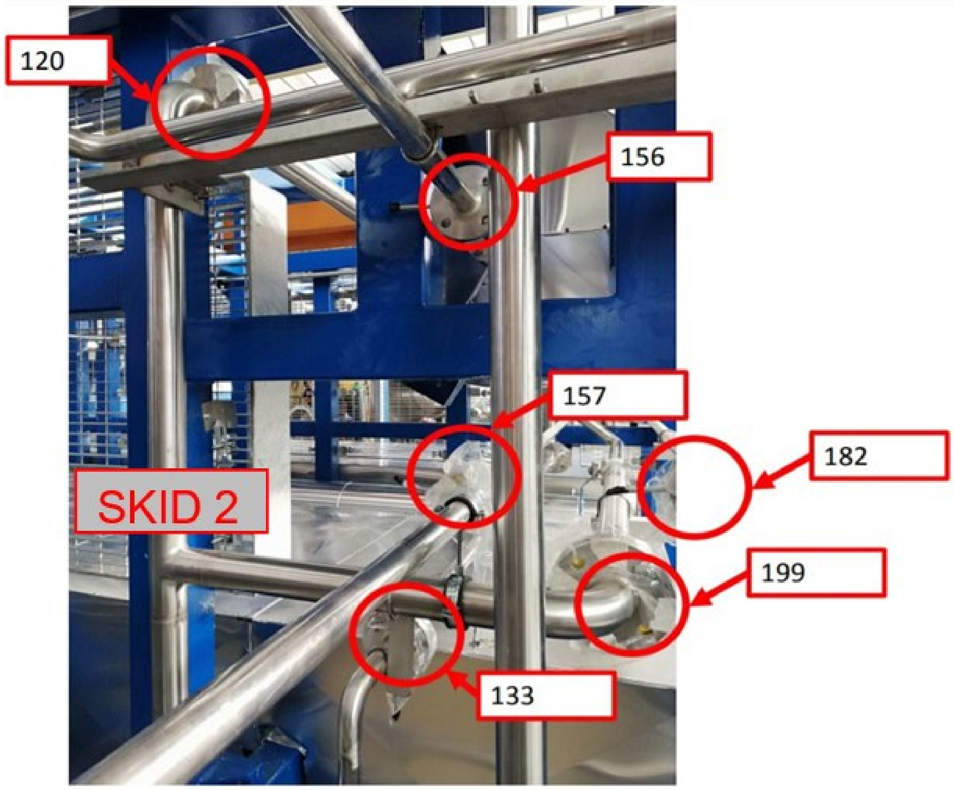


Figure 18: *Blind flanges of skid 2 to be removed before the installation of skid 2 on skid 1. Interconnection lines between skid 2 and skid 3. Lines close to E-105*

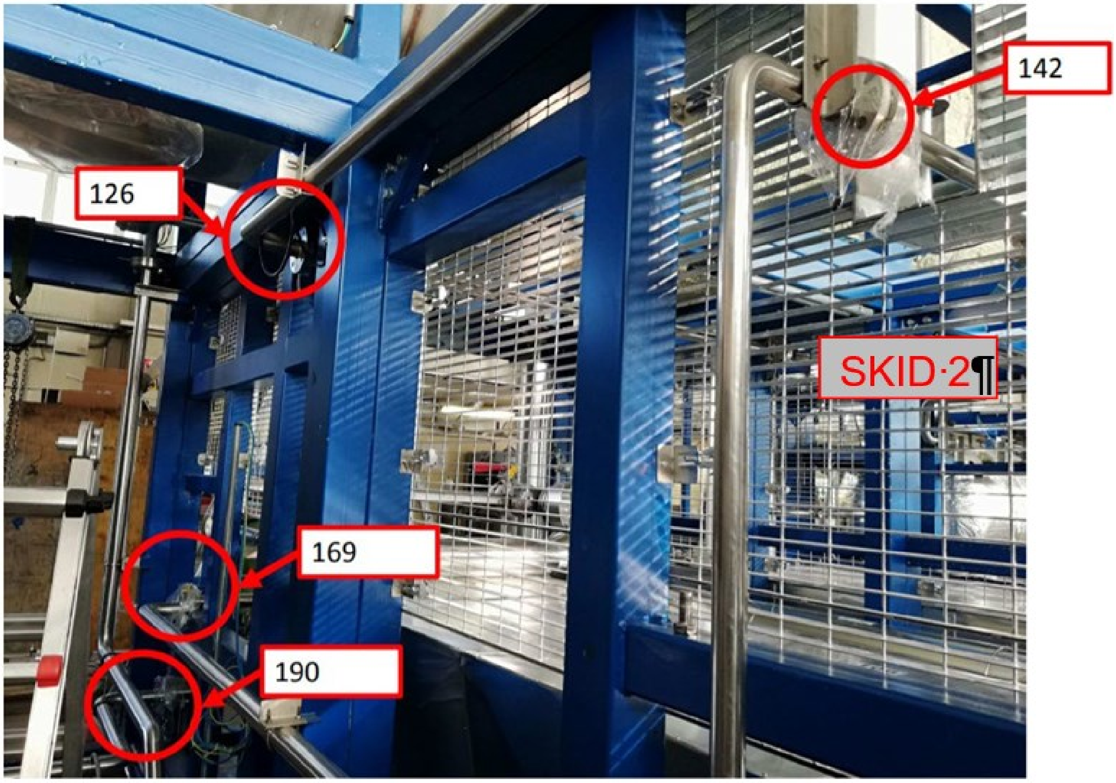


Figure 19: *Blind flanges of skid 2 to be removed before the installation of skid 2 on skid 1. Lines connecting Skid 2 and Skid 3 (126, 142, 169 and 190)*

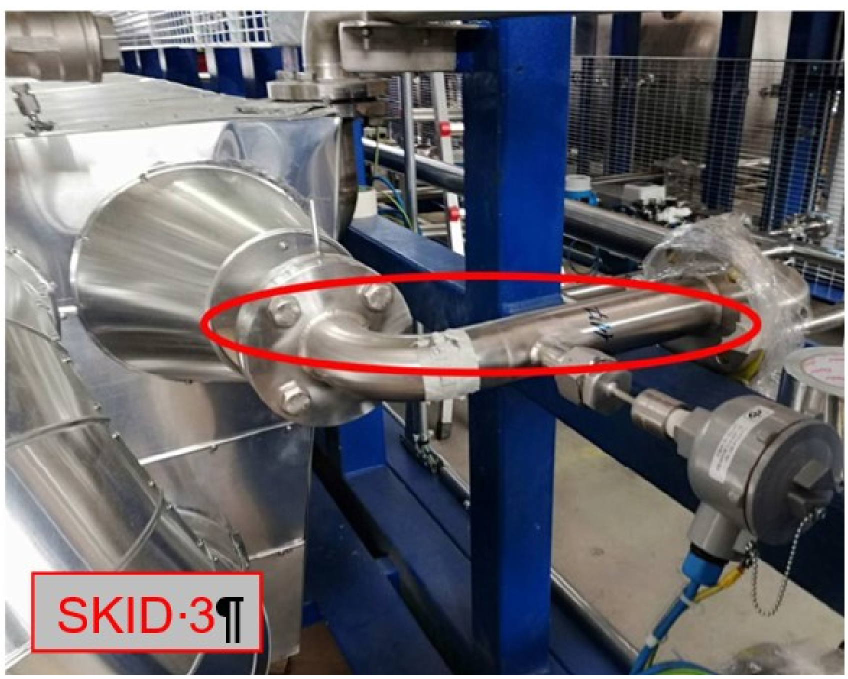


Figure 20: *Blind flanges of skid 3. Line 169 connecting skid 2 and skid 3. It is composed by a removable pipe stub with a temperature transmitter mounted on (Pay attention to the temperature transmitter while removing the pipe stub).*

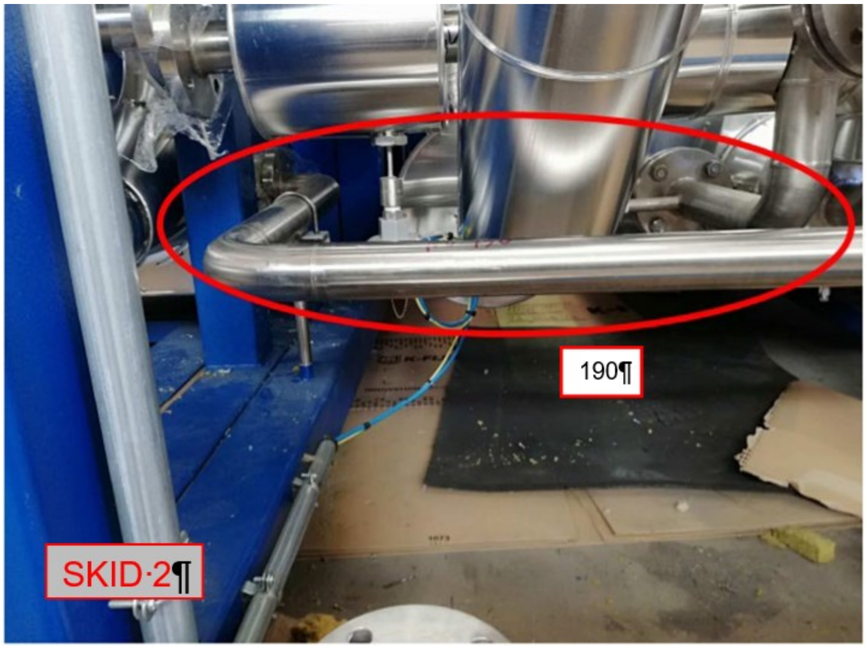


Figure 21: *Line 190 in skid 2*

For each line, remove the corresponding blind flange on side of skid 2.

For easier recognition, the pictures show the position of all the lines of interest.

When removing a protective blind flange, please remember to immediately protect the flange that has beenopened, as described in section 9.1.

The pipe stub of line 169 on skid 2 must be removed before skid erection (see ***Figure 20***). For this purpose,two blind flanges and two clean Teflon gaskets are required (some spare blind flanges and Teflon gasketshave been supplied by Polaris). Unscrew the pipe stub from the bottom of the side of E-106, remove it and seal both the pipe stub and the E-106 flange using the two gaskets and blind flanges. Label the pipe stub for easier recognition and store it with all the other stuff of the stripping plant. Alternatively, it could be sufficient to remove the supports in order separate the flanges for cleaning and O-ring insertion if there is enough space to do this operation without removing the pipe stub.

Interconnecting flanges between skids 2 and 6.

Remove the blind flange listed in ***Table 22*** for the connection between Skid 2 and Skid 6.

Now, operations for erection of skid 2 and positioning of skid 2 on skid 1 can start.

For this purpose, the crane is required. It is advisable to use lifting beams, if available, to avoid the risk of damaging the skid during the erection with the lifting chains.

The picture below (***Figure 22***) shows graphically how to hook and handle the skid. For more details, seethe Lifting Diagram document.

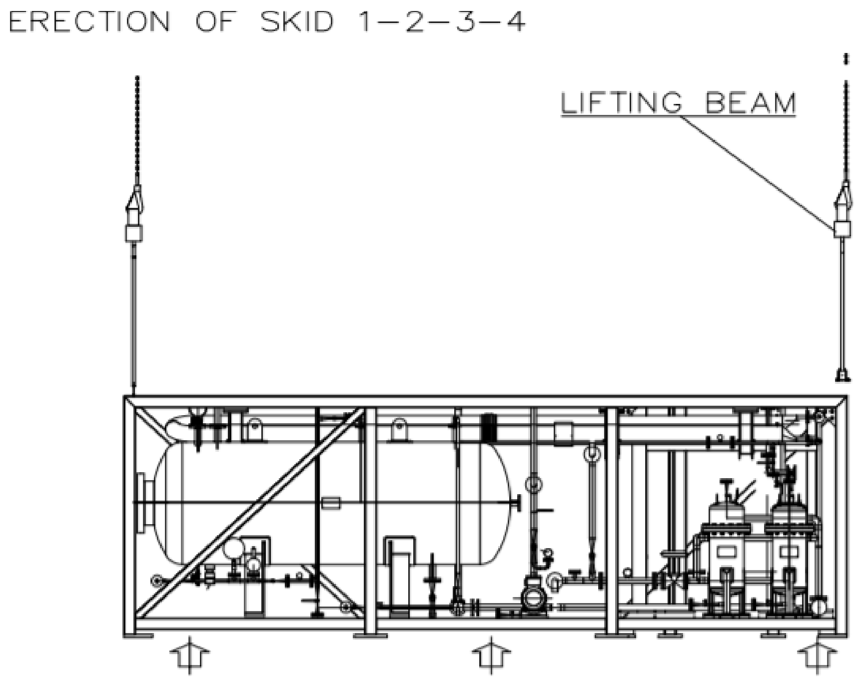


Figure 22: *Erection scheme of skid 2*

Connect the crane at the two sides of skid 2 as shown in ***Figure 22***. It is advisable to use lifting beams (or slings, if the former is not available) to avoid the risk of damaging the skid during the erection.

Before lifting, check carefully the correct orientation of the skid 2 from Distillation plant layout drawings.

Lift horizontally the skid with both chain winches at the same time. Move the skid till the installation position upon skid 1 through the roof.

Move down slowly the skid. Please, be very careful during this operation: do not lay down nor accidentally slide skid 2 on its bottom side, otherwise the opened flanges of the interconnecting pipelines could be damaged.

Adjust the position and align precisely skid 2 on skid 1. The centering operation could be aided by means of some alignment pins, like threaded rods to be inserted from above into the holes of the triangular platesof skid 2, that shall be coupled to the corresponding holed triangular plates of skid 1. Align skid 2 on skid 1 so that the pins can be inserted also into skid 1 plates and can guide the skids alignment until they are joined.

When approaching skid 2 to skid 1, please be very careful and move slowly to avoid hits, bumps and any damages to the skids and their interconnection flanges. Operators should keep monitoring closely each interconnection flange during this phase to check that no strains, misalignments or even breaks could occur.

Finally, gently lay down skid 2 on skid 1 in its final position (see Distillation Plant layout document) and remove the alignment pins.

When erection is completed, unfix the crane from the lifting lugs and from the base of skid 2 using a mobileplatform or similar and fix the skid 2 on the skid 1 with bolts.

9.2.9. POSITIONING OF SKID 3 ON SKID 2

Before positioning skid 3 on skid 2, protective blind flanges of the interconnecting lines must be removed.

Interconnecting flanges between skids 2 and 3.

The list of interconnecting pipes, where blind flanges must be removed, is reported in ***Table 18***. The pipeshave been identified with the corresponding line number indicated on the P&Id.
Please, refer to the P&Id, line list and layout drawings for details.

Table 18: *Skid 2 & skid 3: interconnecting pipelines list*

SKID 2 & SKID 3: INTERCONNECTION PIPES LIST		
Line number	DN	Operations
Line 120	50	Remove blind flanges on skid 3
Line 199	50	Remove blind flanges on skid 3
Line 133	25	Remove blind flanges on skid 3
Line 182	25	Remove blind flanges on skid 3
Line 156	25	Remove blind flanges on skid 3
Line 157	25	Remove blind flanges on skid 3
Line 142	25	Remove blind flanges on skid 3
Line 126	50	Remove blind flanges on skid 3
Line 169	50	Remove blind flanges on skid 3 (remove pipe stub)
Line 190	50	Remove blind flanges on skid 3

Interconnecting flanges between skids 3 and 4.

The list of interconnecting pipes, where blind flanges must be removed, is reported in ***Table 19***. The pipeshave been identified with the corresponding line number indicated on the P&Id.
Please, refer to the P&Id, line list and layout drawings for details.

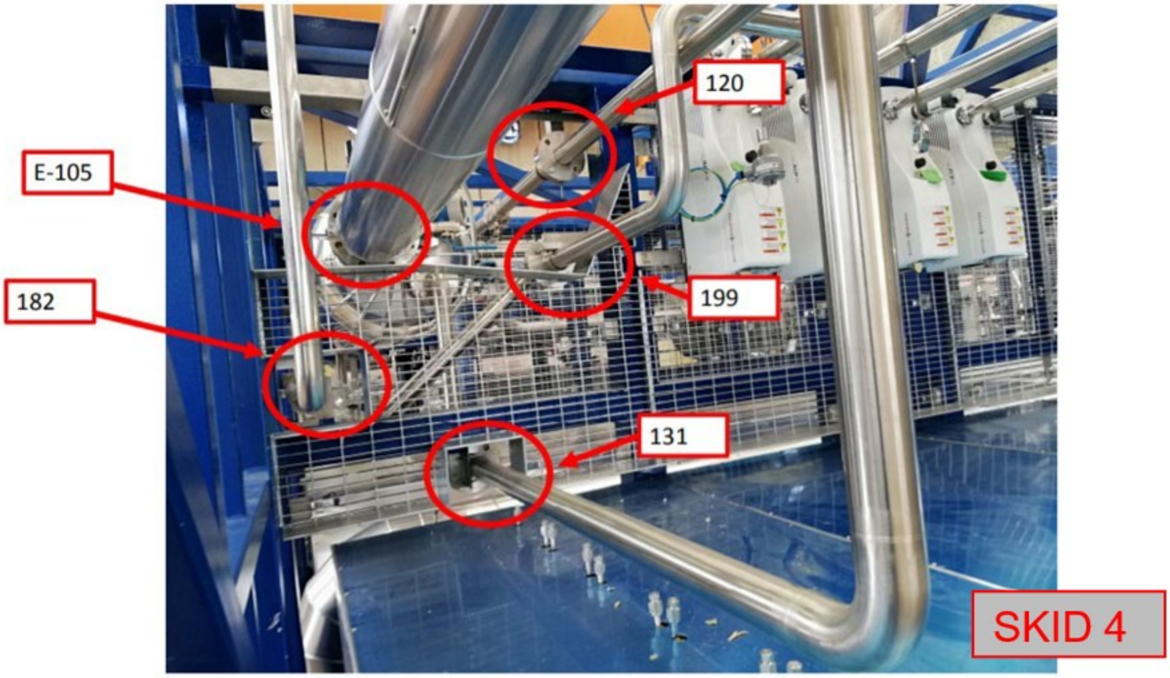


Figure 23: Blind flanges of skid 4 in correspondence of the blind flange on skid 3 to be removed before the installation of skid 3 on skid 2. Interconnection lines between skid 4 and skid 3.

Figure 24: Blind flanges of skid 3 to be removed before the installation of skid 3 on skid 2. Interconnection lines between skid 4 and skid 3.

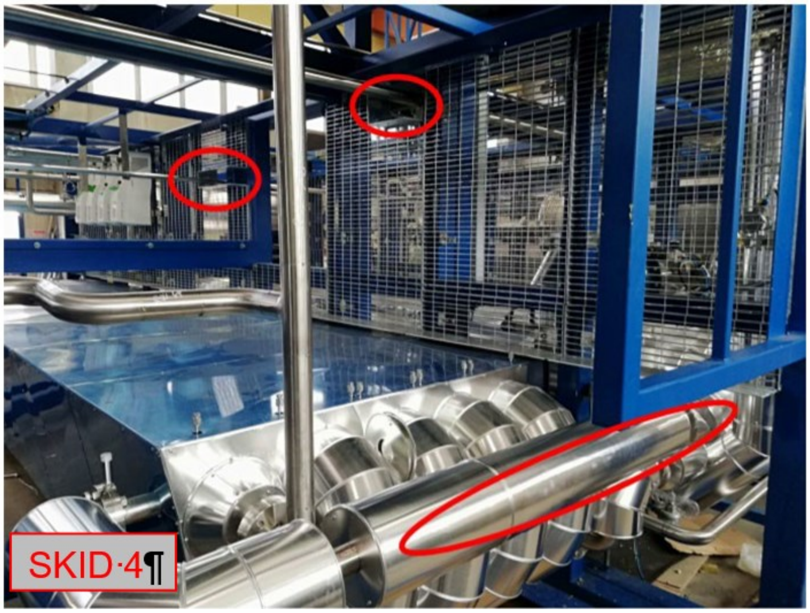


Figure 25: *Blind flanges of skid 4 in correspondence of the blind flange on skid 3 to be removed before the installation of skid 3 on skid 2. Interconnection lines between skid 4 and skid 3.*

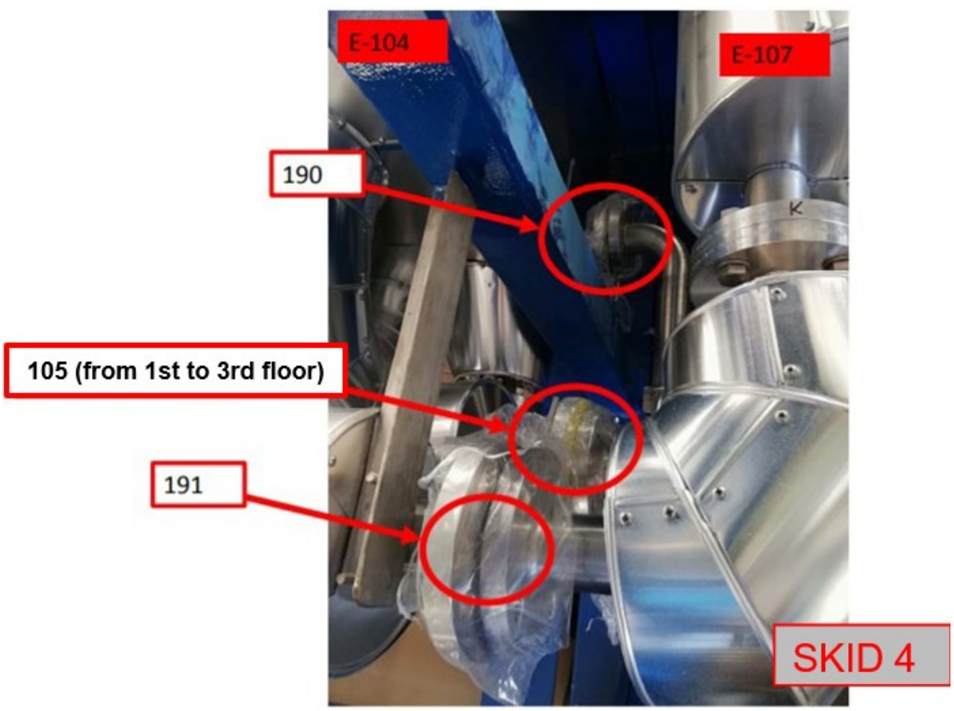


Figure 26: *Blind flanges of skid 4 in correspondence of the blind flange on skid 3 to be removed before the installation of skid 3 on skid 2. Interconnection lines between skid 4 and skid 3.*

For each line, remove the corresponding blind flange both on side of skid 3 and on side of skid 4, so thatthe two bare sides of the interconnecting pipe will face when the two skids will be in the final position.

For easier recognition, the pictures show the position of all the lines of interest.

When removing a protective blind flange, please remember to immediately protect the flange that has beenopened, as described in section 9.1.

While removing the pipe stube on line 191, pay attention on the mounted Kalrez O-ring (internal O-ring). It should be reused.

Table 19: *Skid 3 & skid 4: interconnecting equipment and pipelines list*

SKID 3 & SKID 4: INTERCONNECTION EQUIPMENT AND PIPES LIST		
Line number	DN	Operations
E-105	125	Tolerance on lateral shift on the top part
Line 199	50	Remove blind flanges on skid 3 (close to E-105)
Line 131	25	Remove blind flanges on skid 3 (close to E-105)
Line 182	25	Remove blind flanges on skid 3 (close to E-105)
Line 120	50	Remove blind flanges on skid 3 (close to E-105)
Line 191	50	Remove blind flanges on skid 3
Line 105	50	Remove blind flanges on skid 3
Line 190	50	Remove blind flanges on skid 3
Line 126	50	Remove blind flanges on skid 3
Line 142	25	Remove blind flanges on skid 3

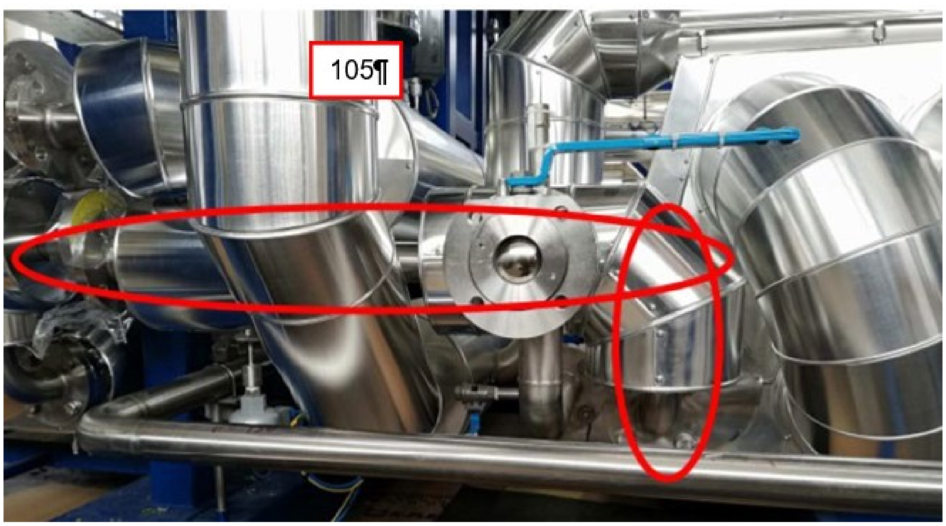


Figure 27: *line 105 connecting E-104 and E-106*

The line 105 between E-104 and E-106 must be removed before skid erection (see ***Figure 27***). For this purpose, two blind flanges and two clean Teflon gaskets are required (some spare blind flanges and Teflon gaskets have been supplied by Polaris). Unscrew the pipe stub from the bottom side of E-104 (on skid 4), remove it and seal both the pipe stub and the E-104 flange using the two gaskets and blind flanges.Label the pipe stub for easier recognition and store it with all the other stuff of the distillation plant. While removing the pipe stube pay attention to the mounted Kalrez O-ring (internal O-ring). It should be reused.

Interconnecting flanges between skids 3 and 6.

Remove the blind flange listed in ***Table 22*** for the connection between Skid 3 and Skid 6.

Now, operations for erection of skid 3 and positioning of skid 3 on skid 2 can start.

For this purpose, the truck crane is required. It is advisable to use lifting beams, if available, in order to avoid the risk of damaging the skid during the erection with the lifting chains.

The picture below (***Figure 28***) shows graphically how to hook and handle the skid. For more details, seethe Lifting Diagram document.

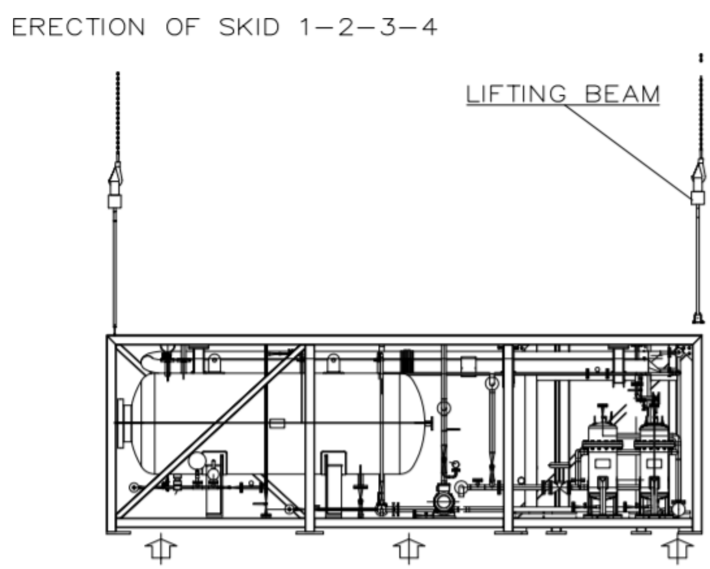


Figure 28: *Erection scheme of skid 3*

Connect the crane at the two sides of skid 3 as shown in ***Figure 28***. It is advisable to use lifting beams (or slings, if the former is not available) to avoid the risk of damaging the skid during the erection.

Before lifting, check carefully the correct orientation of the skid 3 from Distillation plant layout drawings.

Lift horizontally the skid with both chain winches at the same time. Move the skid till the installation position upon skid 2 through the roof.

Move down slowly the skid. Please, be very careful during this operation: do not lay down nor accidentally slide skid 3 on its bottom side, otherwise the opened flanges of the interconnecting pipelines could be damaged.

Adjust the position and align precisely skid 3 on skid 2. The centering operation could be aided by means of some alignment pins, like threaded rods to be inserted from above into the holes of the triangular platesof skid 3, that shall be coupled to the corresponding holed triangular plates of skid 2. Align skid 3 on skid 2 so that the pins can be inserted also into skid 2 plates and can guide the skids alignment until they are joined.

When approaching skid 3 to skid 2, please be very careful and move slowly to avoid hits, bumps and any damages to the skids and their interconnection flanges. Operators should keep monitoring closely each interconnection flange during this phase to check that no strains, misalignments or even breaks could occur.Finally, gently lay down skid 3 on skid 2 in its final position (see Distillation Plant layout document) and remove the alignment pins.

When erection is completed, unfix the crane from the lifting lugs and from the base of skid 3 using a mobileplatform or similar and fix the skid 3 on the skid 2 with bolts.

9.2.10. POSITIONING OF SKID 4 ON SKID 3

Before positioning skid 4 on skid 3, protective blind flanges of the interconnecting flanges must be removed.

Interconnecting flanges between skids 3 and 4.

The list of interconnecting pipes, where blind flanges must be removed, is reported in ***Table 20***. The pipeshave been identified with the corresponding line number indicated on the P&Id.

Please, refer to the P&Id, line list and layout drawings for details.

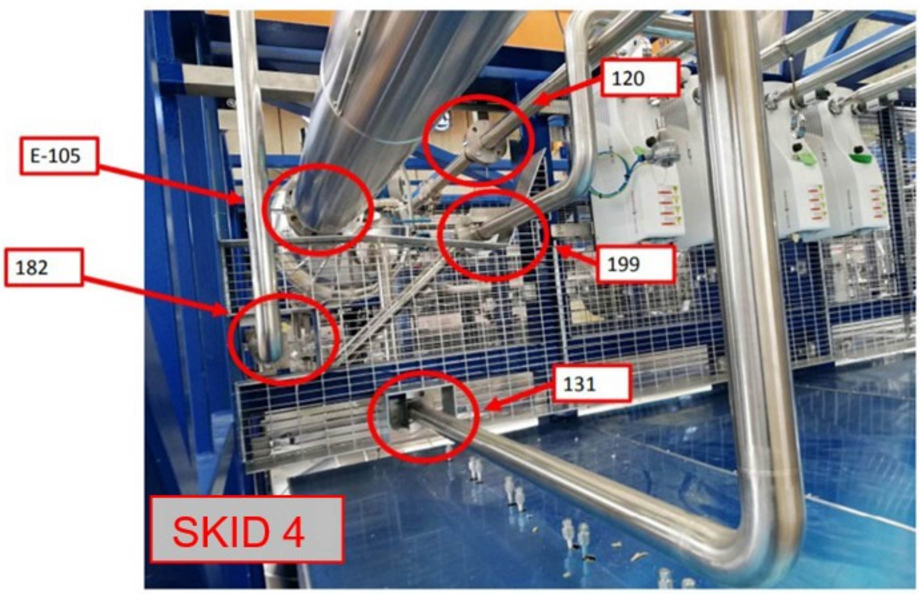


Figure 29: *Blind flanges of skid 4 to be removed before the installation of skid 4 on skid 3. Interconnection lines between skid 4 and skid 3.*

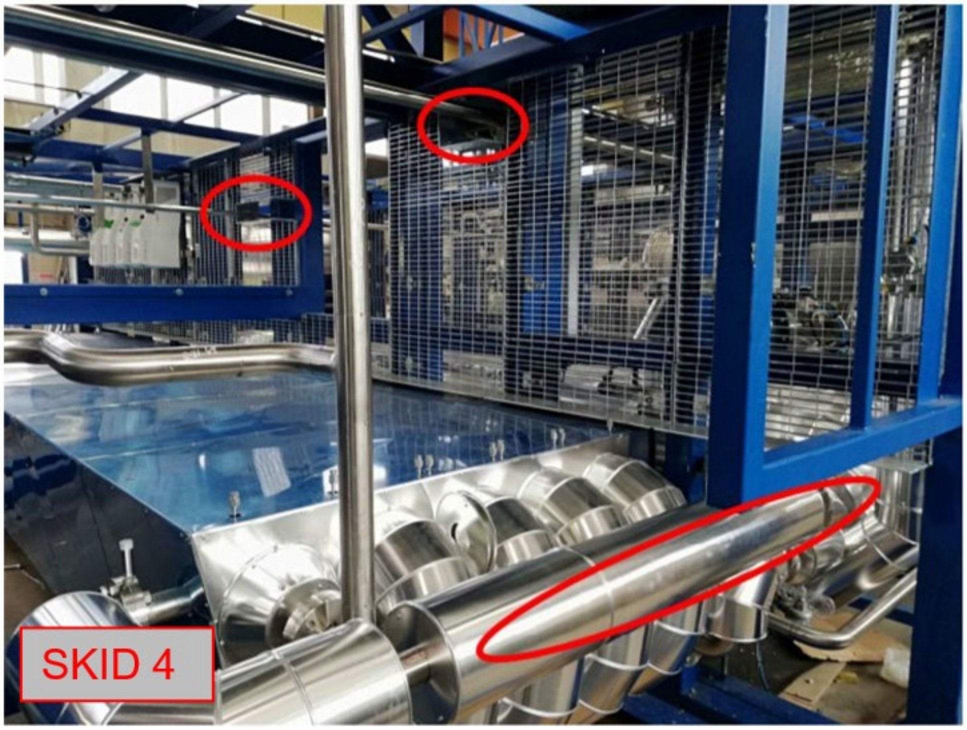


Figure 30: *Blind flanges of skid 4 to be removed before the installation of skid 4 on skid 3. Interconnection lines between skid 4 and skid 3.*

For each line, remove the corresponding blind flange both on side of skid 3 and on side of skid 4, so thatthe two bare sides of the interconnecting pipe will face when the two skids will be in the final position.

For easier recognition, the pictures show the position of all the lines of interest.

When removing a protective blind flange, please remember to immediately protect the flange that has beenopened, as described in section 9.1.

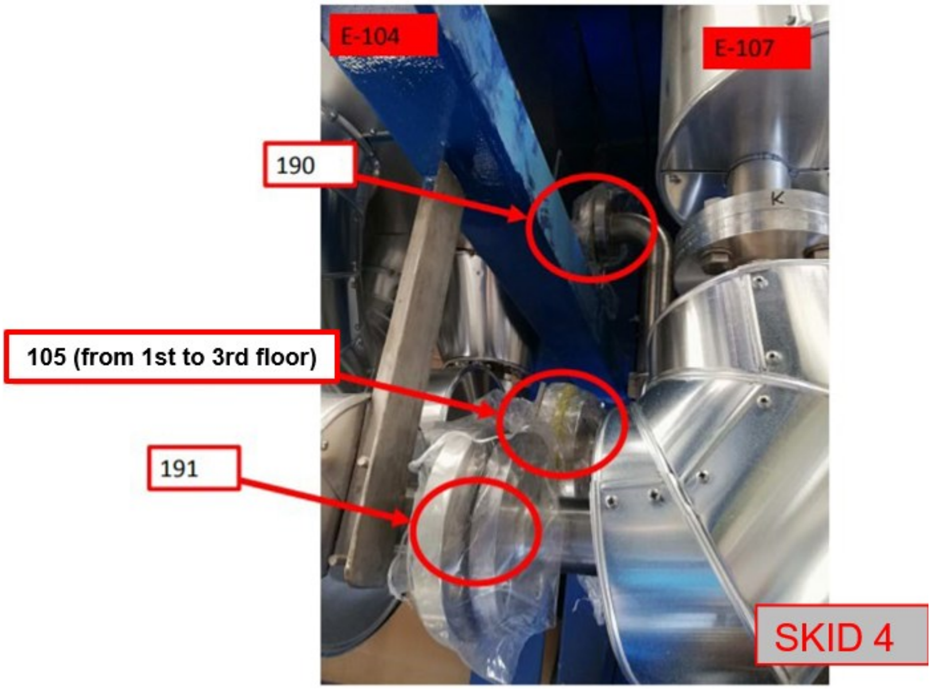


Figure 31: *Blind flanges of skid 4 to be removed before the installation of skid 4 on skid 3. Interconnection lines between skid 4 and skid 3.*

Table 20: *Skid 3 & skid 4: interconnecting equipment and pipelines list*

SKID 3 & SKID 4: INTERCONNECTION EQUIPMENT AND PIPES LIST		
Line number	DN	Operations
E-105	125	Tolerance on lateral shift on the top part
Line 199	50	Remove blind flanges on skid 4 (close to E-105)
Line 131	25	Remove blind flanges on skid 4 (close to E-105)
Line 182	25	Remove blind flanges on skid 4 (close to E-105)
Line 120	50	Remove blind flanges on skid 4 (close to E-105)
Line 191	50	Remove blind flanges on skid 4
Line 105	50	Remove blind flanges on skid 4
Line 190	50	Remove blind flanges on skid 4
Line 126	50	Remove blind flanges on skid 4
Line 142	25	Remove blind flanges on skid 4

Interconnecting flanges between skids 4 and skid 5 (E-102).

The list of interconnecting pipes, where blind flanges must be removed, is reported in ***Table 21***. The pipeshave been identified with the corresponding line number indicated on the P&Id.

Please, refer to the P&Id, line list and layout drawings for details.

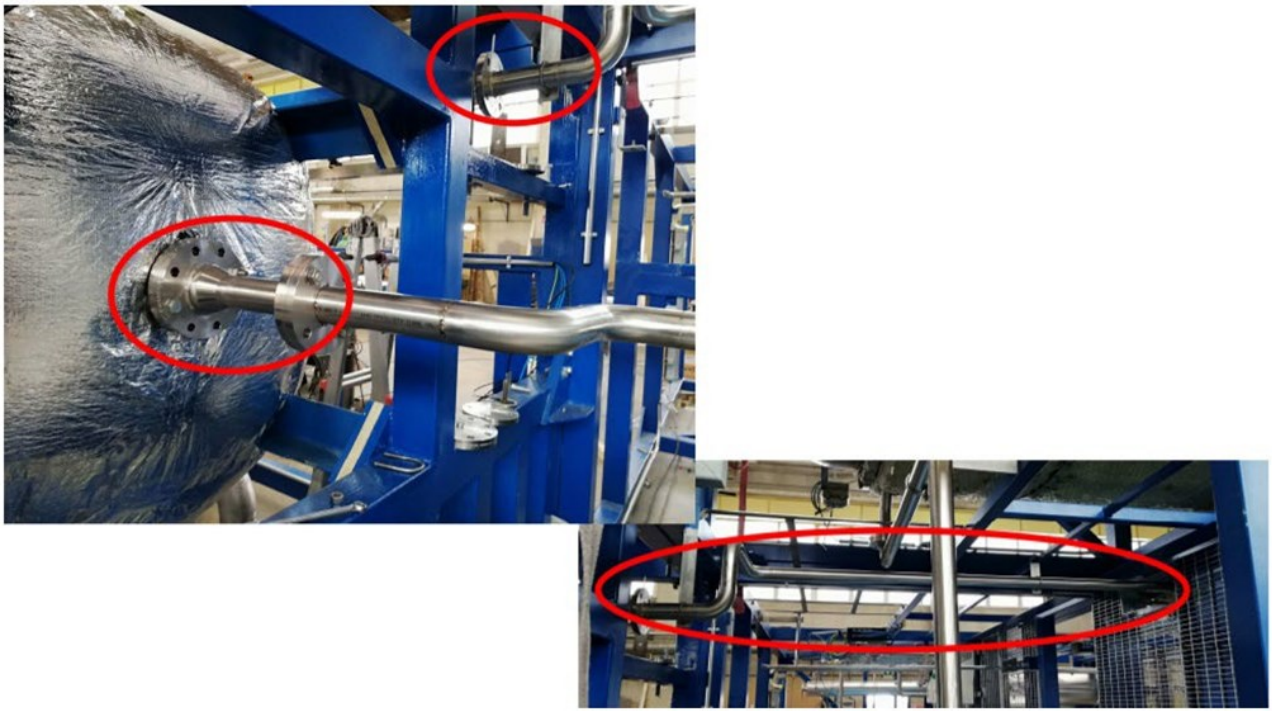


Figure 32: *Blind flanges of skid 4 to be removed before the installation of skid 4 on skid 3. Interconnectionlines between skid 4 and skid 5.*

Table 21: *Skid 4 & skid 5: interconnecting equipment and pipelines list*

SKID 4 & SKID 5: INTERCONNECTION EQUIPMENT AND PIPES LIST		
Line number	DN	Operations
Line 185	50	Remove blind flanges on skid 4 (removable pipe stub)
Line 126	50	Remove blind flanges on skid 4
Line 113	50	Remove blind flanges on skid 4
Line 142	VCR ¼”	

For each line, remove the corresponding blind flange both on side of skid 5 and on side of skid 4, so that the two bare sides of the interconnecting pipe will face when the two skids will be in the final position.

For easier recognition, the pictures show the position of all the lines of interest.

When removing a protective blind flange, please remember to immediately protect the flange that has beenopened, as described in section 9.1.

The pipe stub of line 185 on skid 5 must be removed before skid erection (see ***Figure 32***). For this purpose,two blind flanges and two clean Teflon gaskets are required (some spare blind flanges and Teflon gasketshave been supplied by Polaris). Unscrew the pipe stub from the bottom of the side of E-102, remove it and seal both the pipe stub and the E-102 flange using the two gaskets and blind flanges. Label the pipe stub for easier recognition and store it with all the other stuff of the distillation plant. While removing the pipe stub put attention on the mounted Kalrez O-ring (internal O-ring). It should be reused.*Interconnecting flanges between skids 4 and 6.*

Remove the blind flange listed in ***Table 22*** for the connection between Skid 4 and Skid 6

Now, operations for erection of skid 4 and positioning of skid 4 on skid 3 can start.

For this purpose, the crane is required. It is advisable to use lifting beams, if available, in order to avoid therisk of damaging the skid during the erection with the lifting chains.

The picture below (***Figure 33***) shows graphically how to hook and handle the skid. For more details, seethe Lifting Diagram document.

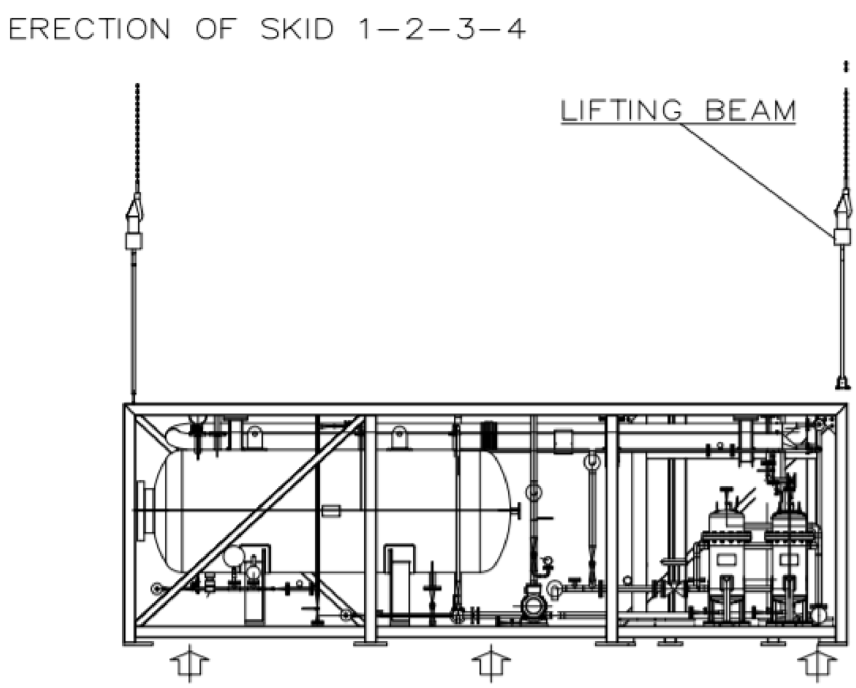


Figure 33: *Erection scheme of skid 4*

Connect the crane at the two sides of skid 4 as shown in ***Figure 33***. It is advisable to use lifting beams (or slings, if the former is not available) to avoid the risk of damaging the skid during the erection.

Before lifting check carefully, the correct orientation of the skid 4 from Distillation plant layout drawings.

Lift horizontally the skid with both chain winches at the same time. Move the skid till the installation position upon skid 3 through the roof.

Move down slowly the skid. Please, be very careful during this operation: do not lay down nor accidentally slide skid 4 on its bottom side, otherwise the opened flanges of the interconnecting pipelines could be damaged.

Adjust the position and align precisely skid 4 on skid 3. The centering operation could be aided by means of some alignment pins, like threaded rods to be inserted from above into the holes of the triangular platesof skid 4, that shall be coupled to the corresponding holed triangular plates of skid 3. Align skid 4 on skid 3 so that the pins can be inserted also into skid 3 plates and can guide the skids alignment until they are joined.

When approaching skid 4 to skid 3, please be very careful and move slowly to avoid hits, bumps and any damages to the skids and their interconnection flanges. Operators should keep monitoring closely each interconnection flange during this phase to check that no strains, misalignments or even breaks could occur.Finally, gently lay down skid 4 on skid 3 in its final position (see Distillation Plant layout document) and remove the alignment pins.

When erection is completed, unfix the crane from the lifting lugs and from the base of skid 4 using a mobileplatform or similar and fix the skid 4 on the skid 3 with bolts.

9.2.11. ERECTION AND POSITIONING OF SKID 6 (VERTICAL SKID)

Before erecting and positioning skid 6 protective blind flanges of the interconnecting lines must be removed.For each line, remove the corresponding blind flange both on side of skid 6 and on side of skids 1-2-3-4, sothat the two bare sides of the interconnecting pipe will face when the two skids will be in the final position (see ***Table 22***).

When removing a protective blind flange, please remember to immediately protect the flange that has beenopened, as described in section 9.1.

Table 22: *Skid 6 & skids 1-4: interconnecting equipment and pipelines list*

SKID 6 & SKID 1-2-3-4: INTERCONNECTION EQUIPMENT AND PIPES LIST		
Line number	DN	Operations
Line 194	50	Remove blind flanges on skid 6 and 4
Line 151	50	Remove blind flanges on skid 6 and 3
Line 152	50	Remove blind flanges on skid 6 and 2
Line 139	25	Remove blind flanges on skid 6 and skid 3
Line 114	25	Remove blind flanges on skid 6 and 1 (removable pipe stub)
Line 154	450	Remove blind flanges on skid 6 and 2
Interconnecting flanges from C-101 to reboiler E-101	150	Remove blind flanges on skid 6 and 2

For line 114, if you need to remove the pipe stub to perform the connection pay attention to the mounted Kalrez O-ring (internal O-ring). It should be reused.

While connecting the lines 151 and 152, if you need to remove the pipe stub to perform the connection, pay attention to the mounted Kalrez O-ring (internal O-ring). It should be reused.

To prevent any damage on the surface of the flanges during the positioning of the skid 6, slide back thereboiler E-101, loosening the legs bolts and using the slotted holes.

Now, operations for erection of skid 6 and positioning of skid 6 next to skid 1-4 can start.

For this purpose, the crane is required. It is advisable to use lifting beams, if available, to avoid the risk of damaging the skid during the erection with the lifting chains.

The picture below (***Figure 34***) shows graphically how to hook and handle the skid. For more details, seethe Lifting Diagram document.

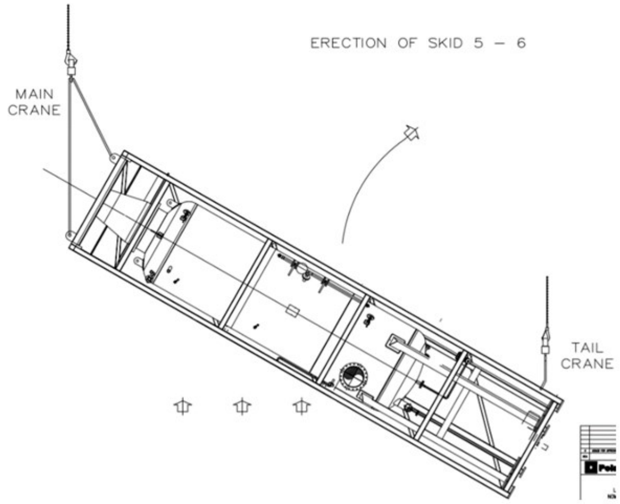


Figure 34: *Erection scheme of Skid 6*

Connect the chain winch of the main crane to the lifting lugs on the top of skid 6 with a lifting beam (or slings,if the former is not available). Connect the chain winch of the tail crane to the base of skid 6 with slings or a lifting beam.

Lift horizontally the skid with both chain winches at the same time. Using only the first chain winch, lift the top of skid 6 to erect it vertically and insert it into the building from the roof.

Before positioning, carefully check the skid orientation from Distillation plant layout drawings.

Move down slowly the skid in vertical position. Adjust the position and align precisely skid 6 and skids 1-4. The centering operation could be aided by alignment pins.

When approaching skid 6 to skids 1-4, please be very careful and move slowly to avoid hits, bumps and any damages to the skids and their interconnection flanges. Operators should keep monitoring closely eachinterconnection flange during this phase to check that no strains, misalignments or even breaks could occur.Finally, gently lay down skid 6 in its final position (see Distillation Plant layout document).

When erection is completed, unfix the crane from the lifting lugs and from the base of skid 6 using a mobileplatform or similar and fix the skid 6 to skids 1-4 with bolts.

9.2.12. ERECTION AND POSITIONING OF SKID 5 ON SKID 4

The list of interconnecting pipes, where blind flanges must be removed, is reported in ***Table 23***. The pipeshave been identified with the corresponding line number indicated on the P&Id.

Please, refer to the P&Id, line list and layout drawings for details.

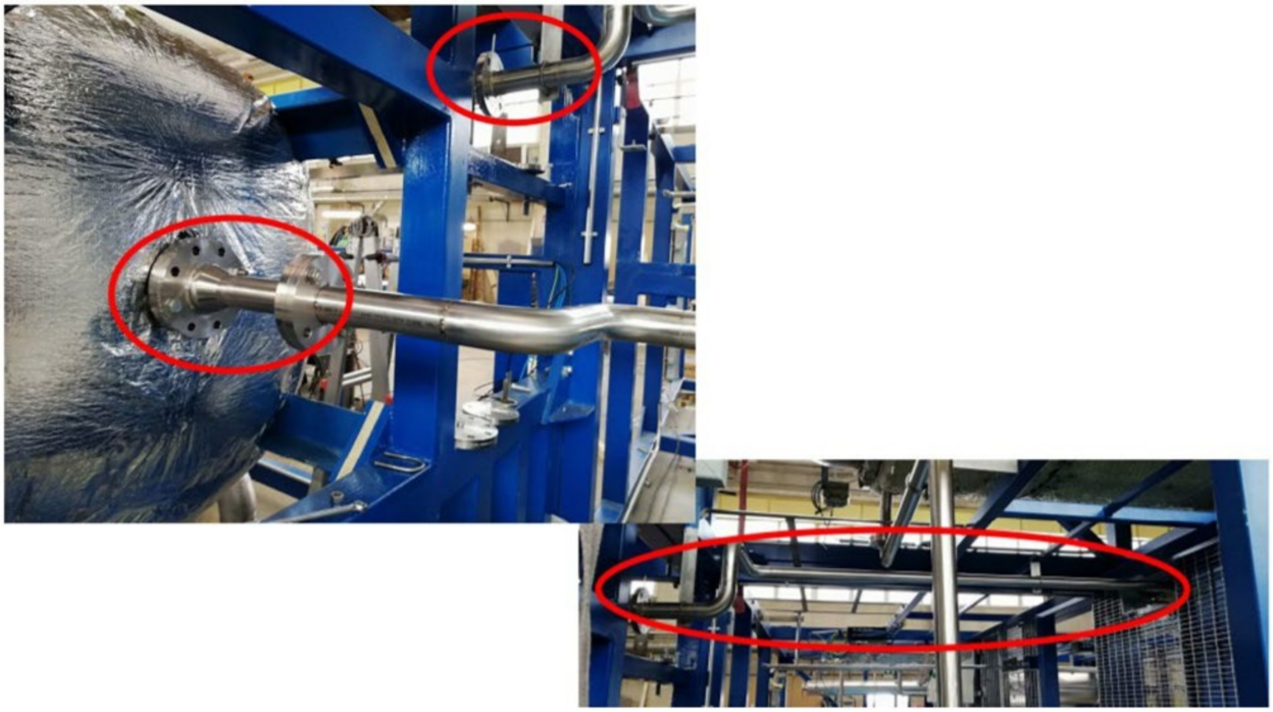


Figure 35: *Blind flanges of skid 5 to be removed before the installation of skid 5 on skid 4. Interconnectionlines between skid 4 and skid 5.*

For each line, remove the corresponding blind flange both on side of skid 5 and on side of skid 4, so that the two bare sides of the interconnecting pipe will face when the two skids will be in the final position.

For easier recognition, the pictures show the position of all the lines of interest.
When removing a protective blind flange, please remember to immediately protect the flange that has beenopened, as described in section 9.1.

Table 23: *Skid 4 & skid 5: interconnecting pipelines list*

SKID 4 & SKID 5: INTERCONNECTION EQUIPMENT AND PIPES LIST a		
Line number	DN	Operations
Line 185	50	Remove blind flanges on skid 5 (removable pipe stub)
Line 126	50	Remove blind flanges on skid 5
Line 113	50	Remove blind flanges on skid 5
Line 142	VCR ¼”	

The pipe stub of line 185 on skid 5 must be removed before skid erection (see ***Figure 35***). For this purpose,two blind flanges and two clean Teflon gaskets are required (some spare blind flanges and Teflon gasketshave been supplied by Polaris). Unscrew the pipe stub from the bottom side of E-102, remove it andseal both the pipe stub and the

E-102 flange using the two gaskets and blind flanges. Label the pipe stub for easier recognition and store it with all the other stuff of the distillation plant.

Now, operations for erection of skid 5 and positioning of skid 5 on skid 4 can start.

For this purpose, the crane is required. It is advisable to use lifting beams, if available, to avoid the risk of damaging the skid during the erection with the lifting chains.

The picture below (***Figure 36***) shows graphically how to hook and handle the skid. For more details, seethe Lifting Diagram document.

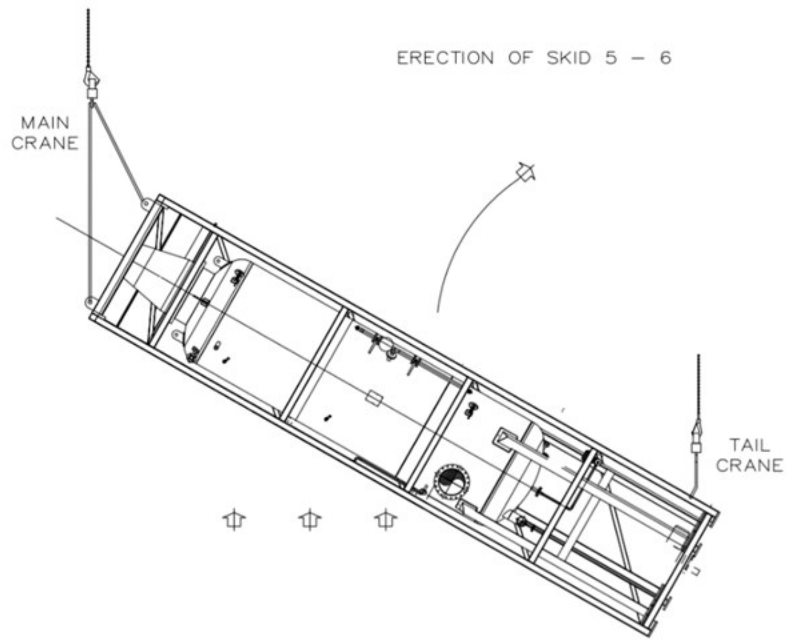


Figure 36: *Erection scheme of skid 5*

Connect the chain winch of the main crane to the lifting lugs on the top of skid 5 with a lifting beam (or slings,if the former is not available).

Connect the chain winch of the tail crane to the base of skid 5 with slings or a lifting beam.

Lift horizontally the skid with both chain winches at the same time. Using only the first chain winch, lift the top of skid 5 to erect it vertically and insert it into the building from the roof. Please, be very careful during this operation: do not lay down nor accidentally slide skid 5 in vertical position on its bottom side, otherwise the opened flanges of the interconnecting pipelines could be damaged.

Before positioning, carefully check the skid orientation from Distillation plant layout drawings.

Move down slowly the skid. Adjust the position and align precisely skid 5 and skid 4. The centering operationcould be aided by means of some alignment pins, like threaded rods to be inserted from above into the holes of the triangular plates of skid 5, that shall be coupled to the corresponding holed triangular plates of skid 4. Align skid 5 on skid 4 so that the pins can be inserted also into skid 4 plates and can guide the skids alignment until they are joined.

When approaching skid 5 to skids 4, please be very careful and move slowly to avoid hits, bumps and anydamages to the skids and their interconnection flanges. Operators should keep monitoring closely each interconnection flange during this phase to check that no strains, misalignments or even breaks could occur.Finally, gently lay down skid 5 in its final position (see Distillation Plant layout document).

When erection is completed, unfix the crane from the lifting lugs and from the base of skid 5 using a mobileplatform or similar and fix the skid 5 on the skid 4 with bolts.

9.2.13. MOUNTING OF LINE 163 FROM C-101 TO E-102

Line 163 is a very delicate and heavy DN1000-DN500 line connecting C-101 (skid 6) and E-102 (skid 5)(***Figure 37***).

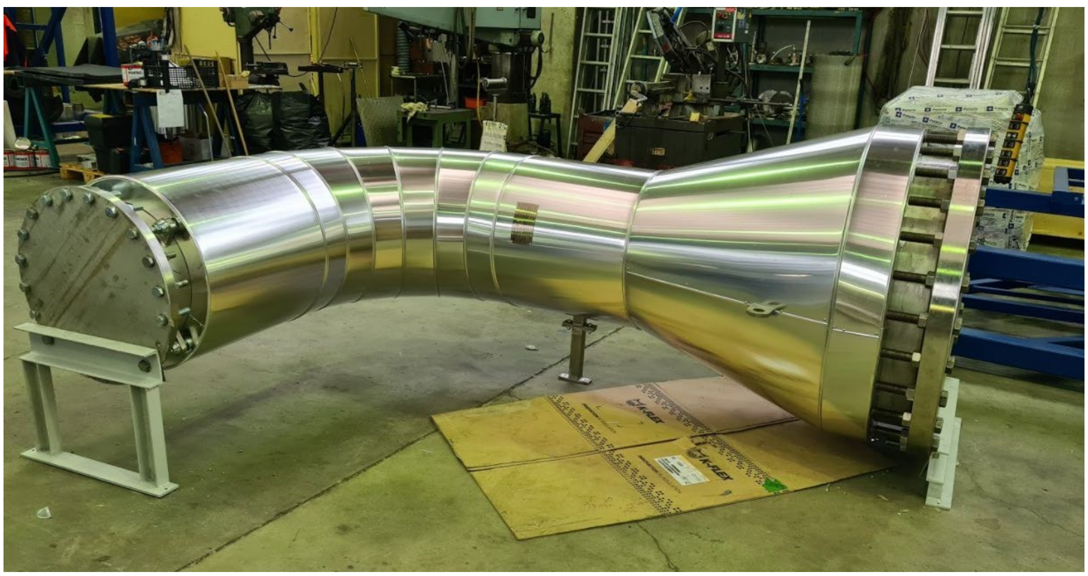


Figure 37: *Line 163*

Figure 38: *Blind flange on skid 5 for the connection with line 163*

Use the lifting ears to connect the line to the crane to lift the line.

Remove the blind flanges on both sides of line 163, on C-101 and on E-102. It is important to use a crane to remove the flanges due to the high weight of them. (***Figure 37*** and ***Figure 38***).

Lift line 163 and approach the top of the skid 6 to establish the correct positioning of the line connecting skid 6 and skid 5. Before connecting the line, insert the correct O-ring between the line 163 and C-101 and E-102. Note thatthe internal O-ring for both the interconnecting flanges DN500 and DN1000 is a dedicated Kalrez oring. For more details, see section 10.3.

The O-rings shall be cleaned and positioned into the flange caves before flanges coupling. For this purpose,O-rings can be temporary held in place inside caves with thin metal "clips". During this operation, operators must wear clean gloves to handle and clean O-rings.

While O-rings are in place, move down slowly the line. Approach carefully the line to the interconnecting flanges of the skids. Adjust the position and precisely align the line to skid 5 and skid 6. The centering operation could be aided by means of some bolts or alignment pins.

Please, be very careful during these operations and avoid any scratches, engravings or dents on the internal surfaces of the flanges, which could compromise the leak tightness of the flanges.

Once flanges are coupled and O-rings cannot move, remove the clips. Finally, fix the line using bolts.

Before unfixing the crane from the line, it is important to perform the leak-test of the DN500 and DN1000 flanges from the nitrogen purge ports welded at the two sides of the two flanges. If JUNO requirements are not satisfied, the test is not passed and you need to re-open the flange and check again the position of the O-rings and of the line using the crane.

9.2.14. POSITIONING OF T-101 VERTICAL TANK

The picture below (***Figure 39***) shows graphically how to hook and handle the tank. For more details, see picture 6 of the Lifting Diagram document.

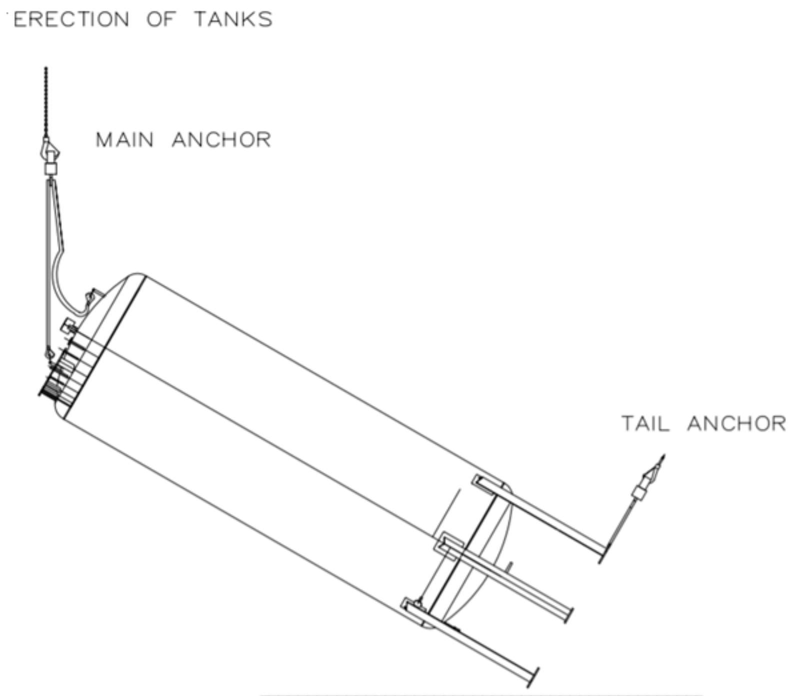


Figure 39: *Erection scheme of T-101*

For T-101, connect the chain winch to the four lifting lugs positioned on tank dome. Connect the tank legs to the tail. It is advisable to use lifting beams, if available. Lift the tank from both sides at the same time.

While keeping the bottom side suspended, lift the top side of the tank to erect the tank vertically. Then, insert it from the roof of the building and move it down slowly.

For T-101 tank positioning, two dedicated metallic templates have been provided from Polaris as spacers to help find the correct position.

Correct alignment and accurate positioning are the major issues for tank erection. Once it will be fixed to the ground, it would be impossible to change and correct its position if inaccurate; so, please, check carefully both the orientation of nozzles on tank dome and the legs accurate positioning before fixing to ground.

First, verify that T-101 is oriented exactly as shown in ***Figure 40***: check the position of the nozzles on tankdome with respect to the skids position. The side of the tank where nozzles are installed must face the skid.The angular position of each nozzle flange has been specified for better understanding.

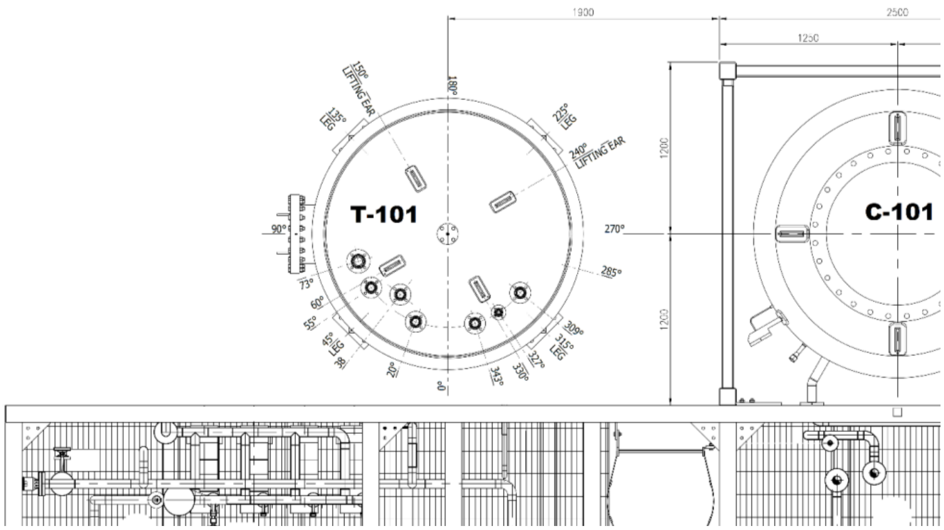


Figure 40: *Angular position of flanges on top of T-101 tank*

Secondly, the positioning of tank legs must be done very precisely. For this purpose, two dedicated metallictemplates have been provided from Polaris as spacers to help find the correct position of T-101. Please, note that the templates are custom made for each tank (T-101 and T-102), so be sure to do not swap them and use the correct ones.

As further check that T-101 has been correctly and precisely positioned with respect to the skids, it is possible to verify that the prefabricated pipe of line 150 fits to the interconnecting flanges of T-101 and skid 4.

9.2.15. STAIRS

The stair was delivered disassembled. It shall be mounted on site, installed alongside skids and fixed tothem.

For details about the assembly and the installation position, please refer to layout drawings.

Bolts, nuts and washers are supplied by Polaris.

9.2.16. MOUNTING OF THE INTERNAL LADDER

The internal ladder shall be installed inside skids and fixed to them.

For details about the assembly and the installation position, please refer to layout drawings.

Bolts, nuts and washers are supplied by Polaris.

9.2.17. ANCHORING OF SKID 6, TANK T-101 AND STAIRS

Once the erection operations for both skids and tanks have been completed and all the main parts of the distillation plant have been positioned, they must be fixed together and anchored to ground for safety reasons.

Check that all skids and stairs are firmly fixed together with bolts.

Then, proceed with the ground anchoring of the plant.

Skid 1, the stairs and T-101 tank shall be fixed to ground with chemical anchors, in accordance with the 'Civil Load Diagram' document.

All the tools and items required for ground anchoring ('Hilti' hammer drill, bits of different length and diameter for the hammer drill, 'Hilti' chemical bolts, …) have been supplied by INFN. See the packing list for more details.

Drill the concrete floor with 'Hilti' hammer drilling machine in correspondence of the holes of each plate of skid 1, stairs and tank.

During drilling operations, it's important to use a dust extractor/aspirator to remove all the drilling powder and prevent it from spreading into the environment and/or entering the plant.

After drilling, place the chemical anchors, let them dry for at least one night and finally seal the anchors with bolts.

9.2.18. CLOSE THE ROOF OF THE BUILDING

When the installation of the main components of the plant is completed, the roof of the building can be re-installed in its initial position.

For this purpose, the 25-ton truck crane is required to lift and handle the roof panel.

During this operation, at least one Chinese manager of the LS ground hall should be present onsite to guide the operation.

10. OTHER MECHANICAL WORKS

When the plant positioning and the main erection activities have been completed, it is possible to finalize the plant installation and connect the Distillation plant with the other plants and auxiliary systems in the LSHall, as described in the following sections. All these operations will be done in a second step (phase 2 of the installation), when both INFN and Polaris operators will be present onsite.

10.1. PIPING AND INSTRUMENT MOUNTING

Some piping, instruments, valves and accessories (see packing list for details) are transported separately and shall be mounted directly at site after skids and tanks erection. For this purpose, at least a couple of people from INFN should be present onsite to manage and guide the operations.

All materials required for connections and assembling are provided by Polaris. Bolts, nuts and washers shall be used for flanges sealing.

Viton and/or Kalrez O-rings have been chosen as flange gaskets. The 2 O-ring shall be cleaned and positioned into the flange caves before flanges coupling. For this purpose, O-rings can be temporary held in place inside caves with thin metal “clips”. Once flanges are coupled and O-rings cannot move, remove the clips.

Before mounting the line, check the correct O-ring to be mounted, if Viton or Kalrez. (see section 10.3)

The correct sequence for flanges sealing is the following: remove the blind flanges or protective sheets, clean accurately the flange surfaces with clean wipes and alcohol, place the O-ring gaskets with clips (if needed), join and align the two connecting flanges, remove the clips (if any) and finally tighten the two coupled flanges with bolts. During cleaning operations, the operators must wear clean gloves.

10.1.1. VALVES

Some small fragile valves (less than 1/2’’ in diameter) and check valves were shipped loose and shall be mounted onsite.

Please refer to the P&Id and valve list document for details. The valves that are shipped spool are:

- valve: XV-169
- valves: 385, 357, 359, 360, 361, 362, 363, 364
- valves: 171, 144

10.1.2. PIPING (TO BE ERECTED AND MOUNTED)

The interconnecting piping both between two adjacent skids and between skids and tanks shall be erected and mounted.

On each pipeline it is reported the line number for easier recognition. It is anyway

recommended to refer tothe P&Id, line list document and layout drawings for details.
The lines that must be erected and mounted onsite are:

- on C-101 column: line 139
- on VP vent: line 183
- on PSE: lines 174, 173, 176, 175
- on T-101: 123,101, 140, 166, 150, 102
- on T-102: 169, 141, 126, 143, 106
- inside the pump well: 106, 107, 121, 122

10.1.3. PIPING (ONLY MOUNTING)

Some pipes were installed in their final position in the skids and sealed with protective blind flanges before shipping; the protective flanges of these lines were removed during erection activities described in the previous sections (phase 1 of the installation), before positioning the skids side by side.

Now, the interconnecting flanges of these pipes have only to be coupled and sealed (no erection nor insertion into skids is required). Remember to clean the flange surface and insert O-rings before to seal it, as described in section 10.1.

These lines are listed below:

- Between skid1 and skid 2: 190, 133, 120
- Between skid 2 and skid 3: 120, 199, 133, 182, 156, 157 4: 142, 126, 169, 190
- Between skid 3 and skid 4: 182, 131, 199, 120, 191, 105, 190, 142, 126, main flangeE-105
- Between skid 4 and skid 5: 185, 126, 113, 142 (VCR)
- Between skids 1-4 and skid 6 (column C-101): 194, 151-152, 139, 114, flanges DN150 and DN450 of E-101 reboiler.

Note that, for these lines, it may be necessary to temporary loosen or remove the pipe support brackets, tomanage to clean the flanges surfaces and insert the O-rings. When flange sealing is completed, please tighten the pipe brackets.

10.1.4. INSTRUMENTS

All the instruments on the top of the two tanks and some other instruments to be installed on piping shippedloose shall be mounted onsite.

These instruments are listed below:

- on T-101 tank: PT-101, PSE-139, LT-103
- on T-102 tank: PT-144, LT-122, PSE-120 with holder
- on C-101 distillation column: PT-143 and PT-151, DPT-111, LT-195, FT-147, PSE-114
- on T-103: PSE-127
- on skid 4: vacuum pumps VP-101A/B/C/D

PT are pressure gauges with transmitters, LT are radar level meters with transmitters, TE are temperatureelements and PSE are safety rupture disks. For more details, see the P&Id and instrument list document. Please, consult the instruction manual of each instrument before to start the installation.

If needed, remember to clean the flange surface and insert O-rings before to seal it, as described in section 10.1.

Note that all these instruments must also be electrically cabled to the junction boxes (see chapter 11).

10.2. OTHER MINOR WORKS

Some additional works will be required, such as:

- Handrails and grating floors mounting and fixing on skids.
- Removal of some temporary supports provided for transportation (for equipment, piping, andinstrumentation)
- Paint touching up where the paint is damaged during erection.
- Erection/removal of blind flanges, caps, etc.

Temporary supports are painted in yellow for easier recognition and removal. These supports can beafterwards disposed.

Do not remove caps from the terminal points until the erection works end, to avoid possible dirty in thepiping.

10.3. KALREZ O-RINGS

All the interconnecting flanges were designed to be sealed with double O-ring gaskets

O-ring dimensions [mm x mm]	Flange dimension	Flange position
Kalrez 42.52 x 2.62	DN25	Line 114 / connection between skids 1-6
		C-101 / L port (for N_2 inlet)
		Line 139 (for N_2 flux) / connection to skid 6
		Line 139 (for N_2 flux) / connection to skid 3
Kalrez 69.52 x 2.62	DN50	Line 191 / connection between skids 3-4
		Line 151 / connection between skids 3-6
		Line 152 / connection between skids 2-6
		C-101 / E port (for LAB reflux inlet)
		Line 185 / connection between skids 4-5
		C-101 / B port (for DPT-111)
		C-101 / A port (for PT-143)
		C-101 / I port (for DPT-111)
		C-101 / N port (for PT-151)
		C-101 / LT-195 on leg mounting
		Line 105 / connection between skids 3-4
Kalrez 177.39 x 3.53	DN150	Interconnecting flange between C-101 (U port) and E-101 (C port)
Kalrez 481.41 x 5.33	DN450	C-101 / P port (hot LAB from reboiler)
Kalrez 532.21 x 5.33	DN500	Line 163 / interconnecting flange between line bellow and E-102 (A port)
Kalrez 1040.00 x 7.00	DN1000	Line 163 / interconnecting flange between C-101 (C port) and line bellow

to prevent the wholeplant from external leakages. Varisco Viton O-rings were chosen as gaskets for Distillation plant.

For all the flanges in which flows LAB at high temperatures, the internal O-ring, which is the one directly exposed to the internal fluid flux, was substituted with a special O-ring made of Kalrez. Kalrez is a perfluoroelastomer which shows excellent physical properties, thermal stability, and no degradation up to 320℃. For safety reasons, for all the flanges exposed to temperatures higher than 150℃, we preferred to use Kalrez instead of Viton as sealing material for the internal O-ring.

C-101 distillation column, E-101 reboiler, heat exchangers and other plant equipment in contact with hot LAB were designed to be equipped on the clean process side with Kalrez gaskets. Some of these special O-rings were already mounted at Polaris site during the pre-assembling phase before shipping. All the remaining Kalrez O-rings that shall be mounted onsite during the installation procedure are reported in thefollowing ( ).

For convenience, ***Figure 41*** shows also the interconnecting flanges position on P&Id diagram were KalrezO-rings shall be mounted (highlighted in blue in figure).

Table 24: *Summary of the O-rings gaskets and where to be installed*

O-ring dimensions [mm x mm]	Flange dimension	Flange position
Kalrez 42.52 x 2.62	DN25	Line 114 / connection between skids 1-6
		C-101 / L port (for N_2 inlet)
		Line 139 (for N_2 flux) / connection to skid 6
		Line 139 (for N_2 flux) / connection to skid 3
Kalrez 69.52 x 2.62	DN50	Line 191 / connection between skids 3-4
		Line 151 / connection between skids 3-6
		Line 152 / connection between skids 2-6
		C-101 / E port (for LAB reflux inlet)
		Line 185 / connection between skids 4-5
		C-101 / B port (for DPT-111)
		C-101 / A port (for PT-143)
		C-101 / I port (for DPT-111)
		C-101 / N port (for PT-151)
		C-101 / LT-195 on leg mounting
		Line 105 / connection between skids 3-4
Kalrez 177.39 x 3.53	DN150	Interconnecting flange between C-101 (U port) and E-101 (C port)
Kalrez 481.41 x 5.33	DN450	C-101 / P port (hot LAB from reboiler)
Kalrez 532.21 x 5.33	DN500	Line 163 / interconnecting flange between line bellow and E-102 (A port)
Kalrez 1040.00 x 7.00	DN1000	Line 163 / interconnecting flange between C-101 (C port) and line bellow

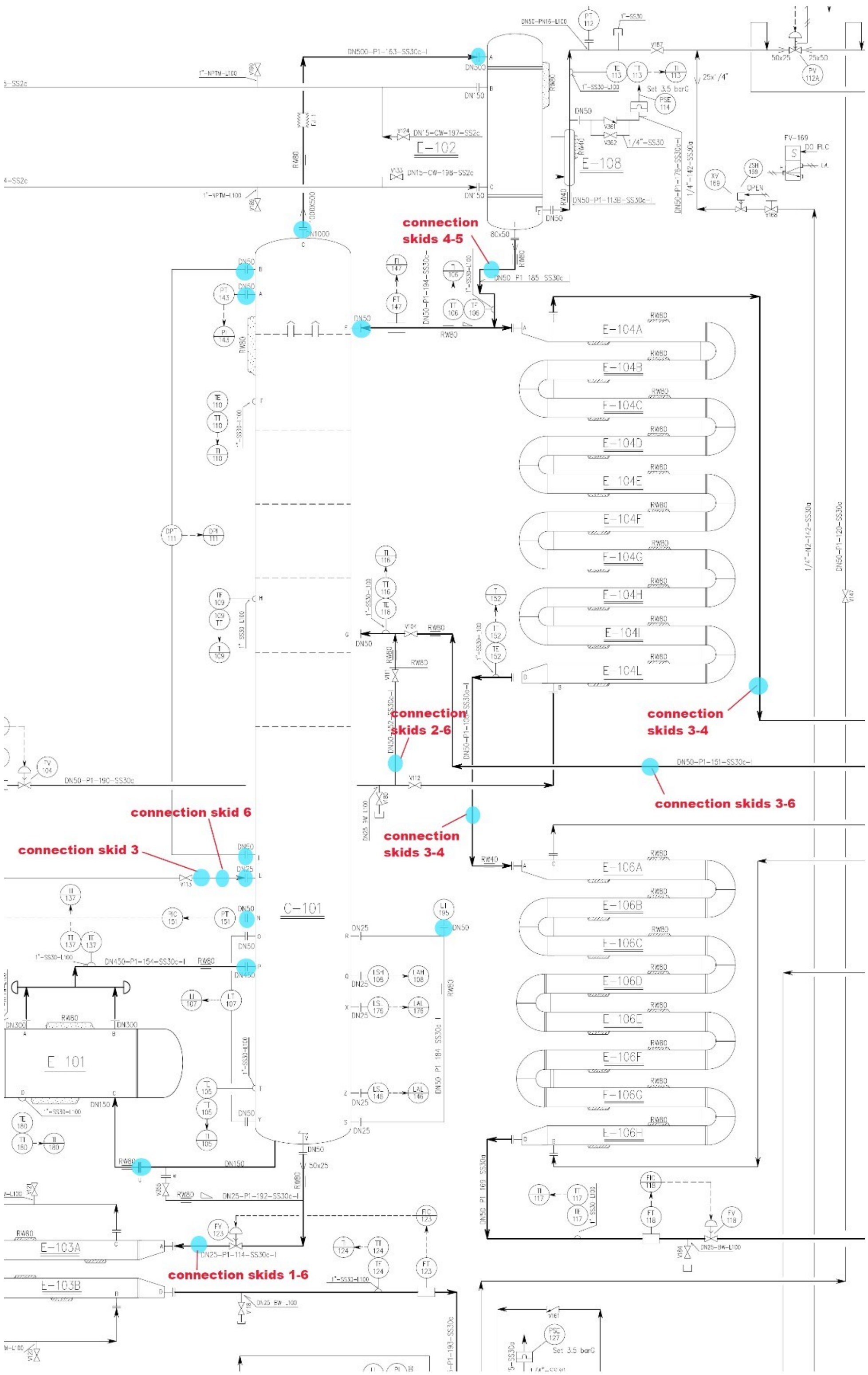


Figure 41: *Kalrez O-ring position*

Kalrez gaskets are provided by Polaris. They were shipped already cleaned and sealed into clean envelopebags. See the packing list for more details.

Kalrez is very expensive, so it should be handled very carefully, preventing it from any scratch or damage.For large flanges such as DN500 or DN1000, the flange coupling is an extremely important and complex issue and no spare Kalrez O-rings are available for such large diameters, so please be careful to do no damage them during the installation.

10.4. CONNECTION OF THE TERMINAL POINTS

During plant operation, the Distillation plant will be supplied by other plants and auxiliary systems, so connections from the terminal points (TP) of the Distillation plant to the other systems of the Over Ground LS Hall are required.

Distillation plant shall be connected both to auxiliary supply systems (hot oil, cooling water, high pure water,nitrogen, compressed air, power supply…) and to other plants for purification and handling of JUNO liquid scintillator (Alumina plant, Mixing plant…).

In ***Table 25***, all the Distillation plant terminal points are listed and for each one the corresponding plant to be connected is specified. The position of each TP can be checked on plant layout drawings.

For more details, see the 'TP information' document for Distillation plant and the over ground LS hall pipelinedesign from FINE company.

Table 25: *Terminal point (TP) list*

TP-No.	FLUID TYPE	PLANT IN/OUT	SIZE	GASKET
TP-1	LAB	Inlet	DN50	Double Viton O-ring
TP-2	LAB waste	Outlet	DN25	Double Viton O-ring
TP-3	Cooling	Outlet	DN25	Spirotallic gasket
TP-4	Cooling	Inlet	DN25	Spirotallic gasket
TP-5	Waste	Outlet	DN25	Double Viton O-ring
TP-6	Cooling	Inlet	DN32	Spirotallic gasket
TP-7	Cooling	Outlet	DN32	Spirotallic gasket
TP-8	Cooling	Inlet	DN50	Spirotallic gasket
TP-9	Cooling	Outlet	DN50	Spirotallic gasket
TP-10	LAB	Outlet	DN50	Double Viton O-ring
TP-12	Nitrogen	Inlet	DN25	Double Viton O-ring
TP-13	Air	Inlet	1/2"	Teflon tape
TP-14	Cooling	Inlet	DN150	Spirotallic gasket
TP-15	Cooling	Outlet	DN150	Spirotallic gasket
TP-16	Heating	Outlet	DN150	Spirotallic gasket
TP-17	Heating	Inlet	DN150	Spirotallic gasket
TP-18	Heating	Outlet	DN80	Spirotallic gasket
TP-19	Heating	Inlet	DN80	Spirotallic gasket

10.5. ELECTRICAL WORKS

The following activities are required:

- Electric control cabinet installation
- Power connection to power distribution and control cabinet
- HMI workstation installation and Ethernet cable connection between workstation and control panel
- Earthing of the structure
- General instrument air supply.

After the above-mentioned electrical activities, the following connections will be carried out, with cablessupplied by Polaris:

- Electrical power connections between the control panel and motors (pumps)
- Cables connections between the control panel and the instruments junction boxes on the skids,with multicore cables
- Connection of instruments disconnected for transportation (for these instruments the connectingcables to the junction boxes are hung to the skid)

Please note that some of the electrical/instrumentation activities can be done in parallel to the mechanicalactivities.

11. CLEANING PROCEDURES & BACKGROUND CONTROL STRATEGIES

Background control is one of the main issues to reach JUNO detection goals. For the Italian purification plants, dedicated operations and strategies have been adopted to remove and control the exposure of all internal surfaces to radioactive contaminants. In the following, all the precautions taken both during construction and installation phases will be listed.

I. **During construction phase**
Just after the construction, each part and component of the plant has undergone a dedicated and accurate cleaning procedure carried out by Bama Company. The cleaning sequence is the following: mechanical polishing, local picking of the welding, degreasing, electropolishing, mild passivation (with solution: 25% nitric acid - 75% demineralized water), rinsing with deionized water, air drying with filtered compressed air. Particle counting tests of the rinsing water were performed to assess the cleanliness level achieved. Ultrasonic bath cleaning with Alconox or Micro-90 detergent was adopted for small components and items.

II. **During installation phase at JUNO site (phase 1 of installation)**
During skids and tanks positioning into the ground LS hall (phase 1 of installation done by an external installation company), interconnecting flanges must be opened and protected with a clean plastic sheet (to prevent dust and radioactive contaminants to enter the plant and dirtying the internal surfaces) and a cardboard sheet (to protect the flange surface from hits and scratches).
The removal of the blind flanges and the protection with plastic and cardboard sheets is mandatory and should be done just before the coupling of two skids together since there is not space enough to leave the blind flanges in place. It's important for the operators to wear clean gloves during this operation. Just in case, clean the flange surface and O-ring caves with a clean wipe and isopropyl alcohol before to seal the flange with the clean plastic sheet.
It's important to protect and seal the flange as soon as the protective blind flange is removed to minimize the exposure time to any external contaminant source.

III. **During mounting phase at JUNO site (phase 2 of installation)**
After positioning skids and tanks, interconnecting pipelines and instruments should be mounted to complete the installation of the plant and seal it. During this phase, protective plastic bags should be removed (if any) and each interconnecting flange must be accurately cleaned with clean wipes and isopropyl alcohol. Also O-ring caves of the flange and O-rings gaskets to be inserted must be properly cleaned. It's important for the operators to wear clean gloves during cleaning operations.
After flange sealing is completed, the flange tightness level must be checked with leak test. If JUNO requirements are not satisfied, cleaning and sealing operations must be repeated.

IV. **During early commissioning phase (phase 3 of installation)**
Before to start the joint commissioning with other JUNO plants, an internal commissioning phase with UP water and LAB is foreseen to rinse the plant and further clean internal surfaces.
    a. **Commissioning with UPW:**
    circulation with ultra-pure water firstly in internal loop mode and

secondly in discharge mode; then, drain of the plant and particle counting to certify the cleanliness level

b. **Change filters:**
Removal of filter cartridges used for water loop (500 nm) and insertion of final filter cartridges (50 nm)

12. Commissioning with LAB:
circulation with LAB firstly in internal loop mode and secondly in discharge mode. LAB samples will be tested to check LAB properties and contamination (measurements of attenuation length, absorption spectra,…)**PICTURES OF DISTILLATION PLANT ASSEMBLED LAYOUT**

See Appendix A document of the Distillation Plant installation procedure.

In Appendix A, some 3D renderings of the fully assembled Distillation plant layout have been inserted.
Figures A.1, A.2, A.3 and A.4 are different views of the plant layout.

13. PICTURES OF DISTILLATION PLANT INSTALLATION SEQUENCE

See Appendix B document of the Distillation Plant installation procedure.

In Appendix B is reported the sequence of images that show graphically the main steps of Distillation Plant installation procedure into the ground LS Hall.
The shown steps correspond to:

- B.1 Ground LS Hall – start of the sequence
- B.2 Positioning of pump skid into the well
- B.3 Positioning of skid 1
- B.4 Positioning of T-102 horizontal tank
- B.5 Positioning of skid 2
- B.6 Positioning of skid 3
- B.7 Positioning of skid 4
- B.8 Positioning of skid 6 (vertical position)
- B.9 Positioning of skid 5 and installation of line 163
- B.10 Positioning of T-101 vertical tank
- B.11 Installation of stairs and ground anchoring

APPENDIX D.

Stripping plant erection works description

INFN - Sezione di Milano

Polaris company srl

Project: C-367 – LAB stripping unit – INFN

Rev.5 18/10/2021

Stripping Plant

ERECTION WORKS DESCRIPTION

SUMMARY

1. REFERENCE DOCUMENTS

- Layout: C367-402 Rev.5 AS BUILT (Document #: JUNOEng-doc-13-v10, Stripping Plant Layout)
- P&ID: C367-102 Rev.12 (Document #: JUNOEng-doc-13-v10, P&Id)
- Lifting diagram: C367-422 (Document #: JUNOEng-doc-13-v10, Lifting Diagram)
- Civil Load Diagram: C367-412 Rev.1 (Document #: JUNOEng-doc-13-v10, Civil Load Diagram)
- Underground Hall Layout – Rev.14 (Document #: JUNOEng-doc-13-v10, Underground Hall Layout)
- Anchor Points Diagram – Rev.2 (Document #: JUNOEng-doc-13-v10, Anchor Points Diagram)
- Equipment list - Rev.5 (Document #: JUNOEng-doc-13-v10, Equipment List)
- Instruments list – Rev.3 (Document #: JUNOEng-doc-13-v10, Instrument List)
- Line list – Rev.1 (Document #: JUNOEng-doc-13-v10, Line List)
- Valve list – Rev.2 (Document #: JUNOEng-doc-13-v10, Valve List)
- TP information (Document #: JUNOEng-doc-13-v10, Battery limits and terminal points TP)
- Packing list (Document #: JUNOEng-doc-13-v10, Detailed packing list)
- Electrical panel diagram
- Appendix A of the Stripping Plant installation procedure
- Appendix B of the Stripping Plant installation procedure

2. REVISION HISTORY

Revision #	Date	Author(s)	Rationale	Sections Updated
0	12-02-2020	Eleonora Canesi (Polaris)	First Version	All
1	19-02-2020	Paolo Lombardi, Cecilia Landini and Michele Montuschi	General revision	All
2	11-05-2020	Cecilia Landini	Layout drawings update	7
3	20-06-2020	Cecilia Landini	Packing list updated (6 containers)	4
4.3	15-03-2021	Cecilia Landini and Michele Montuschi	Detailed installation procedure	All

5	18-10-2021	Cecilia Landini and Michele Montuschi	Tank erection with skates, cleaning procedure section, installation sequence	All

3. INTRODUCTION

The present specification describes the activities required for the erection of the LAB stripping unit to be installed at the JUNO underground laboratory (China). The specification includes several references to other engineering documents. All contractors involved for the required works are supposed to carry out a deep analysis of all documents and adequate site survey. All activities to be carried out at site shall be executed in compliance with any applicable local safety and quality standard as well as specific customer requirements.

Each unit is prefabricated and skid-mounted. The general arrangement of each unit is shown in the Layout drawing. All the main equipment, including piping, insulation, instrumentation, etc., are pre-installed on the skids, excluding the interconnecting piping lines already pre-fabricated and to be connected on site. Most of the instruments are pre-wired up to junction boxes provided on skids; the motors are not pre-wired, since a direct connection from the electrical panel is required. Some other materials, which are part of the supply, are delivered loose.

Please note that all the information regarding procedures and resources recommended for the works described in the present document are based on Polaris experience and expectations, but they shall be adequately checked and adapted to local requirements and safety procedures (LIM, LSO's), in collaboration and agreement with INFN representative.

Please note that some drawing and pictures in this document are for reference only, and do not represent the final assembly.

4. DESCRIPTION OF THE PLANT

The plant includes 1 stripping column C-201, with relevant accessories (heat exchangers, pumps, tanks, piping, instruments, etc.)

Please refer to P&ID and Equipment List for details.

The plant is almost completely prefabricated and delivered in form of skids. Each skid includes the relevant equipment, piping, insulation, instruments, etc. All instruments are pre-wired to junction boxes inside the skids.

From assembly point of view, the plant is composed of the following main parts (see **Figure 42**):

- N. 3 prefabricated skids: n. 1 and 2 are horizontal skids, n. 3 is vertical skid
- N. 1 stair
- N. 2 external tanks.

Interconnecting piping between skids and tanks, and other small parts, are delivered loose.

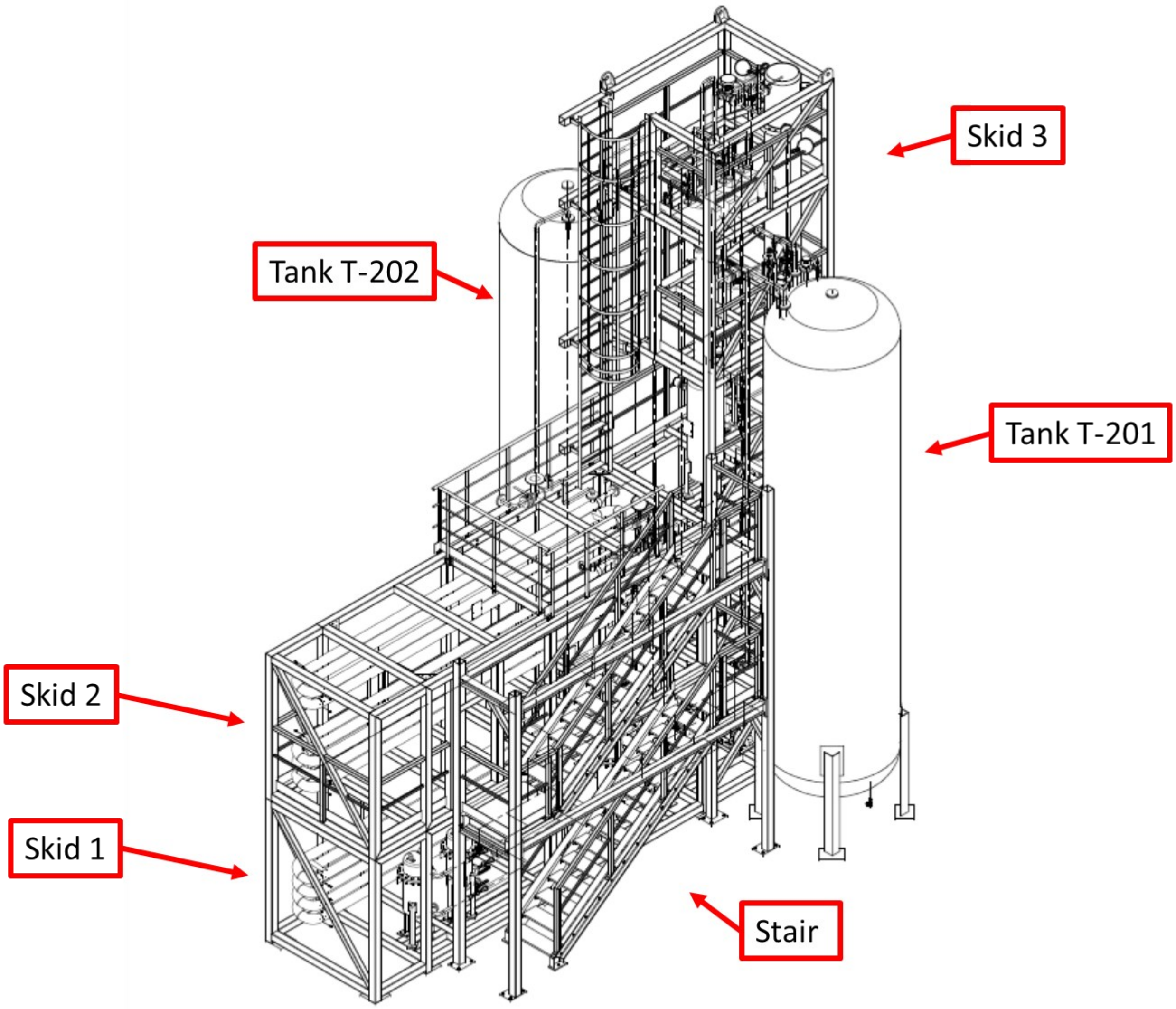


Figure 42: General layout of the Stripping plant

The plant was shipped from Genova port to Shekou port in 6 containers (40' HC), specifically:

Table 26: Containers dimensions and weight

STRIPPING CONTAINERS LIST

PACKAGE NO.	Container No./Seal No. Marks and Numbers	DESCRIPTION (GOODS)	DESCRIPTION (VEHICLE)	GROSS WEIGHT (GOODS) [kg]	APPROX. DIMENSIONS (GOODS) [m]			APPROX. DIMENSIONS (VEHICLE) [m]		
					LENGHT	WIDTH	HEIGHT	LENGHT	WIDTH	HEIGHT
1	BSIU9229844 2541433	stripping system in prefabricated skid (2), spool pipes and instruments, electrical cabinet, accessories	1 X 40' HC S.T.C.	5390	9	2,15	2,45	12,2	2,44	2,9
2	CAIU4452485 2541435	Tank T-202, PC and accessories	1 X 40' HC S.T.C.	5375	6,6 + 4	2,15	2,45	12,2	2,44	2,9
3	HDMU6835077 2541485	Tank T-201	1 X 40' HC S.T.C.	5000	9	2,15	2,45	12,2	2,44	2,9
4	HDMU6836319 2541317	Stairs, spool pipes and accessories	1 X 40' HC S.T.C.	2235	8,8	2,15	2,4	12,2	2,44	2,9
5	KOCU4368759 1779587	stripping system in prefabricated skid (1)	1 X 40' HC S.T.C.	5900	8,8	2,15	2,4	12,2	2,44	2,9
6	TCNU5603147 2541413	stripping system in prefabricated skid (3)	1 X 40' HC S.T.C.	7000	8,8	2,15	2,4	12,2	2,44	2,9

A detailed list of the partition of smaller parts into the packages can be found in the packing list document.

The plant will be afterwards transported and delivered to JUNO site by flat racks or containers.

5. ERECTION SCOPE OF WORK

The required scope of supply for the erection of the system only includes the following:

- Manpower
- Tools
- Lifting devices

Based on Polaris and INFN experience with similar projects, it is expected that the erection of main equipment (chapters 7, 8) should be completed in approximately 5-6 days, excluding the first phase of unloading of containers (chapter 6) and transport of the items down to the underground laboratory.

Please, note that the present document deals with the whole erection, mounting and installation procedure for Stripping purification plant, but its transportation from over ground to underground and from the underground arrival of the slope tunnel to the LS (Liquid Scintillator) Hall will be borne by the Chinese group.

During all erection activities, both Polaris and INFN operator are strongly recommended to be on site.

Due to Covid-19 pandemic, travelling from and to foreign countries will not be allowed until global Covid-19 situation will be under control. To avoid a complete stop of the installation operations in the underground laboratory both for Stripping plant and for all the other plants to be installed after it, some activities (chapters 7 and 8) could be done in advance by an external installation company. Following the instructions of this manual, the aim is at least to complete the plant positioning into the underground laboratory and stack the skids as in the final plant layout, in order to leave space in the hall and allow the other systems to start their installation procedure.
In this case, at least one INFN manager must be remotely connected to follow, manage and guide the Stripping plant positioning operations.
Skids interconnections, piping and instrument mounting, mechanical and electrical works (chapter 9 and 10) will be later realized and finalized by INFN and Polaris personnel as soon as they can go to JUNO site.

So, to summarize, the whole installation procedure could be divided in 3 different phases:

4) **Phase 1:**
it includes the transportation of plant components to JUNO site and to the underground laboratory, the erection of all the main plant components and finally the ground anchoring with chemical bolts (chapters 7 and 8). These operations will be done by an external installation company, with the supervision of 1 or 2 INFN managers onsite (possibly) and the rest of INFN personnel remotely connected.

5) **Phase 2:**
It includes the following operations: interconnecting pipelines mounting and coupling, installation of instruments and sensors, cleaning of flange surfaces and flange sealing, leak test, installation of the electric cabinet, electric connections, cabling of pumps, instruments and other devices (chapters 9 and 10).
To perform these operations, it is recommended for INFN personnel to be present onsite (accordingly to Covid-19 situation).

6) **Phase 3:**
It includes the first start-up and the early commissioning of the plant.
During this phase, INFN personnel must be present onsite.

6. UNLOADING, HANDLING AND STORAGE OPERATIONS

6.1. Handling

Both skids and tanks must be handled with care and protected from accidental bumps and damages, otherwise fragile components could break. Special yellow slides have been mounted on skids and tanks to facilitate loading, unloading and handling operations.

It is important to remember that skids must always be kept in horizontal position. Do not rotate nor pile up in random order.

The Lifting Diagram document shows graphically how to handle and lift the equipment.

Please, handle all the equipment carefully during any operation, especially during loading and unloading from containers or any other transport device (rail wagon of the slope tunnel, …).

6.2. Storage conditions

Before installation into the underground laboratory, any possible long-term or short-term storage of plant equipment should comply with the following requirements:

- The storage hall must have a roof cover against rain
- No air conditioning is required
- In case the hall is open to air and dust (from open walls), a plastic protection foil is suggested to be placed over and around skids/tanks
- The storage hall should have a flat floor with a lower load capability of 1000 kg/m^2
- The storage hall should be high enough to move skids/tank inside in horizontal position with proper crane truck or forklift
- Skids/tanks must be protected from damages, occasional bumps and hits

Long-term storage could be done in the SAB Hall (Surface Assembly Building) or similar.

6.3. Unloading and temporary storage

The unloading operations of skids and tanks require one crane and one forklift, and a lifting beam (or slings). The crane capacity shall be selected by the contractor based on weights and position. The lifting beam or slings are required in order to avoid the risk of damaging the skid during the erection with lifting chains.

The procedure for unloading and temporary storage the skid shall be defined on site, depending on the space and size of cranes available; anyway, an example is shown graphically in the lifting diagram and in the description below:

1) Connect the forklift to the bottom of the skid (access side) and pull the skid out from the container (see **Figure 43** and **Figure 44**).

Figure 43: Connection of the forklift to the skid

Figure 44: Extraction of the skid

2) Keep the access side slightly suspended and slide the opposite side on the container floor (special yellow slides have been provided by Polaris to facilitate loading and unloading, see **Figure 45**).

Figure 45: Temporary yellow slides, provided on skid and tanks.
They shall be removed before positioning operations into the laboratory hall.

3) When the equipment is almost completely pulled out from the container (while the forklift is keeping the external part supported), join the crane to the top of the skid to hold the equipment and complete the unloading.

4) When the skid is completely out from the container, it can be laid down on the ground and the crane and the forklift can be disconnected.

The prefabricated skids, the tanks and the other ancillary items must be pulled out from the containers as soon as the trucks arrive, since each container will remain on its truck and leave with it.

All the items must be kept in an environment protected from water and occasional bumps, during the phases of unloading, transport, storage, as well as in the waiting times between subsequent activities.

7. TRANSPORT AND POSITIONING INTO THE UNDERGROUND LABORATORY

The expected time required for plant transportation to JUNO site and to the underground laboratory is foreseen to be approximately 3 working days. The availability of the cable train of the slope tunnel should be checked and booked in advance before to start the operations.

For the transport of the skids in horizontal position, triangular plates with holes have been provided on the groundside of the skids (see **Figure 46**): they allow to securely fix the skid to the transportation cable train of the slope tunnel.

Figure 46: Triangular plates for the skid fixing

In underground, skids will be handled by means of the 10-ton uniaxial double hook crane inside the LS hall. Several anchor points have been designed and placed in the stripping area to allow the right positioning of the skids and tanks by means of temporary lifting devices (chain winches or similar). It is important to notice that a mobile lifting platform or some other dedicated tool will be required to reach and connect the temporary lifting devices to the anchor points on the hall ceiling.

If available, a forklift and other useful tools can be used to facilitate handling and positioning operations.

Temporary supports for skids and tanks are painted in yellow for easier recognition (**Figure 45**). These supports must be removed before positioning and erection activities start. They can be afterwards disposed.

In the following, the positioning sequence will be shown.
The anchor points scheme and the stripping plant layout and precise position into the LS hall should be carefully examined from the corresponding documents.

Moreover, before to start the positioning sequence, it is important to draw on the hall ground floor the shape of edges and corners of skid 1, so to have a reference for the theorical final position of the assembled plant into the hall. Distances from walls and from OSIRIS shall be checked from the LS hall layout drawings.

This operation could help the initial positioning of the elements of the plant; then, the precise alignment of each component shall be carefully done using dedicated tools (alignment pins, spacers, bubble level, …), as described in chapter 8.

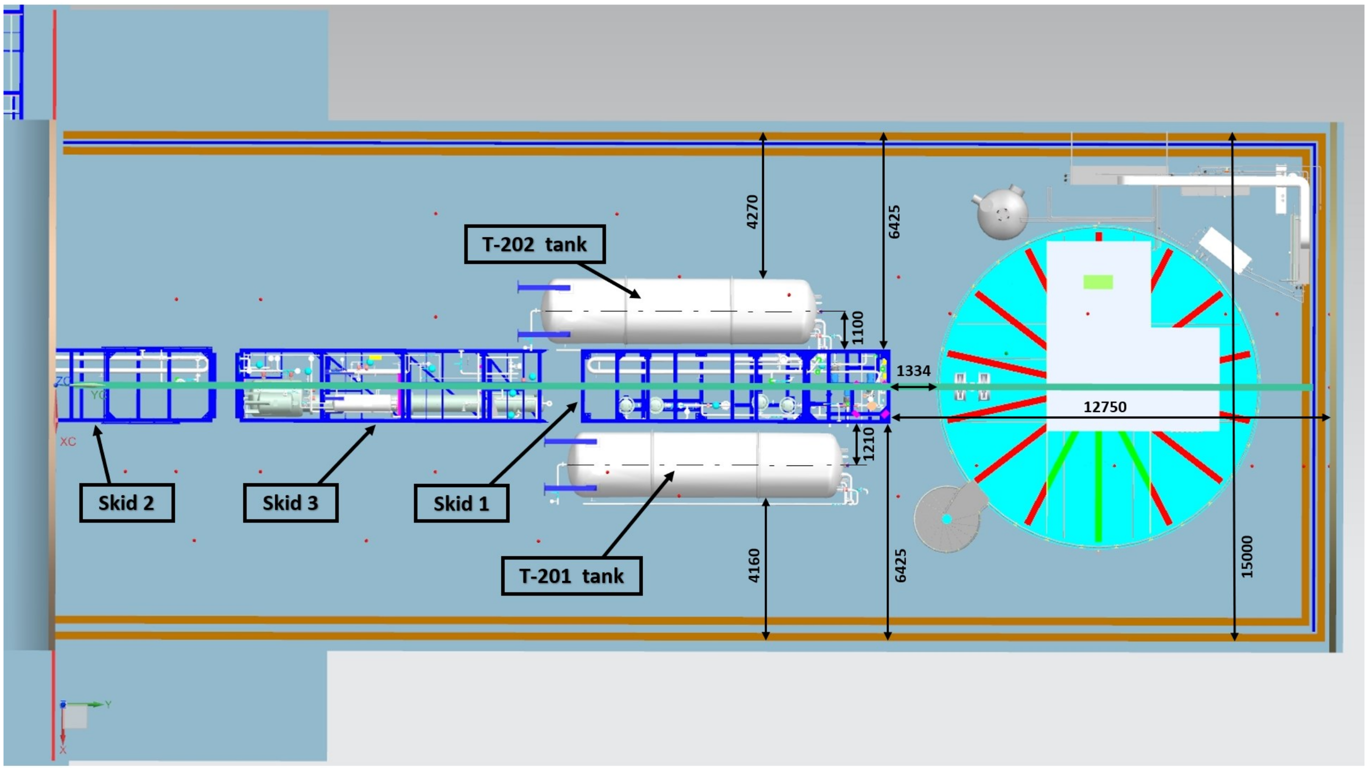


Figure 47: Skid and tank positioning before erection

To prepare the subsequent activity of plant erection, the items should be positioned into the LS hall in the following order and position (see **Figure 47**):

1) **Skid 1, to be positioned in its foreseen final position.**
The distances from walls and from OSIRIS can be carefully checked from the 'Underground Hall Layout' drawings, while the skid orientation into the hall can be understood from the plant layout drawings. The skid must be oriented so that the short-side with the three pumps (P-201, P-202 and P-203; see **Figure 48**) faces OSIRIS plant.
Please, remove the yellow-coloured slides, if present, before positioning the skid.

Figure 48: Skid 1 (left) and location of P-201, P-202, P-203 pumps (right) on skid 1

2) **Tanks T-201 and T-202, in horizontal position, near skid 1.**

They will be erected vertically and positioned alongside the skids.

After swapping OSIRIS and stripping plant positions, no more anchor points could be realized on the roof of the LS Hall, so we do not have any anchor points on the vertical axis of the installation position of the tanks to erect them vertically. They will be erected vertically using either one of the older anchor points (already installed before the decision of swapping; check the 'Anchor points diagram' document) or using the overhead crane of the hall; then each tank could be moved to its installation position with some sliding blocks or skates positioned under the tank legs. (Another alternative solution could be to transport to underground a small truck crane that could be moved independently inside the LS hall and could be used to erect vertically and place the two tanks. The tanks are 9 m tall, so the truck crane should be properly chosen).

Figure 49: Tanks T-201 (left) and T-202 (right)

3) **Skid 3**, in horizontal position, in a row behind skid 1.
It will be erected and stacked vertically on skid 1.
Skid 3 must be oriented with the top of the stripping column (C-201) facing skid 1.

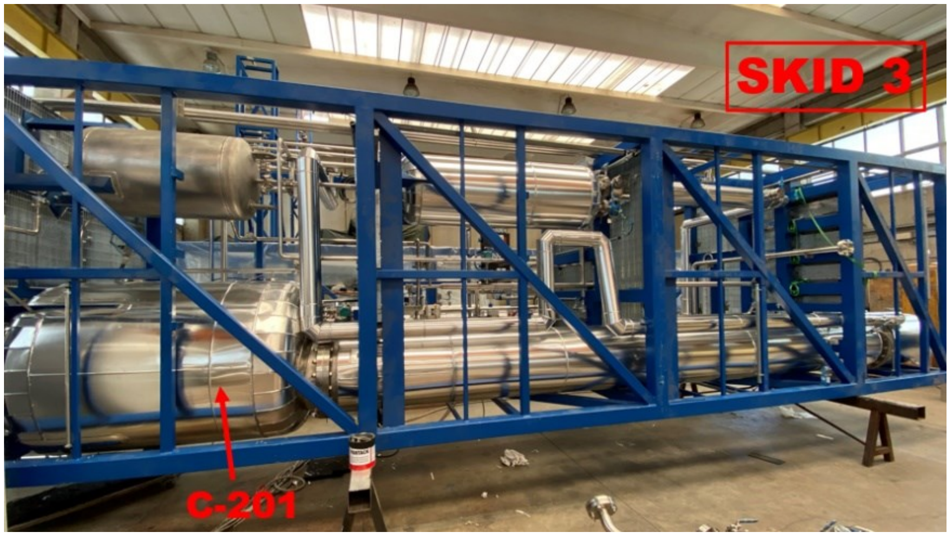


Figure 50: Location of C-201 stripping column inside the Skid 3

4) **Skid 2**, in horizontal position, in a row behind skids 1 and 3.
This is the last skid to be positioned and it will be stacked horizontally on skid 1.
Skid 2 must be oriented so that its E-201 and E-202 heat exchangers will be aligned above E-204 heat exchanger of skid 1.

Figure 51: Location of E-201 and E-202 heat exchangers inside the Skid 2

When all skids and tanks are ready, placed in position, the installation procedure can continue with erection and mounting operations in the next chapter.

8. ERECTION ACTIVITIES

Erection sequence has been supposed based on the available information related to the anchor points and lifting tools present in the underground laboratories, specifically:

- INFN drawing "Stripping layout anchor points – Rev.2" dated 2020-12-17
- Capacity of each anchor point: 7.000 kg
- Capacity of the overhead crane: 10.000 kg each hook, n. 2 hooks.

The procedure can be further optimized on site, depending on available space and tools.

During skids and tanks erection operations, it is advisable to use a lifting spreader beam if available, in order to avoid the risk of any damages during the erection with lifting chains.

In the following sections, it will be provided a general introductory description of the erection sequence and subsequently a detailed description for each step.

8.1. Erection sequence: introduction and general description

The optimal sequence considered by Polaris company and agreed with INFN is the following:

Foreseen on first day:

1. Positioning of skid 1
2. Installation of vertical ladder on skid 3

Foreseen on second day:

3. Erection of skid 3 and positioning of skid 3 on skid 1

Foreseen on third day:

4. Positioning of skid 2 on skid 1
5. Erection of T-201 tank

Foreseen on fourth day:

6. Erection of T-202 tank
7. Stair: delivered disassembled, to be mounted on site and installed alongside skid 1

Foreseen on fifth/sixth days:

8. Ground anchoring of skid 1, stairs, T-201 and T-202 tanks.

It must be carefully taken into account that, before placing two skids side by side, it is necessary to remove protective blind flanges from the flanges of the interconnecting pipes (see **Figure 52**). Please note that this operation cannot be done once the skids are aligned, because there would not be enough space and/or pipes would not be enough flexible.

Figure 52: Interconnecting pipe sealed with a protective blind flange

When removing a protective blind flange, the flange that has been opened must be immediately sealed with a clean plastic sheet to prevent dust from entering and dirtying the plant. In fact, all the internal surfaces of the plant have undergone a complete cleaning process, as required from the cleanliness standards for JUNO experiment.
Moreover, these uncovered flanges must be carefully protected from hits and bumps that could occur when approaching and positioning two skid side by side. Even slight scratches, engravings or dents on the flange surface could compromise the leak tightness of the flange.
To protect a flange from both dust and surface damages, one of these two solutions should be adopted:

- A clean plastic sheet and one dedicated cap to close the flange.
  Some yellow caps of different dimensions (see **Figure 53**) have been inserted into the shipping packages (but not enough to close all interconnection flanges of all skids).

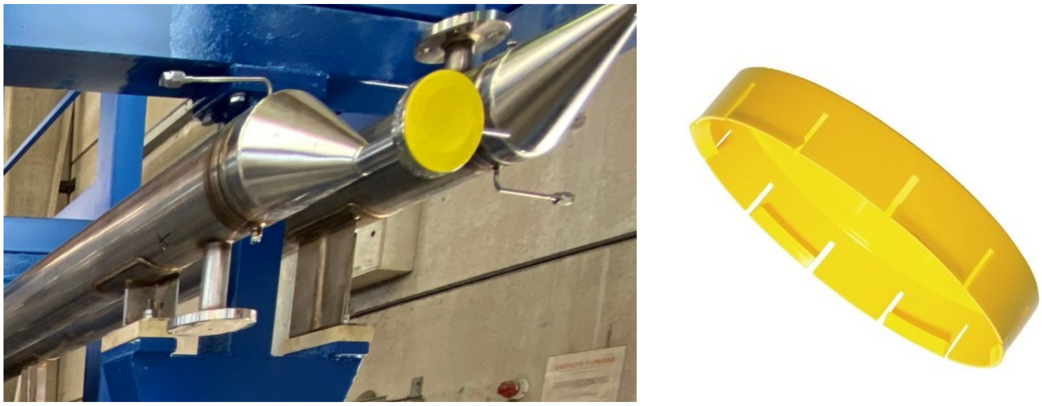


Figure 53: Plastic cap to be used for protecting the connections after the removal of the blind flanges

- A clean plastic sheet and a cardboard sheet (or similar, to protect the flange surface).

Please, remember to protect immediately and accurately each flange as soon as it is opened.

During erection activities, the structures shall be aligned using a bubble level (to "centre the bubble") and if necessary adequate shims shall be used. All skids shall be aligned and installed so that the internal piping connections will fit. Once positioned the first skid, the alignment of the subsequent skids shall be verified so that the connection flanges match.

After erection of vertical items, it will be necessary to unfix the crane from the lifting lugs at an elevation of max 12 m. For this activity, an independent access system (e.g. a mobile platform) shall be provided (see drawing 5 of the Lifting Diagram document).

The following pictures (**Figure 54**) represent an example of sequence of erection of a skid.
Please note the use of: lifting spreader beam, shackles (both top and bottom, see **Figure 54** panel 8).

Figure 54: Skids erection sequence

8.2. Detailed description of erection sequence

In the next sections, the erection sequence will be described in detail, step by step. It is important to follow the sequence in the correct order.

Some long interconnecting piping have been inserted into the main skids for transport: before to start the erection activities, remove all these pieces from skids and store them with all the other stuff of the stripping plant. For a detailed list of the items present on each truck, please refer to the packing list compiled during trucks loading.

8.2.1. Positioning of skid 1

Skid 1 must be placed in its final installation position using the overhead crane and/or a forklift. Use the lines drawn on the floor (see section 7) to guide the positioning of skid 1, then check carefully the distances from OSIRIS and walls as in LS hall layout drawings.

8.2.2. Installation of vertical ladder on skid 3

Before the erection of skid 3, it is advisable to install on it the external ladder, which is transported loose. A picture is reported below (**Figure 55**); for details about the assembly of the ladder please refer to layout drawings.

Bolts, nuts and washers are supplied by Polaris.

Figure 55: Position of the vertical ladder on skid 3

8.2.3. Erection and positioning of skid 3

Before positioning skid 3 on skid 1, protective blind flanges must be removed from the interconnecting pipes between skids 1 and 3 and between skids 3 and 2.

Interconnecting flanges between skids 1 and 3

The list of interconnecting pipes, where blind flanges have to be removed, is reported in table 2. The pipes have been identified with the corresponding line number indicated on the P&Id. Please, refer to the P&Id, line list and layout drawings for details.

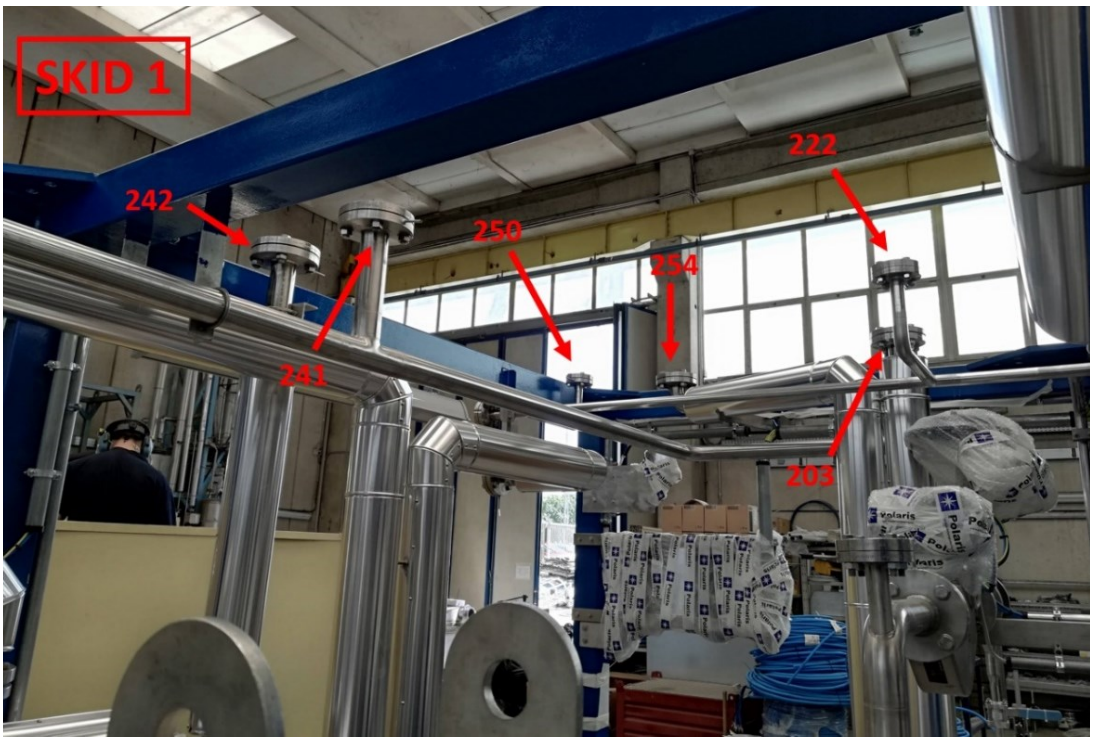


Figure 56: Blind flanges of skid 1 to be removed before the installation of skid 3 on skid 1. Leave the connection 241 and 242 with blind flanges on.

Figure 57: Blind flanges of skid 3 to be removed before the installation of skid 3 on skid 1.

Table 27: Skid 1 and skid 3 interconnection pipes list

SKID 1 & SKID 3: INTERCONNECTION PIPES LIST		
Line number	**DN**	**Operations**
Line 203	50	Remove the pipe stub
Line 222	25	Remove blind flanges both on skid 1 and skid 3
Line 250	25	Remove blind flanges both on skid 1 and skid 3
Line 254	50	Remove blind flanges both on skid 1 and skid 3
Lines 241, 242	50	Will be mounted later

For each line, remove the corresponding blind flange both on side of skid 1 and on side of skid 3, so that the two bare sides of the interconnecting pipe will face when the two skids will be in the final position.

For easier recognition, the pictures show the position of all the lines of interest. When removing a protective blind flange, please remember to immediately protect the flange that has been opened, as described in section 8.1.

The pipe stub of line 203 on skid 3 must be removed before skid erection (see **Figure 57**). For this purpose, two blind flanges and two clean Teflon gaskets are required (some spare blind flanges and Teflon gaskets have been supplied by Polaris). Unscrew the pipe stub from the bottom of the stripping column, remove it and seal both the pipe stub and the column bottom flange using the two gaskets and blind flanges. Label the pipe stub for easier recognition and store it with all the other stuff of the stripping plant.

Do not remove blind flanges from lines 241 and 242 of skid 1. The corresponding lines on skid 3 were dismounted before shipping and they will be mounted later in the procedure, so it is not necessary to remove their protective flanges on skid 1 now.

Since some of these blind flanges has been opened on this side of skid 3 (that is shown in **Figure 57** and corresponds to its bottom side), please remember to DO NOT lay skid 3 on the ground in vertical position when it will be erected vertically during the next steps of the procedure, otherwise the surfaces of the opened flanges could be damaged.

Interconnecting flanges between skids 2 and 3

The same procedure has to be done for interconnecting pipes between skids 2 and 3.

The list of interconnecting pipes, where blind flanges have to be removed, is reported in table 3. As explained before, the pipes have been identified with the corresponding line number indicated on the P&Id. Please, refer to the P&Id, line list and layout drawings for details.
For easier recognition, the pictures below (**Figure 58** and **Figure 59**) show the position of all the lines of interest.

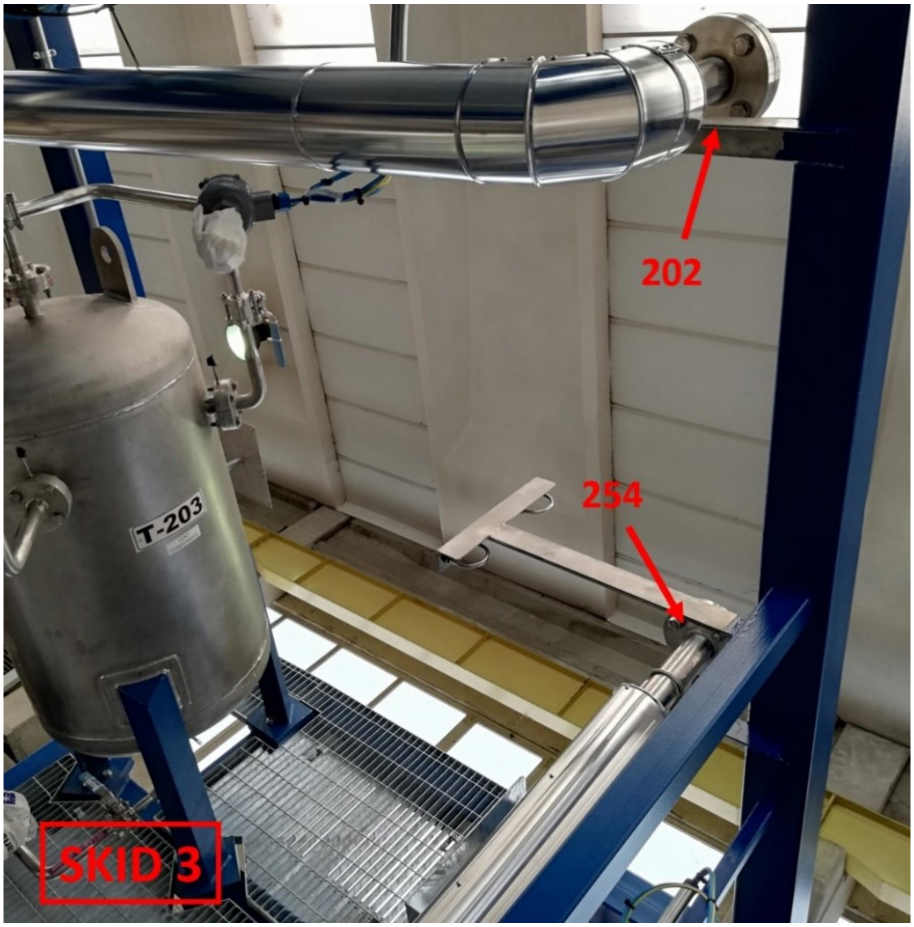


Figure 58: Blind flanges of skid 3 to be removed before the installation of skid 3 on skid 1

Figure 59: Blind flanges of skid 2 to be removed before the installation of skid 3 on skid 1. Leave the connection 241 and 242 with blind flanges on.

Table 28: Skid 2 and skid 3 interconnection pipes list

SKID 2 & SKID 3: INTERCONNECTION PIPES LIST		
Line number	**DN**	**Operations**
Line 202	50	Remove blind flanges both on skid 2 and skid 3
Line 254	50	Remove blind flanges both on skid 2 and skid 3
Lines 241, 242	50	Will be mounted later

For lines 202 and 254, remove the corresponding blind flange both on side of skid 2 and on side of skid 3, so that the two bare sides of the interconnecting pipe will face when the two skids will be in the final position.
When removing a protective blind flange, please remember to immediately protect the flange that has been opened, as described in section 8.1.

Do not remove blind flanges from lines 241 and 242 of skid 2. The corresponding lines on skid 3 were dismounted before shipping and they will be mounted later in the procedure, so it is not necessary to remove their protective flanges on skid 2 at the moment.

Now, operations for erection of skid 3 and positioning of skid 3 on skid 1 can start. For this purpose, the overhead crane is required. It is advisable to use lifting beams, if available, in order to avoid the risk of damaging the skid during the erection with the lifting chains. The picture below (**Figure 60**) shows graphically how to hook and handle the skid. For more details, see the Lifting Diagram document.

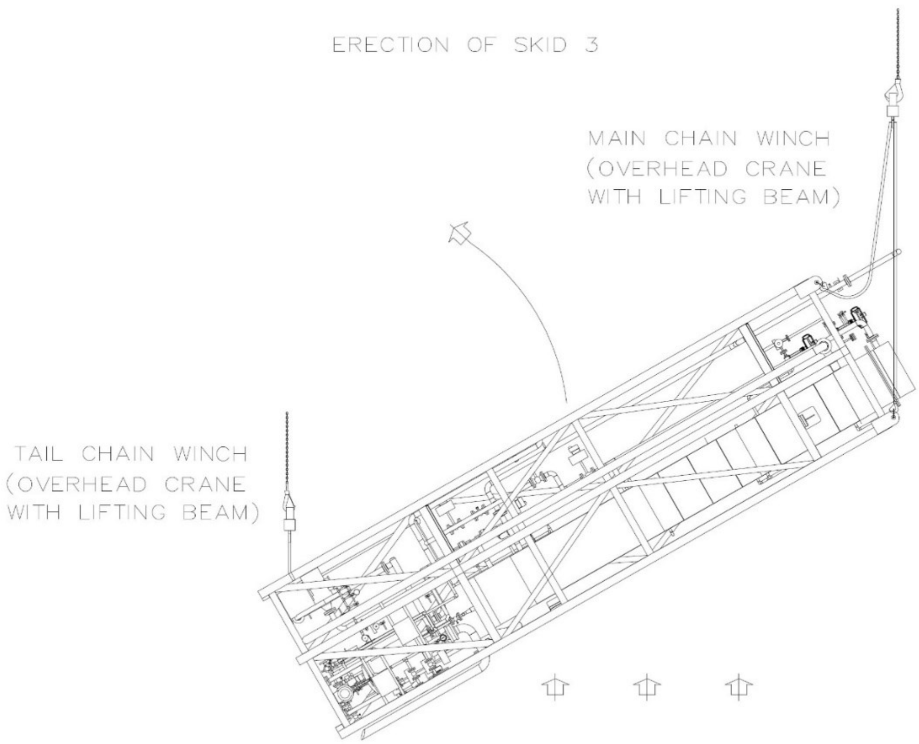


Figure 60: Erection scheme of skid 3

Connect the first chain winch of the crane to the four lifting lugs on the top of skid 3 with a lifting beam (or slings, if the former is not available).
Connect the other chain winch of the crane to the base of skid 3 with slings or a lifting beam.
Lift horizontally the skid with both chain winches at the same time. Move forward the skid till the installation position upon skid 1.
Using only the first chain winch, lift the top of skid 3 to erect it vertically. Please, be very careful during this operation: do not lay down nor accidentally slide skid 3 in vertical position on its bottom side, otherwise the opened flanges of the interconnecting pipelines could be damaged.
While skid 3 is kept suspended in vertical position, do not rotate it: the skid orientation should already be the correct one. Anyway, check it carefully from Stripping plant layout drawings.
Move down slowly the skid. Adjust the position and align precisely skid 3 on skid 1. The centering operation could be aided by means of some alignment pins, like threaded rods to be inserted from

above into the holes of the triangular plates of skid 3, that shall be coupled to the corresponding holed triangular plates of skid 1. Align skid 3 on skid 1 so that the pins can be inserted also into skid 1 plates and can guide the skids alignment until they are joined.
When approaching skid 3 to skid 1, please be very careful and move slowly to avoid hits, bumps and any damages to the skids and their interconnection flanges. Operators should keep monitoring closely each interconnection flange during this phase to check that no strains, misalignments or even breaks could occur.
Then, gently lay down skid 3 on skid 1 in its final position (see Stripping Plant layout document).

Remove the alignment pins from the holed plates and fixed together skids 1 and 3 with bolts, nuts and washers, which are supplied loose by Polaris.

When erection is completed, unfix the crane from the lifting lugs and from the base of skid 3 using a mobile platform or similar.

8.2.4. Positioning of skid 2

Before positioning skid 2 on skid 1, protective blind flanges must be removed from the interconnecting pipes between skids 1 and 2, as done also for skid 3 in the previous section.

There is only one interconnecting pipe where blind flanges have to be removed and is reported in table 4. Please, refer to the P&Id, line list and layout drawings for details.

Table 29: Skid 1 and skid 2 interconnection pipe list

SKID 1 & SKID 2: INTERCONNECTION PIPES LIST		
Line number	**DN**	**Operations**
Line 246	50	Remove blind flanges both on skid 1 and skid 2

Figure 61: Blind flanges to be removed before the installation of skid 2 on skid 1

Figure 62: Blind flanges to be removed before the installation of skid 2 on skid 1

For line 246, remove the corresponding blind flange both on side of skid 1 and on side of skid 2 (see **Figure 61** and **Figure 62**), so that the two bare sides of the interconnecting pipe will face when the two skids will be in the final position.
When removing a protective blind flange, please remember to immediately protect the flange that has been opened, as described in section 8.1.

Now, operations for positioning skid 2 on skid 1 can start.
For this purpose, the overhead crane is required. It is advisable to use lifting beams, if available, in order to avoid the risk of damaging the skid during handling with the lifting chains. The picture below (**Figure 63**) shows graphically how to hook and handle the skid. For more details, see the Lifting Diagram document.

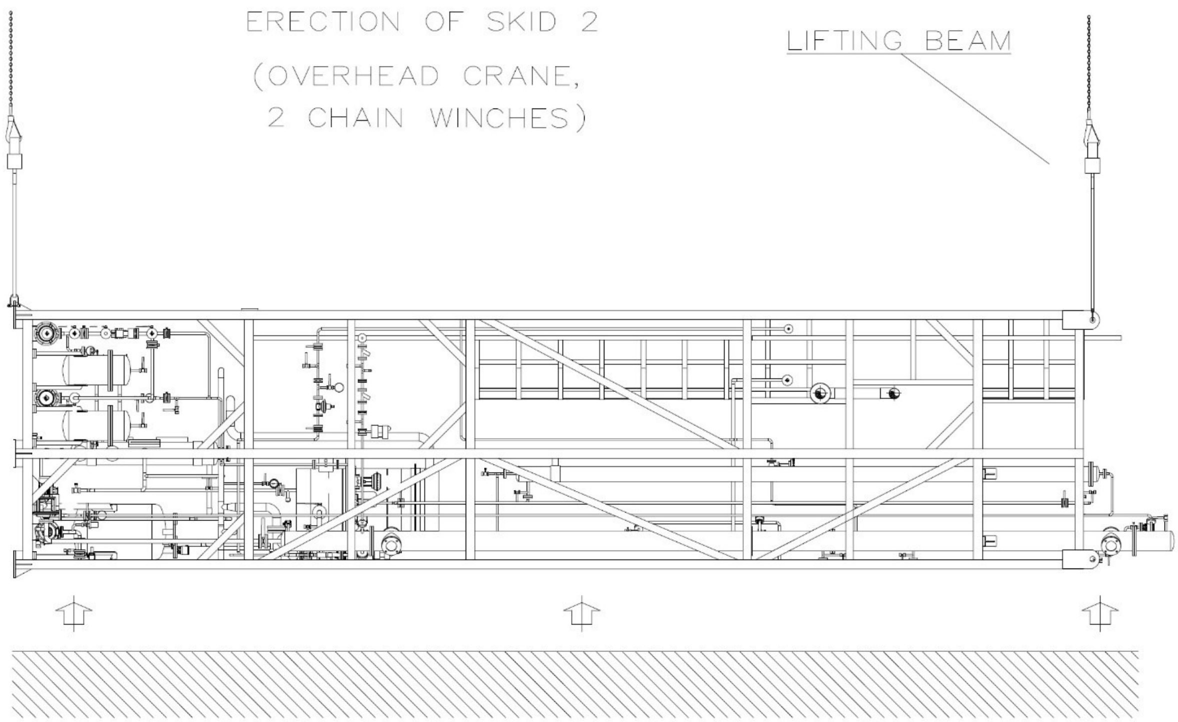


Figure 63: Erection scheme of skid 2

Connect the two chain winches of the crane to the two end sides of skid 2 with lifting beams (or slings, if the former are not available).
Lift horizontally the skid and move forward the skid till the installation position upon skid 1.
Move down slowly the skid. Adjust the position and align precisely skid 2 with both skid 1 and skid 3. As done before in section 8.2.3, the centering operation could be aided by means of some alignment pins to be inserted into the holed triangular plates of the skids to be coupled. Since the pin centering cannot be done simultaneously both for skid 1 and 3, center and align skid 2 on skid 1 first. Skid 3 will be verified later.
On skid 2, insert from above the alignment pins into the holes of the triangular plates. Align skid 2 on skid 1 so that the pins can be inserted also into skid 1 plates and can guide the skids alignment until they are joined.
When approaching skid 2 to skids 1 and 3, please be very careful and move slowly to avoid hits, bumps and any damages to the skids and their interconnection flanges. Operators should keep monitoring closely each interconnection flange (line 246 for skids 1 and 2, lines 202 and 254 for skids 2 and 3) during this phase to check that no strains, misalignments or even breaks could occur.
While the skids are only a few millimetres apart, insert the alignment pins also for skid 2 and 3 coupling.
Then, gently lay down skid 2 on skid 1 in its final position (see Stripping Plant layout document).

Remove the alignment pins from the holed plates and fixed together skids 2 and 3 and skids 2 and 1 with bolts, nuts and washers, which are supplied loose by Polaris.

When erection is completed, unfix the crane from the two sides of skid 2 using a mobile platform, a scaffold or a ladder.

8.2.5. Erection of T-201 tank

As said before, no anchor points on the vertical axis of the installation position of the tanks are available because of swapping. To solve this problem, the installation of T-201 an T-202 tanks will be done using the same procedure foreseen from FINE company for erecting its 30 m^3 tanks.

Depending on the available space and tools onsite, the tanks should be erected vertically using either one of the “old” anchor points (already installed before the decision of swapping; check ‘Anchor points diagram’ document) or using the overhead crane of the hall.

In **Figure 64**, a portion of the Anchor point diagram has been reported to show the position of all the existing anchor points installed on the LS Hall ceiling. If you decide to use anchor points for tanks erection, probably anchors labelled as ‘15’ or ‘18’ in **Figure 64** could be used for T-201 tank, while ‘16’ or ‘17’ for T-202 tank.
In this case, it will be necessary to temporary connect chain winches to these anchor points.

The alternative option is to use the LS Hall overhead crane to lift and erect vertically the two tanks.

In both cases, the tanks need to be moved afterwards to their final installation position by means of some sliding blocks or skates positioned under the tank legs.

(Another alternative solution could be to transport to underground a small truck crane that could be moved independently inside the LS hall and could be used to erect vertically and place the two tanks in their installation position. The tanks are 9 m tall, so the truck crane should be properly chosen).

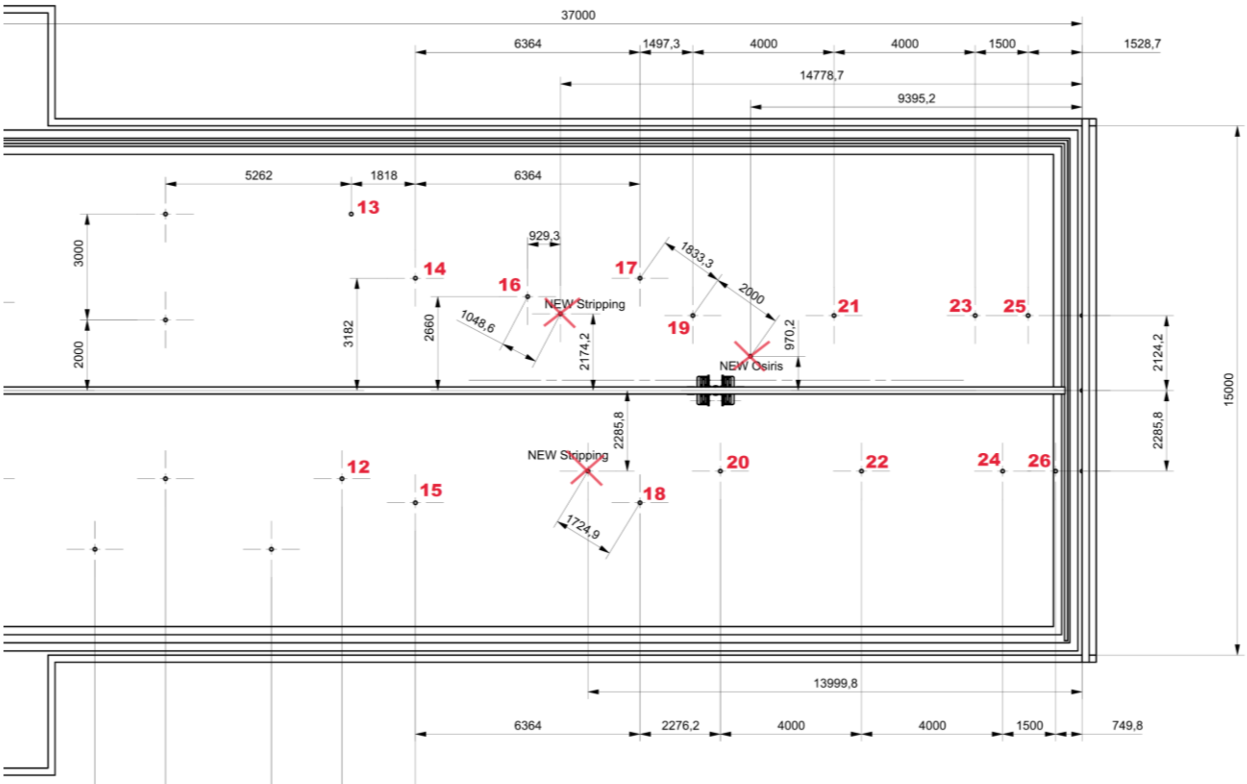


Figure 64: Anchor point diagram of the Underground LS Hall

Before to start, note that T-201 tank must be insulated, as described in detail in section 9.2. Insulation can be done either before or after tank erection, as preferred.

The picture below (**Figure 65**) shows graphically how to hook and handle the tank.

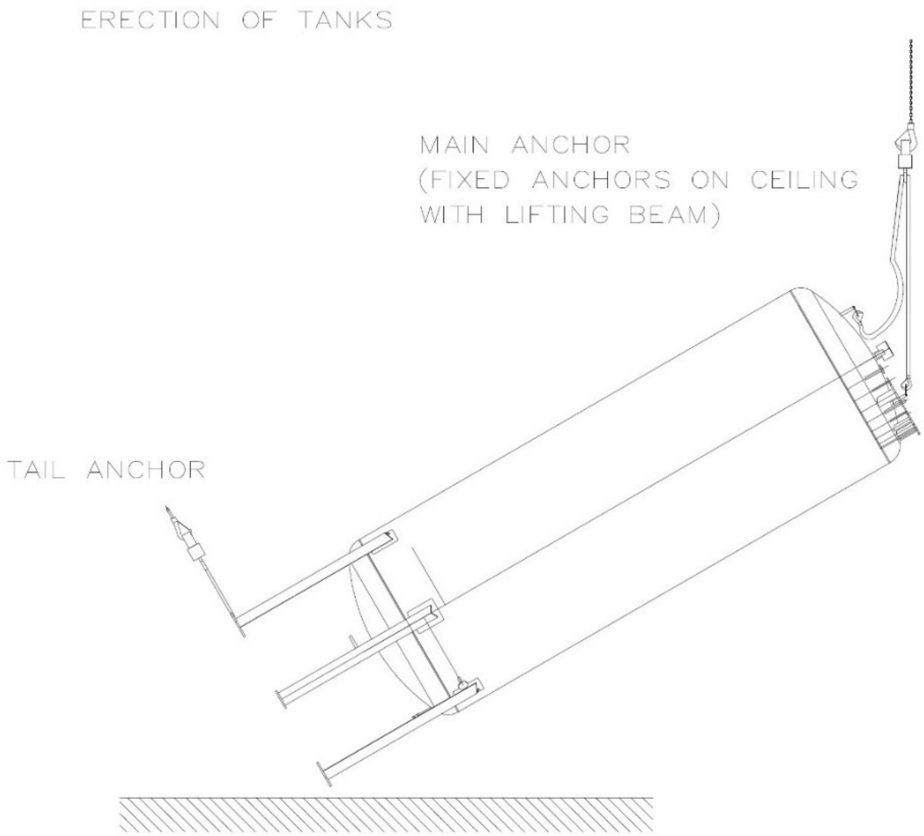


Figure 65: T-201 and T-202 erection scheme

For T-201, connect either the overhead crane hook or the chain winch of the anchor point (depending on the chosen solution) to the four lifting lugs positioned on tank dome. Connect the tank legs to other hook of the crane or a second anchor point to keep suspended the bottom side of the tank. It is advisable to use lifting beams, if available.

Lift the tank from both sides at the same time.
While keeping the bottom side suspended, lift the top side of the tank to erect it vertically. Position the sliding blocks (an example is shown in **Figure 66**) under the tank legs, as indicated into the FINE company procedure (see **Figure 67**). Then, move down slowly the tank and place it on the blocks. Finally disconnect the lifting lugs and the tank legs from the hooks.

Figure 66: example of sliding blocks or skates to move tanks

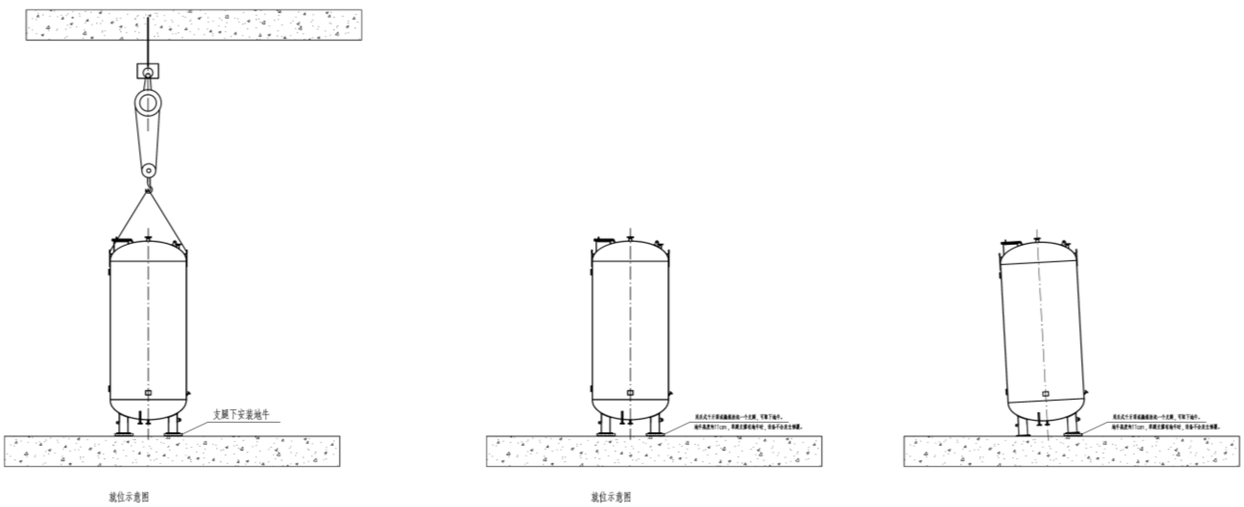


Figure 67: FINE company erection and installation procedure for vertical tanks (without anchor points)

The tank is now ready to be moved to its final installation position. Check it from the LS hall 2D layout before to start this operation.

Pulling slowly and carefully the sliding block, move the tank to its installation position. During this operation, the tank can also be somehow bound or fastened on the top to prevent it from falling.

Once in place, carefully check the position of the tank with respect to the skids before removing the sliding blocks. Correct alignment and accurate positioning are the major issues for tank erection. Once it will be fixed to the ground, it would be impossible to change and correct its position if inaccurate; so, please, check carefully both the orientation of nozzles on tank dome and the legs accurate positioning before fixing to ground as described in section 8.2.8.

First of all, verify that T-201 is oriented exactly as shown in **Figure 68**: check the position of the nozzles on tank dome with respect to the skids position. The side of the tank where nozzles are installed must face the skid. The angular position of each nozzle flange has been specified for better understanding.

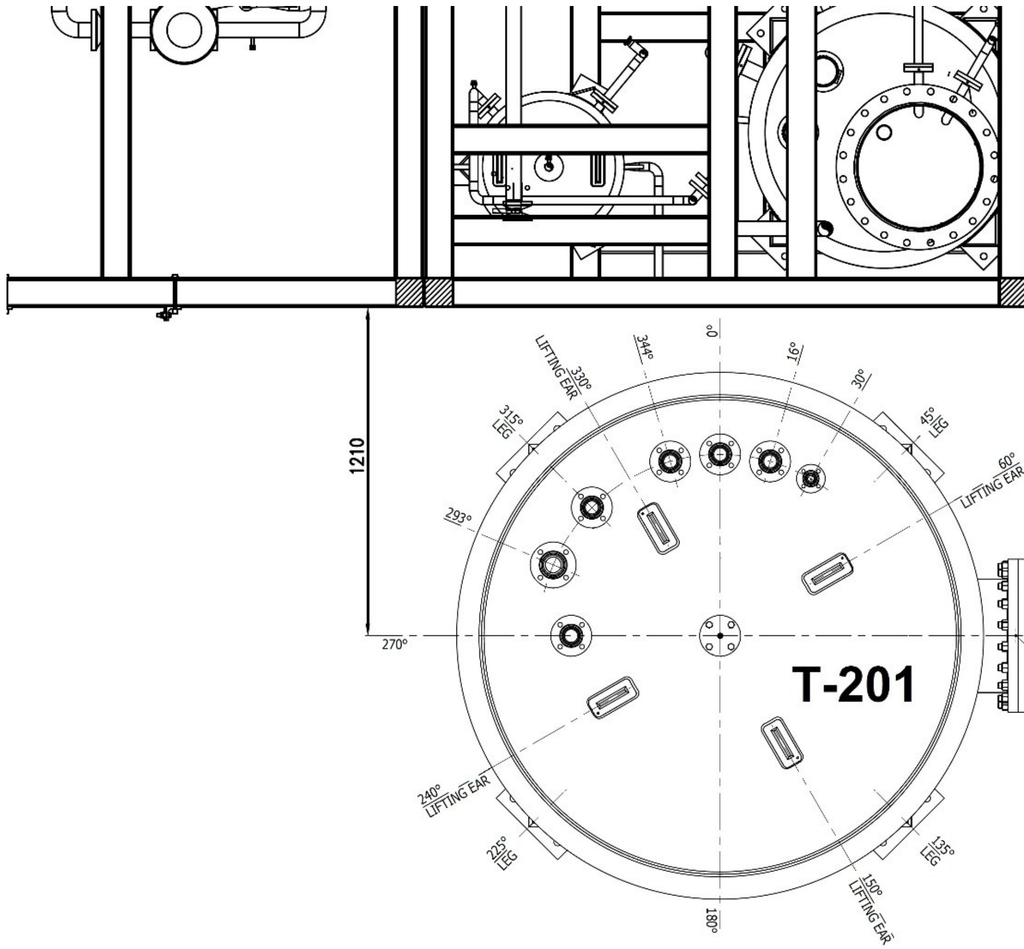


Figure 68: Relative position between T-201 and the skids

Secondly, the positioning of tank legs must be done very precisely. For this purpose, two dedicated metallic templates have been provided from Polaris as spacers to help find the correct position of T-201.

The following pictures (**Figure 69**) show the plant pre-assembling test carried out at Polaris company. The metallic spacers have been painted in yellow for easier recognition.

Figure 69: Metal templates (in yellow) for the correct positioning of T-201.

T-201 must be positioned so that the metallic templates fit perfectly on the tank legs, as shown in the pictures. Please, note that the templates are custom made for each tank (T-201 and T-202), so be sure to do not swap them and use the correct ones.

As further check that T-201 has been correctly and precisely positioned with respect to the skids, it is possible to verify that line 239 fits to the interconnecting flanges of T-201 and skid 3.

Line 239 was shipped dismounted and sealed with protective blind flanges. Take the pipeline and lift it over the top of T-201, in its installation configuration (see **Figure 70**).
Remove the four blind flanges from the interconnecting flanges of line 239. Please, handle the pipeline carefully to avoid scratches or any damage to the internal surface of the flanges.
Place the pipeline side by side to its corresponding pipes on T-201 and skid 3. Check that the positioning of T-201 is precise enough so that the interconnecting flanges fit each other and can be correctly matched and mounted later in the installation procedure. Then, remove the pipeline and immediately reseal all the interconnecting flanges.
Note that for these operations a lifting platform (or scaffold) is required to reach the upper side of the tank. Alternatively, one operator, tied up with safety harness, can climb directly onto the top of the tank.

If the alignment is not correct and flanges do not match, T-201 positioning operations must be repeated until the final correct position is obtained (both the interconnection flanges matching and the tank leg alignment with metallic spacers).

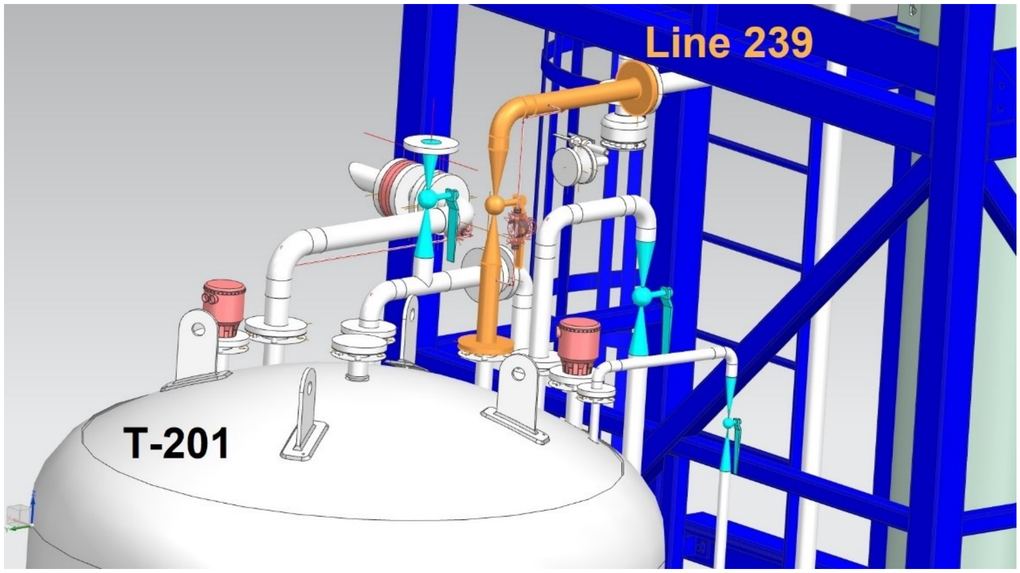


Figure 70: Correct position of line 239 between T-201 and the skids

Finally, when, T-201 tank has been correctly positioned, remove the sliding blocks under tank legs.

8.2.6. Erection of T-202 tank

The erection sequence of T-202 tank is similar to the one described for T-201 in the previous section (8.2.5).

For this purpose, the overhead crane or the anchor points labelled as '16' or '17' (see **Figure 64**) could be used for T-202 tank. In the latter case, it will be necessary to temporary connect chain winches to them.

Anyway, in both cases, the tanks need to be afterwards moved to their final installation position by means of some sliding blocks or skates positioned under the tank legs.

Connect either the overhead crane hook or the chain winch of the anchor point (depending on the chosen solution) to the four lifting lugs positioned on tank dome. Connect the tank legs to other hook of the crane or a second anchor point to keep suspended the bottom side of the tank. It is advisable to use lifting beams, if available.

As done before for T-201, lift the tank from both sides at the same time. While keeping the bottom side suspended, lift the top side of the tank to erect it vertically. Position the sliding blocks under the tank legs, as indicated into the FINE company procedure. Then, move down slowly the tank and place it on the blocks. Finally disconnect the lifting lugs and the tank legs from the hooks.

The tank is now ready to be moved to its final installation position. Check it from the LS hall 2D layout before to start this operation.

Pulling slowly and carefully the sliding block, move the tank to its installation position. During this operation, the tank can also be somehow bound or fastened on the top to prevent it from falling.

Once in place, carefully check the position of the tank with respect to the skids, before removing the sliding blocks.

Both the orientation of nozzles on tank dome and the legs accurate positioning must be checked carefully.

First of all, verify that T-202 is oriented exactly as shown in the picture below (**Figure 71**): check the position of the nozzles on tank dome with respect to the skids position. The side of the tank where nozzles are installed must face the skid. The angular position of each nozzle flange has been specified for better understanding.

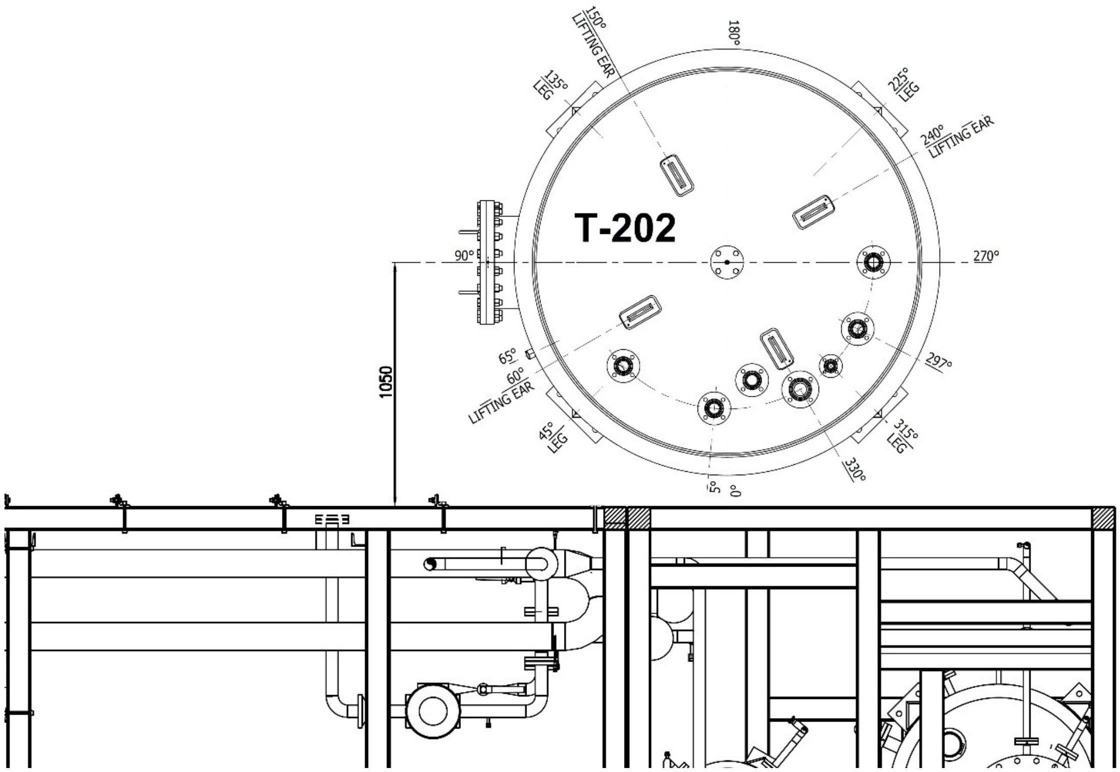


Figure 71: Relative position between T-202 and the skids

Secondly, the positioning of tank legs must be done very precisely. For this purpose, two dedicated metallic templates have been provided from Polaris.
T-202 must be positioned so that the metallic templates fit perfectly on the tank legs, as done also for T-201. Please, note that the templates are custom made for each tank, so be sure to do not swap them and use the correct ones.

As further check that T-202 has been precisely positioned with respect to the skids, it is possible to verify that line 255 fits to the interconnecting flanges of T-202 and skid 3.

Line 255 was shipped dismounted and sealed with protective blind flanges. Take the pipeline and lift it over the top of T-202, in its installation configuration (see **Figure 72**).
Remove the four blind flanges from the interconnecting flanges of line 255. Please, handle the pipeline carefully to avoid scratches or any damage to the internal surface of the flanges.
Place the pipeline side by side to its corresponding pipes on T-202 and skid 3. Check that the positioning of T-202 is precise enough so that the interconnecting flanges fit each other and can be correctly matched and mounted later in the installation procedure. Then, remove the pipeline and immediately reseal all the interconnecting flanges.

Note that for these operations a lifting platform (or scaffold) is required to reach the upper side of the tank. Alternatively, one operator, tied up with safety harness, can climb directly onto the top of the tank.

If the alignment is not correct and flanges do not match, T-202 positioning operations must be repeated until the final correct position is obtained (both the interconnection flanges matching and the tank leg alignment with metallic spacers).

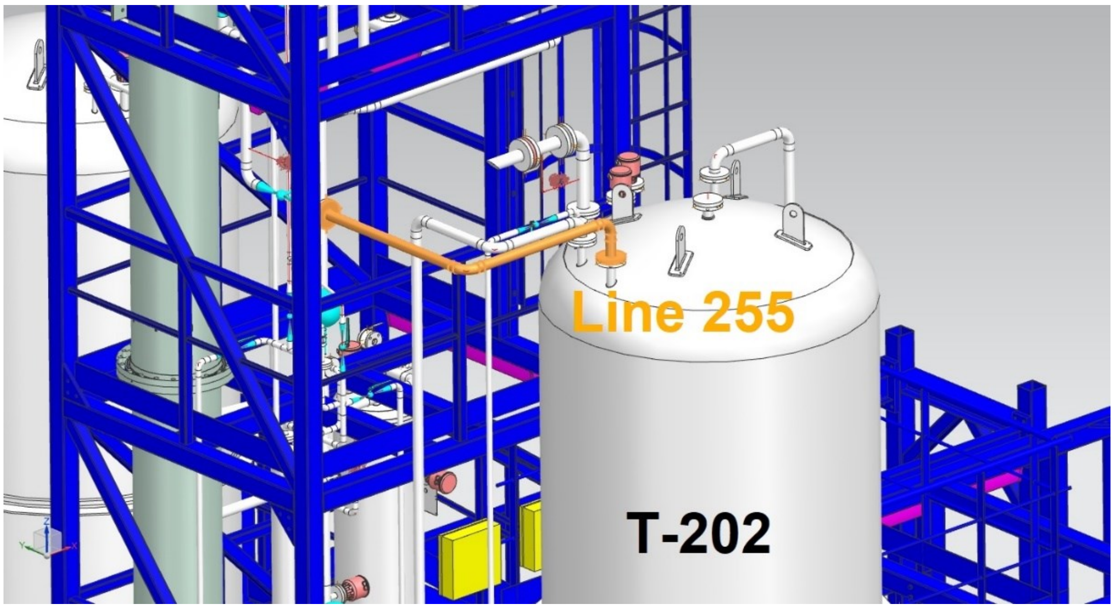


Figure 72: Correct position of line 239 between T-202 and the skids

Finally, when T-201 tank has been correctly positioned, remove the sliding blocks under tank legs.

8.2.7. Stair

The stair was delivered disassembled (see **Figure 73**). It shall be mounted on site, installed alongside skid 1 and fixed to it.

For details about the assembly and the installation position, please refer to layout drawings.

Bolts, nuts and washers are supplied by Polaris.

Figure 73: Picture of the stair to be mounted alongside skid 1

8.2.8. Fixing and ground anchoring

Once the erection operations for both skids and tanks have been completed and all the main parts of the stripping plant have been positioned, they must be fixed together and anchored to ground for safety reasons.

Check that all skids and stairs are firmly fixed together with bolts.

Then, proceed with the ground anchoring of the plant.
Skid 1, the stairs and the two tanks shall be fixed to ground with chemical anchors, in accordance with the 'Civil Load Diagram' document.
All the tools and items required for ground anchoring ('Hilti' hammer drill, bits of different length and diameter for the hammer drill, 'Hilti' chemical bolts, …) have been supplied by INFN. See the packing list for more details.

Drill the concrete floor with ‘Hilti’ hammer drilling machine in correspondence of the holes of each plate of skid 1, stairs and tanks.
During drilling operations, it’s important to use a dust extractor/aspirator to remove all the drilling powder and prevent it from spreading into the environment and/or entering the plant.
After drilling, place the chemical anchors, let them dry for at least one night and finally seal the anchors with bolts.

9. OTHER MECHANICAL WORKS

When the plant positioning and the main erection activities have been completed, it is possible to finalize the plant installation and connect the Stripping plant with the other plants and auxiliary systems in the LS Hall, as described in the following sections. All the subsequent operations will be done in a second step, when both INFN and Polaris operators will be present onsite.

9.1. Piping and instrument mounting

Some piping, instruments, valves and accessories (see packing list for details) are transported separately and shall be mounted directly at site after skids and tanks erection. For this purpose, at least a couple of people from INFN should be present onsite to manage and guide the operations.

All materials required for connections and assembling are provided by Polaris.

Bolts, nuts and washers shall be used for flanges sealing.
Viton o-rings have been chosen as flange gaskets. The 2 o-ring shall be cleaned and positioned into the flange caves before flanges coupling. For this purpose, o-rings can be temporary held in place inside caves with thin metal “clips”. Once flanges are coupled and o-rings cannot move, remove the clips.
The correct sequence for flanges sealing is the following: remove the blind flanges or protective sheets, clean accurately the flange surfaces, place the o-ring gaskets with clips (if needed), join and align the two connecting flanges, remove the clips (if any) and finally tighten the two coupled flanges with bolts.

Valves

Some small fragile valves (less than 1/2’’ in diameter) or check valves to be connected to piping shipped loose shall be mounted onsite.
These valves are listed below:

- check valves: V-219, V-229, V-313, V-318, V-320
- small valves: V-314, V-319, V-321

Please refer to the P&Id and valve list document for details.

Piping (to be erected and mounted)

The interconnecting piping both between two adjacent skids and between skids and tanks shall be erected and mounted.
On each pipeline it is reported the line number for easier recognition. It is anyway recommended to refer to the P&Id, line list document and layout drawings for details.
The lines that must be erected and mounted onsite are:

- on T-201 tank: lines 226, 227, 239, 248, 253, 265
- on T-202 tank: lines 205, 216, 229, 255, 258, 264
- between skid 1 and 3: lines 203, 241, 242
- on C-201 stripping column: line 266
- on VP-201 vacuum pumps: line 267
- on E-202 heat exchanger: line 232 (hot oil line)

Moreover, check carefully line 234 for chilled water, that it is installed on E-204 heat exchanger, because it may have disassembled during plant shipping.

Note that, for pipes and instruments to be installed on the top of the tanks, a lifting platform and/or safety harnesses for operators are required.

Piping (only mounting)

Some piping were installed in their final position in the skids and sealed with protective blind flanges before shipping; the protective flanges of these lines were removed during erection activities described in sections 8.2.3 and 8.2.4, before positioning the skids side by side.
Now, the interconnecting flanges of these pipes have only to be coupled and sealed (no erection nor insertion into skids is required).
These lines are listed below:

- between skids 1 and 2: line 246
- between skids 1 and 3: lines 203, 222, 250, 254
- between skids 2 and 3: lines 202, 254

Note that, for these lines, it may be necessary to temporary loosen or remove the pipe support brackets, to manage to clean the flanges surfaces and insert the o-rings. When flange sealing is completed, please tighten the pipe brackets.

Instruments

All the instruments on the top of the two tanks and some other instruments to be installed on piping shipped loose shall be mounted onsite.
These instruments are listed below:

- on T-201 tank: PT-229, LT-223, PSE-230

- on T-202 tank: PT-222, LT-231, PSE-221
- on C-201 stripping column: TE-208, PSE-217
- on E-202 heat exchanger: TE-251

PT are pressure gauges with transmitters, LT are radar level meters with transmitters, TE are temperature elements and PSE are safety rupture disks. For more details, see the P&Id and instrument list document. Please, consult the instruction manual of each instrument before to start the installation.
Note that all these instruments must also be electrically cabled to the junction boxes (see chapter 10).

9.2. Plant insulation

The plant is supplied with both hot and chilled fluids, so thermal insulation is required.

Some parts of the plant have already been insulated by Polaris, while other parts will be insulated onsite by the Chinese LS group, during plant installation.

E-201 heat exchanger will be used to heat up the liquid scintillator of Water Extraction (W.E.) plant, which is located just before the Stripping plant along the LS purification sequence adopted for JUNO. After the water extraction process, hot LS will be sent directly to the Stripping plant, so the entire pipeline from W.E. plant to Stripping plant and the first part of the Stripping plant (the whole path from LS inlet nozzle to E-201 heat exchanger; see **Figure 74**) need to be insulated. For this purpose, the thermal insulation of these parts shall be supplied and done by the Chinese group of the W.E plant.

In **Figure 74**, the first part of the Stripping plant P&Id is reported: the internal path from LS inlet nozzle to E-201 heat exchanger, which shall be insulated, has been highlighted in orange.

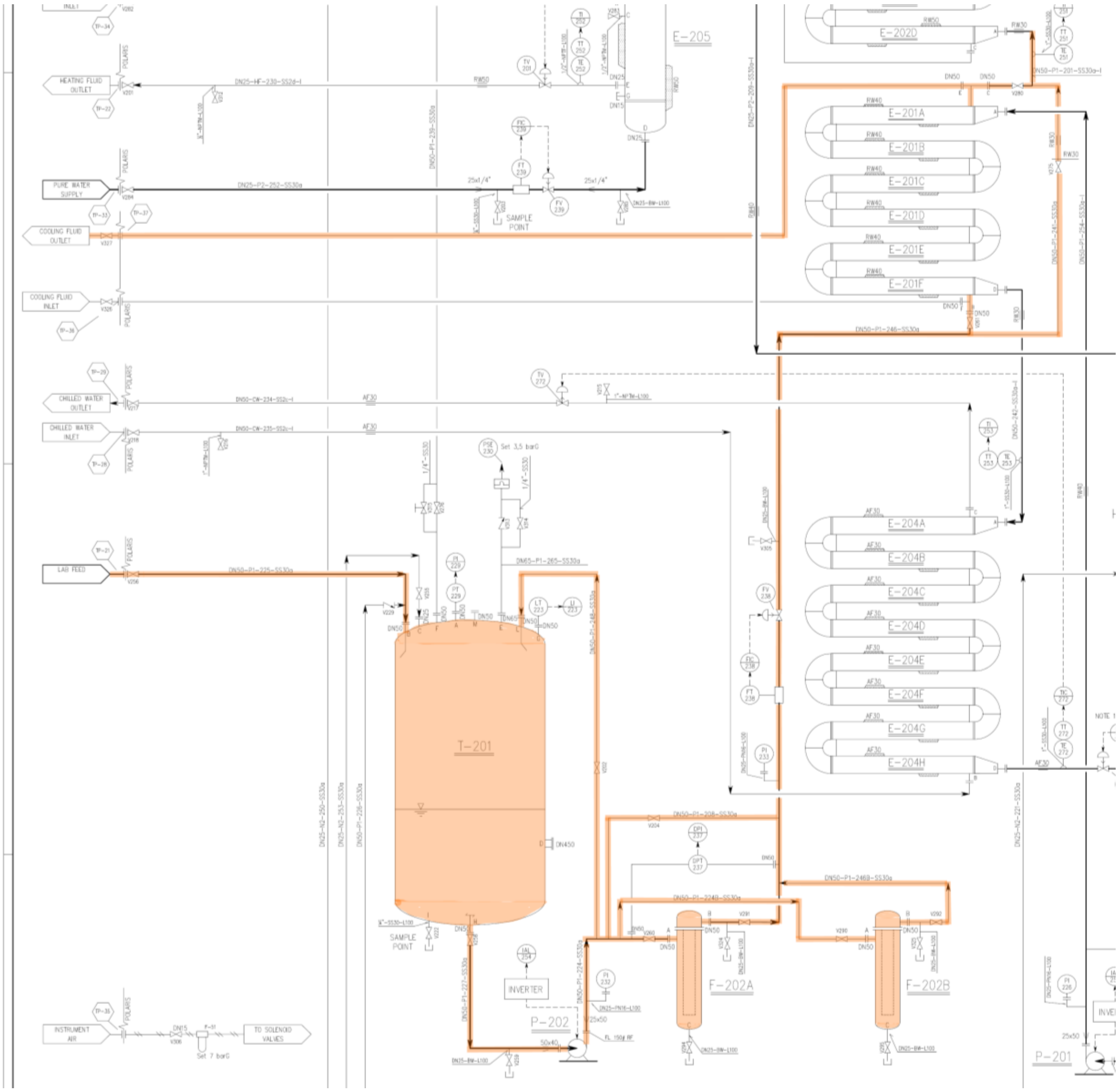


Figure 74: Components (highlighted in orange) of the Stripping plant
to be thermally insulated by the Chinese group of Water Extraction plant

As you can see from **Figure 74**, also the whole T-201 tank must be insulated. This operation can be done either before or after tank erection, as preferred. For convenience, maybe the former option is easier to be realised, because the tank should be more accessible while laying horizontally on the ground and no lifting platform nor dedicated tools should be required.

The same goes also for the interconnecting pipelines to be mounted on the top of the tank (lines 225 and 248): it should be better to insulate them before their erection and mounting.

All the other lines and the two filters (F-202-A/B) should be instead insulated after that all the installation operations have been completed.

Rock wool is recommended as insulating material for hot lines, as in this case. The thickness of the thermal insulation has been already calculated and for each component shall be 30 mm.
After the insulating layer, each part must be wrapped and covered with a protective foil of aluminium, as shown in **Figure 75** and **Figure 76**.

Figure 75: Tank insulation with Rockwool and a protective layer of aluminium.
On left, some details of the aluminium protective layer properly shaped to fit the tank dome.

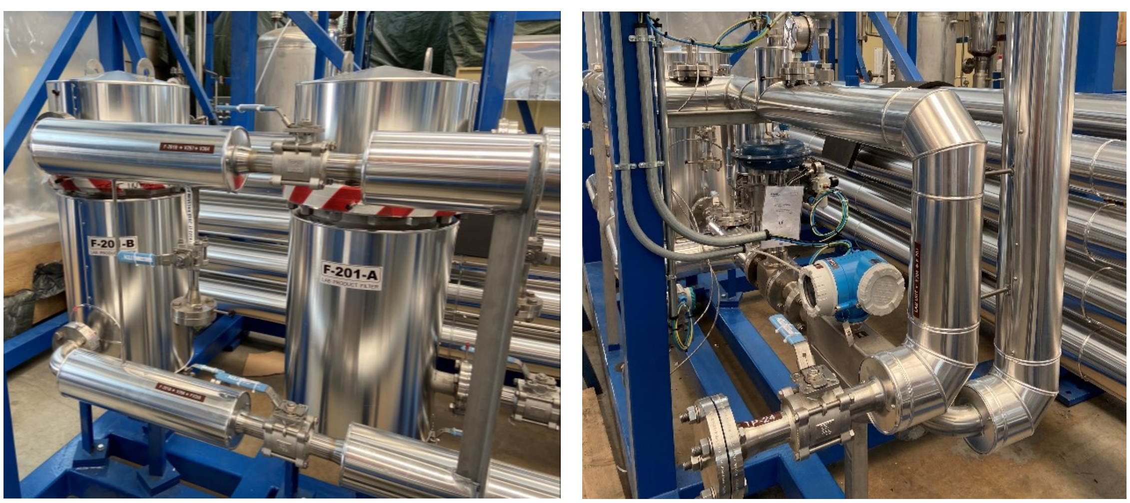


Figure 76: Some details of the thermal insulation for filters (left picture) and pipelines (right).

9.3. Other minor works

Some additional works will be required, such as:

- Handrails and grating floors mounting and fixing on skids

- Removal of some temporary supports provided for transportation (for equipment, piping and instrumentation)
- Paint touching up where the paint is damaged during erection
- Erection/removal of blind flanges, caps, etc.

Temporary supports are painted in yellow for easier recognition and removal. These supports can be afterwards disposed.

Do not remove caps from the terminal points until the erection works end, to avoid possible dirty in the piping.

9.4. Connection of the Terminal Points

During plant operation, the Stripping plant will be supplied by other plants and auxiliary systems, so connections from the terminal points (TP) of the Stripping plant to the other systems of the LS Hall are required.

Stripping plant shall be connected both to auxiliary supply systems (hot oil, chilled water, high pure and ultra-pure water, high pure nitrogen, compressed air, power supply…) and to other plants for purification and handling of JUNO liquid scintillator (Water Extraction plant, OSIRIS, FOC system, …).

In table 5, all the Stripping plant terminal points are listed and for each one the corresponding plant to be connected is specified. The position of each TP can be checked on plant layout drawings.
For more details, see the 'TP information' document for Stripping plant and the 'Underground LS hall man pipeline design' from FINE company.

Table 30: List of all the TP (Terminal Points) and their dimension and gasket type

TP–No.	FLUID TYPE	PLANT IN/OUT	SIZE	GASKET
TP-21	LAB	Inlet	DN50	Double Viton O-ring
TP-22	Heating	Outlet	DN25	Spirotallic gasket
TP-23	Nitrogen	Inlet	DN25	Double Viton O-ring
TP-24	LAB	Outlet	DN50	Double Viton O-ring
TP-25	Cooling	Outlet	DN25	Spirotallic gasket
TP-26	Cooling	Inlet	DN25	Spirotallic gasket
TP-27	Waste	Outlet	DN25	Double Viton O-ring
TP-28	Cooling	Inlet	DN50	Spirotallic gasket
TP-29	Cooling	Outlet	DN50	Spirotallic gasket
TP-31	Heating	Inlet	DN50	Spirotallic gasket
TP-32	Heating	Outlet	DN50	Spirotallic gasket
TP-33	UP water	Inlet	DN25	Double Viton O-ring
TP-34	Heating	Inlet	DN25	Spirotallic gasket
TP-35	Air	Inlet	1/2"	Teflon tape
TP-36	LAB	Inlet	DN50	Double Viton O-ring
TP-37	LAB	Outlet	DN50	Double Viton O-ring

TP–No.	FLUID TYPE	PLANT IN/OUT	SIZE	GASKET
TP-38	Exhaust gas	Outlet	DN50	Teflon (?)

10. ELECTRICAL WORKS

The following activities are required:

- Electric control cabinet installation
- Power connection to power distribution and control cabinet
- HMI workstation installation and Ethernet cable connection between workstation and control panel
- Earthing of the structure
- General instrument air supply.

After the above-mentioned electrical activities, the following connections will be carried out, with cables supplied by Polaris:

– Electrical power connections between the control panel and motors (pumps)

– Cables connections between the control panel and the instruments junction boxes on the skids, with multicore cables

– Connection of instruments disconnected for transportation (for these instruments the connecting cables to the junction boxes are hung to the skid)

– Connection of lights to junction boxes

Please note that some of the electrical/instrumentation activities can be done in parallel to the mechanical activities.

11. CLEANING PROCEDURES & BACKGROUND CONTROL STRATEGIES

Background control is one of the main issues to reach JUNO detection goals. For the Italian purification plants, dedicated operations and strategies have been adopted to remove and control the exposure of all internal surfaces to radioactive contaminants. In the following, all the precautions taken both during construction and installation phases will be listed.

V. **During construction phase**

Just after the construction, each part and component of the plant has undergone a dedicated and accurate cleaning procedure carried out by Bama Company. The cleaning sequence is the following: mechanical polishing, local picking of the welding, degreasing, electropolishing, mild passivation (with solution: 25% nitric acid - 75% demineralized water), rinsing with deionized water, air drying with filtered compressed air. Particle counting tests of the rinsing water were performed to assess the cleanliness level achieved.
Ultrasonic bath cleaning with Alconox or Micro-90 detergent was adopted for small components and items.

VI. **During installation phase at JUNO site (phase 1 of installation)**

During skids and tanks positioning into the underground LS hall (phase 1 of installation done by an external installation company), interconnecting flanges must be opened and protected with a clean plastic sheet (to prevent dust and radioactive contaminants to enter the plant and dirtying the internal surfaces) and a cardboard sheet (to protect the flange surface from hits and scratches).
The removal of the blind flanges and the protection with plastic and cardboard sheets is mandatory and should be done just before the coupling of two skids together since there is not space enough to leave the blind flanges in place. It's important for the operators to wear clean gloves during this operation. Just in case, clean the flange surface and O-ring caves with a clean wipe and isopropyl alcohol before to seal the flange with the clean plastic sheet.
It's important to protect and seal the flange as soon as the protective blind flange is removed to minimize the exposure time to any external contaminant source.

VII. **During mounting phase at JUNO site (phase 2 of installation)**

After positioning skids and tanks, interconnecting pipelines and instruments should be mounted to complete the installation of the plant and seal it. During this phase, protective plastic bags should be removed (if any) and each interconnecting flange must be accurately cleaned with clean wipes and isopropyl alcohol. Also O-ring caves of the flange and O-rings gaskets to be inserted must be properly cleaned. It's important for the operators to wear clean gloves during cleaning operations.
After flange sealing is completed, the flange tightness level must be checked with leak test. If JUNO requirements are not satisfied, cleaning and sealing operations must be repeated.

VIII. **During early commissioning phase (phase 3 of installation)**

Before to start the joint commissioning with other JUNO plants, an internal commissioning phase with UP water and LAB is foreseen to rinse the plant and further clean internal surfaces.

a. **Commissioning with UPW:**

circulation with ultra-pure water firstly in internal loop mode and secondly in discharge mode; then, drain of the plant and particle counting to certify the cleanliness level

b. **Change filters:**

Removal of filter cartridges used for water loop (500 nm) and insertion of final filter cartridges (50 nm)

c. **Commissioning with LAB:**
circulation with LAB firstly in internal loop mode and secondly in discharge mode.
LAB samples will be tested to check LAB properties and contamination (measurements of attenuation length, absorption spectra,…)

12. STRIPPING PLANT ASSEMBLED LAYOUT

See Appendix A document of the Stripping Plant installation procedure.

In Appendix A, some 3D renderings of the fully assembled Stripping plant layout have been inserted. Figures A.1, A.2 and A.3 are different views of the plant layout: isometric view, front view and side view respectively.

13. STRIPPING PLANT INSTALLATION SEQUENCE

See Appendix B document of the Stripping Plant installation procedure.

In Appendix B is reported the sequence of images that show graphically the main steps of Stripping Plant installation procedure into the Underground LS Hall.
The shown steps correspond to:

B.12 Underground LS Hall – start of the sequence

B.13 Positioning of skid 1

B.14 Positioning of skid 3 (vertical position)

B.15 Positioning of skid 2

B.16 Positioning of T-201 vertical tank

B.17 Positioning of T-202 vertical tank

B.18 Installation of stairs and ground anchoring

APPENDIX E.
JUNO liquid scintillator software installation procedure

Istituto Nazionale di Fisica Nucleare

JUNO Liquid Scintillator Software Installation Procedure

Process Procedure Number: LS Software Installation Rev. 0

Last Revision Date:30 September 2022

Author(s) Procedures:

Michele Montuschi ________________________________

Reviewed by:

Paul Lombardi________________________________

Last Revised and Approved by:

Paul Lombardi________________________

Procedure validity: from: Revision Date
to:End of Project

1.Table of Contents

2.Revision History

Revision #	Date	Author(s)	Rationale	Sections Updated
1	30/09/2022	Michele Montuschi	First Version	All

3.PLC Software Installation

IP addresses: (to check)

IP Distillation: 192.168.11.200

IP Stripping: 192.168.11.250

1) Download the *TiaPortal 14* Virtual Machine to your PC. (may already be present).
2) Open the *TiaPortal 14* software (link on the Desktop).
3) If the project has been modified and you want to install a version that is not present in the virtual machine (for example, if modified by Polaris or by me):
    a. Click **Project**->**Retrieve** to retrieve the compressed project
    b. Select the project to open from the window (*C367-101_XXX.zap14* for distillation and *C367-102_XXX.zap14* for Stripping) and save the unpacked version on PC
4) If the project is already on your PC, open the corresponding one. (*C367-101_XXX* for distillation and *C367-102_XXX* for Stripping)
5) Connect via Ethernet the PC (the port is located behind the PC) directly to the PLC (the port is on the front of the PLC. Use port 1, the one above)
6) Check that your PC's Ethernet card has an address like *192.168.11.XXX*
7) Check the correct communication by making a "ping" on the PLC from inside the virtual machine (from the command terminal type *ping* < *IP*> address). (If you do not find it try to control the communication between PC and PLC and making a "ping" from the external PC and then try again with the virtual machine)
8) In the TiaPortal 14 software, fill in the Project by clicking on 
9) Click on to send the project to the PLC 
10) Check that options in Figure 1 are selected

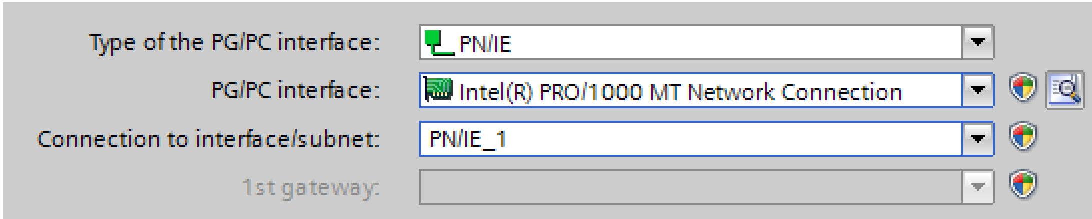


Figure 1 Fields to use to specify the type of connection between PLC and Computer

11) Click **Start Search.** It should list compatible devices

12) Select the PLC on which to send the software (there should only be one) and then click **on Load** to load the software on the PLC.

13) If you ask to start the PLC give the ok.

4.HMI Software Installation

Start RunTime mode (preferred)

1) Open the TdPro32 Virtual Machine.
2) Check that your PC's date is the current one.
3) From the Desktop, open the *TdPro32* Folder (see Figure 2).

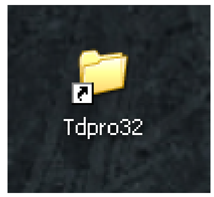


Figure 2 TdPro32 folder shortcut icon on the desktop

4) Delete the *DB* folder if present and unpack the **.rar* file containing the software (*DB_Strip_XXX.rar* for stripping or *DB_Dist_XXXX.rar* for distillation). Check that the extracted folder is named *DB*
5) Check that in the newly created *DB* folder there is a folder named *A C367 INFN Stripping* for stripping or *A C367 INFN Distillation* fordistillation.
6) If there are two *tdpro32.check files. r* and a *tdpro32.check* file, rename the *tdpro32.check* file to *tdpro32.check. p* and *tdpro32.check. r* in *tdpro32.check.*
7) Open the *TdPro32 3.1* software located on your Desktop (see Figure 3)

Figure 3 TdPro32 3.1 program shortcut icon on the desktop

Booting in Programming mode (to be used if there is something to change)

1) Open the TdPro32 Virtual Machine.
2) Check that your PC date is 02/08/2007. If not, set it to this date
3) From the Desktop, open the *TdPro32* Folder (See Figure 4).

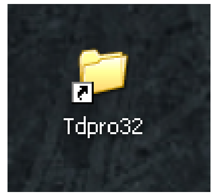


Figure 4 TdPro32 folder shortcut icon on the desktop

8) Delete the *DB* folder if present and unpack the *.rar file containing the software ("DB_Strip_XXX.rar" for stripping or "DB_Dist_XXXX.rar" for distillation). Check that the extracted folder is named *DB*
4) Check that in the newly created *DB* folder there is a folder named *A C367 INFN Stripping* for stripping or *A C367 INFN Distillation* for distillation.
5) if there are two *tdpro32.check.p* files and one *tdpro32.check* file rename the *tdpro32.check* file to *tdpro32.check.r* and *tdpro32.check.p* to *tdpro32.check*
6) Open TdPro32 3.1 software (see Figure 5)

Figure 5 TdPro32 3.1 program shortcut icon on the desktop

5.DB Software Installation

1) Install the *mysql-connector-odbc-8.0.30-winx64* driver.
2) Open *ODBC Data Source Administrator(64-bit)* (Just search for it with the windows search system) (see Figure 6)

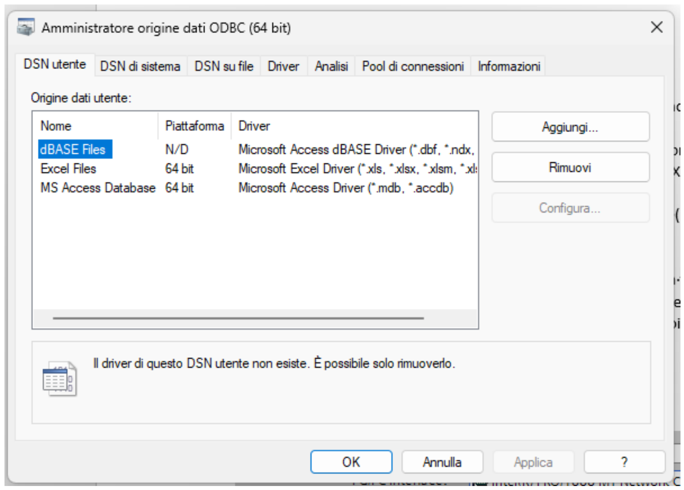


Figure 6 Window for adding a link to a SQL database to Windows

3) Add a new database link by clicking add.
4) Select the Database type (MySQL ODBC 8.0 ANSI Driver) (see Figure 7).

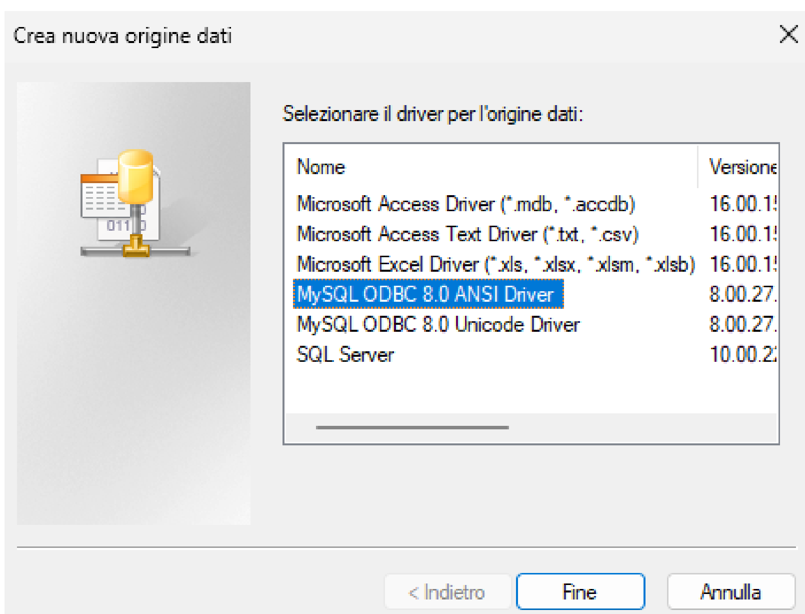


Figure 7 Window to select the database driver

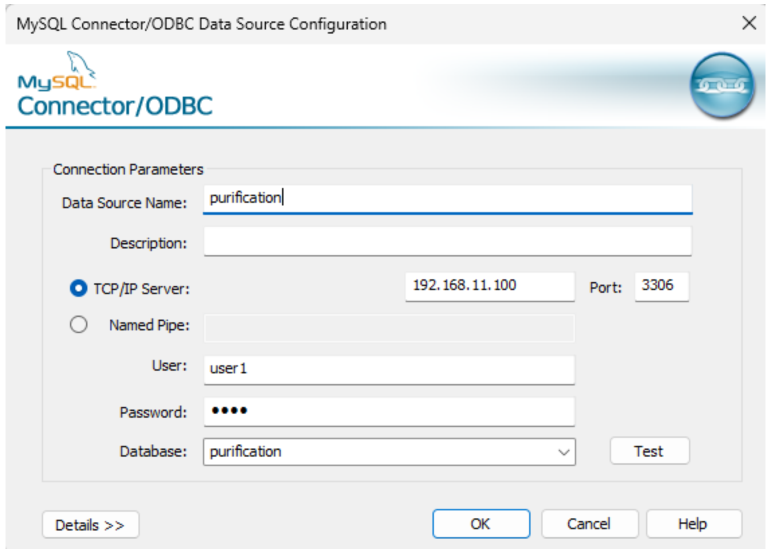


Figure 8 MySQL Database Driver Dialog Box

5) Enter the name of the link to the database (field "Data Source Name", it may be what you want) and its IP address (the port should be standard but it may be appropriate to ask for it). Then enter user and password (if required) and do a communication test by pressing the **Test** button. Then select the database from the "Database" drop-down menu. (see Figure 8)
6) Install the communication software between PLC and DB (*OPC_DB_Dist_Installer* for the Distiller and *OPC_DB_Strip_Installer* for stripping.
7) Move the OPC_SQL folder *to C:*
8) Install the *software OPUCA_License* located in the *folder .\OPC DB Connection\LabVIEW OPC UA Toolkit License Files [19.00.49152]\OPUCA00.*
9) Start the "*DB_OPC_Connect_Dist.exe*" software for the distiller and "*DB_OPC_Connect_Strip*" for the stripping. They are located in *C:\Program Files\OPC_JUNO_DIST* and *C:\Program Files\OPC_JUNO_STRIP*, respectively. You may want to create a desktop shortcut to these software.
10) A window made like the following will appear (see Figure 9)

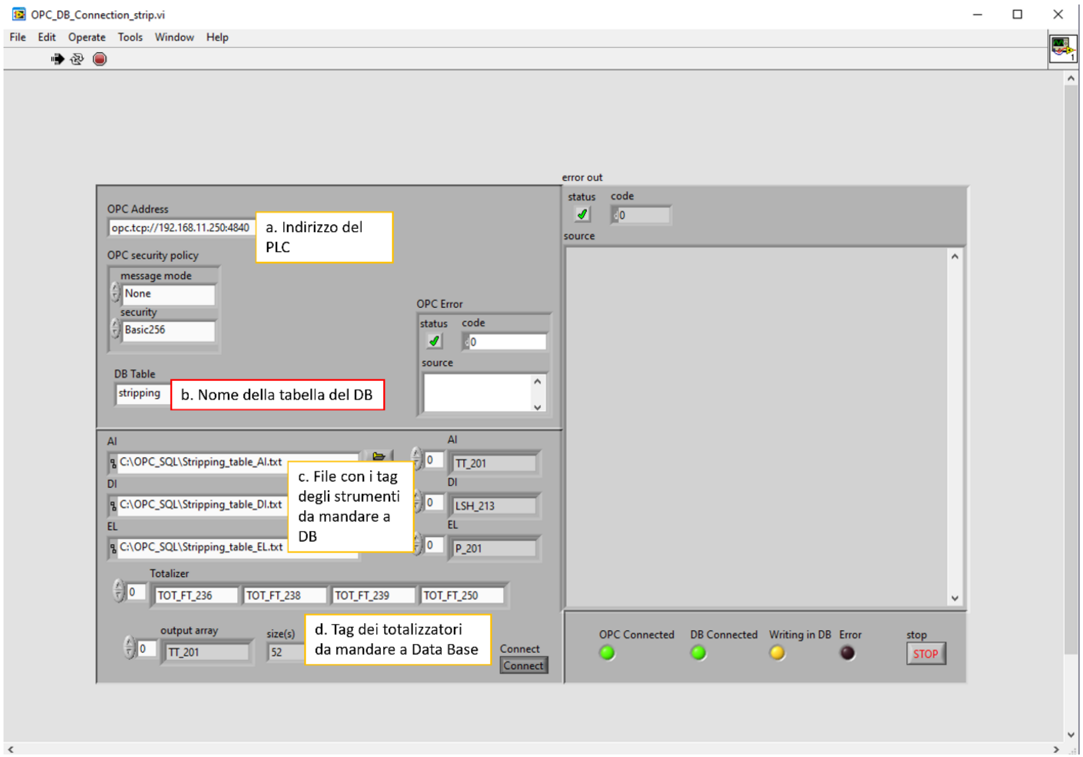


Figure 9 Main screen of OPC-database linking software

11) Enter the required data:

a. IP address of the PLC

b. Name of the DB table where to go to save the data. It must be given to you by those who will build the DB.

c. Files that contain the tags and tool range. If you have saved in C: the folder "OPC_SQL" are not to be changed. (you must make sure that these tags written exactly as in these files are present in the table)

d. Tags of the totalizers to be saved on the Database (you must make sure that in the table there are these tags written exactly as here)

NB: at the moment the software is set to save all the data but if there is a need to reduce the number of tags saved on the database you have to make a change to the LabView software. (I can do it myself or explain how to do it) as well as edit the corresponding files.

12) Click Connect.

13) A window like the following will open (see Figure 10):

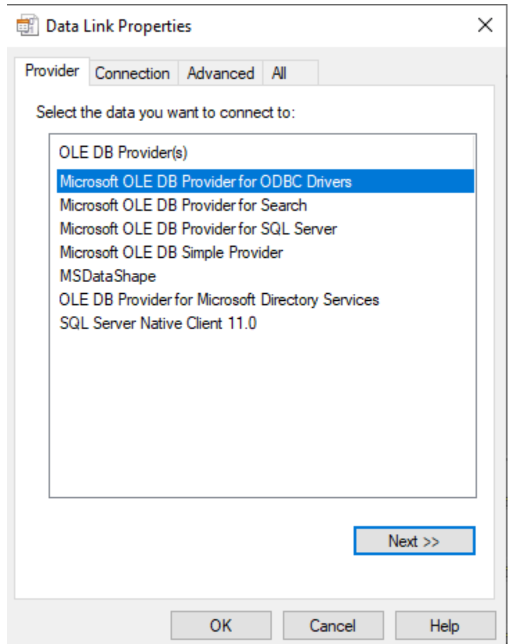


Figure 10 Screen for selecting the type of connection with the database

14) Select "Microsoft OLE DB Provider for ODBC Drivers" and then press Next (see Figure 11).

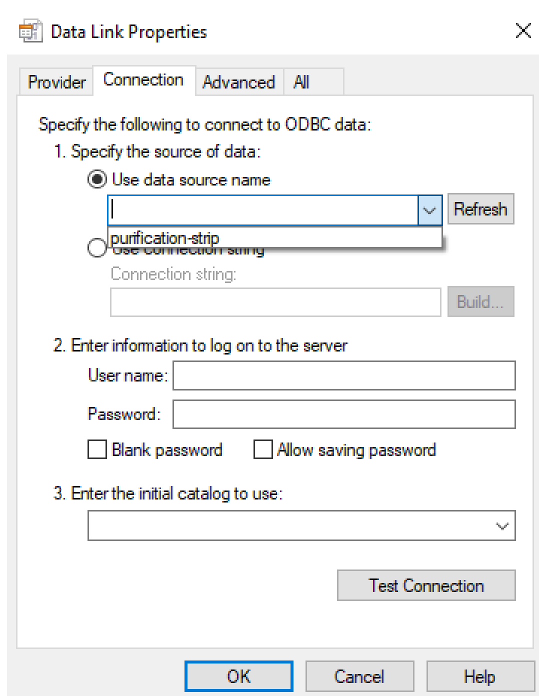


Figure 11 Screen for selecting the connection between PC and database

15) Select from "User data source name" the link created in step 5 and test the communication.

16) Test the connection and if everything is fine click OK.

17) If the LEDs are lit as in the image (see Figure 12), the software is writing the data from the PLC to the DB.

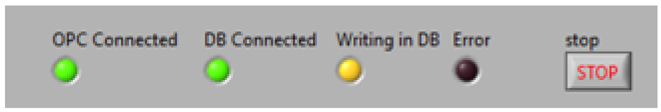


Figure 12 LEDs for the indication of the operation of the software. Correct configuration is: Green on, Green on, Yellow on, Red off

The information to be requested from the administrators of the Database are:

a. Database Name
b. IP address of the Database
c. User and Password
d. Name of the table where to go to save the data

The information to be sent to the database administrators are:

e. Analog Input Tags (vd. *Stripping_table_AI.txt* or *Distillation_table_AI.txt*)
f. Digital Input Tags (vd. *Stripping_table_DI.txt* or *Distillation _table_DI.txt*)
g. Electrical Load Tags(vd. *Stripping_table_EL.txt* or *Distillation _table_EL.txt*)