CNRS
Centre National de la Recherche Scientifique

INFN
Istituto Nazionale di Fisica Nucleare

Review Of Vacuum Pumping System Operation Safety And Enhanced Safety Measures

Code: VIR-TRE-PIS-3400-159
Issue: 1
Date: 29/02/00

VIRGO * A Joint CNRS-INFN Project
Project Office: INFN-Sezione di Pisa*Via Livornese, 1291-56010 San Piero a Grado, Pisa, Italy.
Secretariat: Telephone (39) 50 880 327 or 880352*Fax (39) 50 880 350* e-maill: virgo@Pisa.infn.it

CHANGE RECORD

Issue/Rev	*Date*	*Section Affected*	*Reason/remarks*

Authors:	Date	Signature
J. L. Beney, S. Cuzon, A. Pasqualetti, Z. Zhang	29/02/00	

1. Purpose and scope

The recent accident of opening the valve between BS and SR (VIR-PIS-MEM-3400-156) pushes us to review the vacuum system operation safety.

The control system of the central vacuum system is already existing and operative since long time; it includes safety for all the operations considered hazardous for personnel or dangerous for equipment. Only the part of the control system to operate the valves on the tubes linking the towers has not yet been installed. At this moment the link valves are operated by a provisional manual system, not including any protection.

In the following we describe several proposals to improve vacuum system safety, in particular introducing redundancy on all hazardous operations: at least two completely independent safety conditions are required, one of them being possibly hardwired. What follows has to be read together with Pumping System Operation Sequences (VIR-PIS-TRE-3400-99).

The most important safety measure is to operate the vacuum system only via computer, to activate also the software protections; these protections are excluded by manual operation, which uses only hardwired protections (always active).

In general, when using a gauge reading, the control software checks that any valve in front of the relevant gauge is open. Gauge calibrations will be frequently verified inside the regular maintenance program.

In addition we propose to supply the whole pumping system through UPS; this will avoid problems arising while restarting the system, after a power failure.

2. Security requirements

2.1 UHV Tower Pumping System

There are 7 UHV towers. The pumping system is shown in Figure 1.

2.1.1 **Rough pumping safety**: - If P41 and P61 are stopped, the valves on the pump port will be closed. This safety is working well, but when we come back from the safety case, the valves are opened too fast, the pressure is still high, a hardware delay timer is needed.

2.1.2 **P51 big turbo pump safety** - The pump now is on IPS line. Since power cuts are very frequent we suggest supplying it with UPS line. One pump has already been damaged by power cuts.

2.1.3 **V51 valve** - Existing hardware safety: the valve can be opened only when the pumping speed of P51 is higher than the half of full speed. Additional safety measure: Gc1<0.5 mbar.

2.1.4 **V31** - No safety measure exists. The valve will be locked at open position (manual lock). It will be manually unlocked and closed only for regeneration or replacement of Ti or ion pumps.

2.1.5 **V81** - No safety measure exists. The valve will be locked at open position (manual lock). It will be manually unlocked and closed only for replacement of ion pump.

2.1.6 **V71, V72, V92** - In order to protect the three valves V71 (150mm), V72 (200mm) and V92 (200mm) that are connected on the bypass, we suggest to add a capacitance gauge (G72) on the bypass (it can be installed easily at the exit port of P71). The gauge will give us information for the safety of the three valves. There is a free

channel in the gauge controller and cables for the gauge are already available. See below for details.

2.1.7 **V92** - New safety: V92 can be opened only if G72>990 mbar(software), and valve V41, V42 and V91 are opened (software). Later on the condition G72>990mbar will be set to hardware measure.

2.1.8 **V71 and V72** - Existing hardware safety: the valve can be opened only when P71 is running with >half of the full speed or when V92 is opened. Enhanced safety: A) Adding condition Gd1<0.5mbar to the safety with P71 speed. B) adding condition Gc2-G72<10mbar to the V92 open condition.

2.2 HV Tower Pumping System

The three HV tower are Detection, Injection and MC towers. The pumping system is shown in Figure 2.

2.2.1 **Rough pumping** - The safety measures for, P51, and V51 are same as the UHV tower pumping system.

2.2.2 **V92** - enhanced software safety: the valve can be opened only if Gc2>990mbar and valve V91 is opened. There is only software safety now, later on a hardware safety measure will be developed.

2.3 Tube Pumping System

The tube pumping system is much simpler than the towers one (see VIR-TRE-PIS-3400-151 and VIR-CRE-08/99).

2.3.1 V21 - the pumping group is shown in Figure 3. The group must have the safety sequence as: 1) If P21 is running with <0.5 full speed or the pressure in the tube is higher than 0.5 mbar, V21 can not be opened. 2) When P21 is stopped, venting valve V24 must be opened. 3) A delay timer for V22 is needed to compensate the transit time of P22.

2.3.2 V31 - Safety is the same as for V31 of the tower pumping system. The pumping group is shown in Figure 4.

2.4. Link Valves

These are the 250mm gate valves on the tubes linking the different towers. We must have hardware safety active in manual operation and in remote computer operation, both for vacuum and atmospheric pressure case. Operation is not allowed between 10 mbar and 990 mbar. Scheme of safety measures for the valves between towers are shown in Figure 5.

2.4.1 **Valve between MC tower and Injection towers**

Hardware safety for manual and remote operation requires one of the two following conditions, in alternative: A) The pressure in both towers is less than 5 mbar, implemented through the pressure switches existing in the controllers of the two Gc1 gauges. B) The two venting valves (V91) are opened and the pressure in both towers is >990mbar, implemented through the pressure switches existing in the controllers of the two Gc2 gauges. Each

condition A) or B) is in series (AND) with the instrument error relay (if error in gauges the valve can not be opened). Remote operation requires an additional software safety: difference of pressure between the two towers <10 mbar, as measured by the two Gc2 gauges.

2.4.2 **Valves between BS and WI, SR, PR, NI towers**

Hardware safety for manual and remote operation requires one of the two following conditions, in alternative: A) The pressure in both towers is less than 5 mbar, implemented through the pressure switches existing in the controllers of the two Gc1 gauges. B) The four venting valves (two V91 and two V41) are opened and the pressure in both towers is >990mbar, implemented through the pressure switches existing in the controllers of the two Gc2 gauges. Each condition A) or B) is in series (AND) with the instrument error relay (if error in gauges the valve can not be opened). Remote operation requires an additional software safety: difference of pressure between the two towers <10 mbar, as measured by the two Gc2 gauges.

2.4.3 Large Valves

They are the four large (1000mm) gate valves at each end of the 3km tubes. Scheme of safety measures for the large valves on the tubes are shown in Figure 6.

Hardware safety: the valve can be opened neither by remote nor by local manual operation if difference of pressure between the two sides of the valve is higher than 0.5 mbar, as measured by a precision differential gauge. In addition, it is also required (hardwired) that both valves which are between the tube, the input tower and the differential gauge are opened.

Additional (AND) software safety: the valve can not be opened if the two capacitance gauges installed on either sides of the valve read a pressure difference larger than 5.0 mbar.

3. Safety implementation

3.1. General

This chapter has to give a response to the requirements of the part 2 which has been discussed in the meeting "Vacuum safety" (24/11/99).

The software safeties can be separated in two types: conditional and active.

A conditional software safety forbids to act on the pumping bench if the condition specified is not true.

An active software safety monitors permanently the status of the pumping bench (as long as the server and the controllers is running) and executes a specified action when a specified condition is detected.

Most of the software safeties required are conditional.

Many safeties use the status of a measurement bottle entrance valve. To avoid locking some actions, these valves must be completely opened. Furthermore, all maintenance operations on these measurement bottles will involve to foresee to close the link valve.

For the remote control, it is mandatory to avoid that more than one person take the mastership of different servers. In practice, one and only one client will be able to become master at server level in a first time and at the VTT partition level in a second time.

For the UHV and HV towers, the S/W safeties will be implemented within "To" servers. For the link and gate valves, they will be implemented in the VTT server.

Some acronyms are used in the following tables:

- H/W : Hardware
- S/WC : Conditional Software
- S/WA : Active Software
- TBA : To Be Added
- TBC : To Be Completed
- AI : Already Installed
- T(state1, state2) : Transition from state1 to state2

3.2. UHV tower pumping system

Each safety shall be implemented in the SRT, PRT, BST, NIT, NET, WIT and WET control stations.

N°	Goal	Triggering status	Action	Type	Remarks	Status
1	Avoid to rough pump only one part of the tower.	[(V41 is open **AND** V42 is closed) **OR** (V41 is closed **AND** V42 is open)] after an adjustable delay.	Close V41 and V42.	H/W		AI
2	Avoid to open a valve in front of an off pump.	P41 off	Close V43.	H/W		AI
3	i.e.	P61 off	Close V75 and V52.	H/W		AI
4	i.e.	Speed (P51) < SpeedThreshold	Close V51.	H/W	The SpeedThreshold is not adjustable.	AI
5	i.e.	Speed (P71) < SpeedThreshold	Close V71 and V72.	H/W	i.e.	AI
6	Avoid to put high pressure to the back of the TMPs when IPS power restarts.	IPS-T(off,on) **AND** V43 open command active	Delay on V43 opening (few minutes after P41 start).	H/W		TBA
7	i.e.	IPS-T(off,on) **AND** V52 open command active	Delay on V52 opening (few minutes after P61 start).	H/W		TBA
8	i.e.	IPS-T(off,on) **AND** V75 open command active	Delay on V75 opening (few minutes after P61 start).	H/W		TBA
9	Avoid to not be able to close valve in case of low level of compressed air.	Compressed Air Pressure < Pressure Threshold	Close all valves (except V31, V71 and V51).	H/W		AI
10	Avoid to open the valve in front of the TMPs if the pressure of the tower is high .	Vc1 is closed **OR** P(Gc1) > 0.5mbar	Forbid V51 opening.	S/WC		TBA
11	i.e.	Vc1 is closed **OR** P(Gc1) > 0.5mbar	Forbid V71 opening.	S/WC		TBA

12	i.e.	Vd1 is closed **OR** P(Gd1) > 0.5mbar	Forbid V72 opening.	S/WC		TBA
13	Protect the valve (200) at high pressure.	Vc1 is closed **OR** P(Gc2) < 990mbar **OR** | (P(Gc2)-P(G72) | > 10mbar	Forbid V71 **AND** V72 opening.	S/WC		TBA
14	i.e.	V41 **OR** V42 **OR** V91 are closed **OR** P(G72) < 990mbar	Forbid V92 opening.	S/WC	Need to open V74.	TBA
15	Prevent V31 or V81 opening.	Manual lock in open state.		S/WC	Confirmation message to operate these two valves.	TBA
16	Prevent valve opening after active H/W safety (except in case of IPS default)	Valve closing status without sent command.	Send closing command.	S/WA	False when the valves are closed due to an IPS default.	TBC

3.3. HV tower pumping system

Each safety shall be implemented in the MCT, IT and DT control stations.

N°	Goal	Triggering status	Action	Type	Remarks	Status
1	Avoid to open a valve in front of an off pump.	P41 off	Close V41 and V53.	H/W		AI
2	i.e.	P61 off	Close V52.	H/W		AI
3	i.e.	Speed (P51) < SpeedThreshold	Close V51.	H/W	The SpeedThreshold is not adjustable.	AI
4	Avoid to put high pressure to the back of the TMPs when IPS power restarts.	IPS-T(off,on) **AND** V52 open command active.	Delay on V52 opening (few minutes after P61 start).	H/W		TBA
5	i.e.	IPS-T(off,on) **AND** V53 open command active.	Delay on V53 opening (few minutes after P41 start).	H/W		TBA
6	Avoid to not be able to close valve in case of low level of compressed air.	Compressed Air Pressure < Pressure Threshold	Close all valves (except V51).	H/W		AI
7	Avoid to open the valve in front of the TMPs if the pressure of the tower is high.	Vc1 is closed **OR** P(Gc1) > 0.5mbar	Forbid V51 opening.	S/WC		TBA
8	Protect the valve (200) at high pressure.	Vc1 **OR** V91 are closed **OR** P(Gc2) < 990mbar	Forbid V92 opening.	S/WC		TBA
9	Prevent valve opening after active H/W safety (except in case of IPS default)	Valve closing status without sent command.	Send closing command.	S/WA	False when the valves are closed due to an IPS default.	TBC

3.4. Tube pumping system

Each safety shall be implemented in all the tube control stations.
The configuration of each arm is described in the following table.

North arm pumping benches	PN01	PN02	PN03	PN04	PN05	PN06	PN07	PN08	PN09	PN10	PN11
North arm control stations	CN01		CN03		CN05		CN07		CN09		CN11
West arm pumping benches	PW01	PW02	PW03	PW04	PW05	PW06	PW07	PW08	PW09	PW10	PW11
West arm control stations	CW01		CW03		CW05		CW07		CW09		CW11

N°	Goal	Triggering status	Action	Type	Remarks	Status
1		P22 off	Close V22.	H/W		TBI
2	Avoid to put high pressure to the back of the TMPs when IPS power restarts	IPS-T(off,on) **AND** V22 open command active.	Delay on V22 opening (few minutes after P22 start).	H/W		TBI
3	Avoid to open the valve in front of the TMPs if the speed is not quick enough.	Speed (P21) < SpeedThreshold	Close V21.	H/W	The SpeedThreshold is not adjustable.	TBI
4	Avoid to open the valve in front of the TMPs if the pressure of the tower is high.	Va1 is closed **OR** P(Ga1) > 0.5mbar	Forbid V21 opening.	S/WC		TBI
5	Prevent V31 opening.	Manual lock in open state.		S/WC	Confirmation message to operate this valve.	TBI
6	Venting P21.	P21 stopped	Venting valve open during a defined time.	H/W	Depends on the pump controller features. TBA in the call for tender.	TBI

Up to now, safety is foreseen to protect rough pumping and venting of the two tubes locally. The rough pumping and a venting operation are local, and the safeties associated to the environment (essentially large valve status) are to be defined.

3.5. Link valves (Diameter 250)

MG is the MultiGauge controller which reads the Gc1 and the Gc2 gauges.

N°	Goal	Triggering status	Action	Type	Remarks	Status
1	Avoid to not be able to close the link valve in case of low level of compressed air.	Compressed Air Pressure < Pressure Threshold	Close the link valve.	H/W	True for all the link valves.	AI
2	Avoid to open a link valve in bad conditions specially if the pressure belongs to [5 - 990] mbar.	(Vc1(PRT) **OR** Vc1(BST) are closed) **OR** MG in error **OR** **[** (V41(PRT) **OR** V91(PRT) **OR** V41(BST) **OR** V91(BST) **OR** are closed **OR** P(Gc2-PRT) < 990mbar **OR** P(Gc2-BST) < 990mbar) **AND**	Forbid VSR opening.	H/W	The conditions on the Gc1,Gc2 pressure is given by a relay thresholds of the gauge	TBC

		(P(Gc1-PRT) > 5mbar **OR** P(Gc1-BST) > 5mbar) **]**			controllers.	
3	i.e.	(Vc1(SRT) **OR** Vc1(BST) are closed) **OR** MG in error **OR** **[** (V41(SRT) **OR** V91(SRT) **OR** V41(BST) **OR** V91(BST) are closed **OR** P(Gc2-SRT) < 990mbar **OR** P(Gc2-BST) < 990mbar) **AND** (P(Gc1-SRT) > 5mbar **OR** P(Gc1-BST) > 5mbar) **]**	Forbid VSS opening.	H/W	i.e.	TBC
4	i.e.	(Vc1(NIT) **OR** Vc1(BST) are closed) **OR** MG in error **OR** **[** (V41(NIT) **OR** V91(NIT) **OR** V41(BST) **OR** V91(BST) are closed **OR** P(Gc2-NIT) < 990mbar **OR** P(Gc2-BST) < 990mbar) **AND** (P(Gc1-NIT) > 5mbar **OR** P(Gc1-BST) > 5mbar) **]**	Forbid VNS opening.	H/W	i.e.	TBC
5	i.e.	(Vc1(WIT) **OR** Vc1(BST) are closed) **OR** MG in error **OR** **[** (V41(WIT) **OR** V91(WIT) **OR** V41(BST) **OR** V91(BST) are closed **OR** P(Gc2-WIT) < 990mbar **OR** P(Gc2-BST) < 990mbar) **AND** (P(Gc1-WIT) > 5mbar **OR** P(Gc1-BST) > 5mbar) **]**	Forbid VWS opening.	H/W	i.e.	TBC
6	i.e.	(Vc1(MCT) **OR** Vc1(IT) are closed) **OR** MG in error **OR** **[** (V91(MCT) **OR** V91(IT) are closed **OR** P(Gc2-MCT) < 990mbar **OR** P(Gc2-IT) < 990mbar) **AND** (P(Gc1-MCT) > 5mbar **OR** P(Gc1-IT) > 5mbar) **]**	Forbid VLI opening.	H/W	i.e.	TBC
7	Protect a link valve against the differential pressure	Vc1(PRT) **OR** Vc1(BST) Are closed **OR** | P(Gc2-PRT) - P(Gc2-BST) | > 10mbar **OR** d/dt| P(Gc2-PRT) - P(Gc2-BST) | > Threshold	Forbid VSR opening.	S/WC	Only active in remote control with VTT.	TBA
8	i.e.	Vc1(SRT) **OR** Vc1(BST) Are closed **OR** | P(Gc2-SRT) - P(Gc2-BST) | > 10mbar **OR**	Forbid VSS opening.	S/WC	i.e.	TBA

		d/dt| P(Gc2-SRT) - P(Gc2-BST) | > Threshold				
9	i.e.	Vc1(NIT) **OR** Vc1(BST) Are closed **OR** | P(Gc2-NIT) - P(Gc2-BST) | > 10mbar **OR** d/dt| P(Gc2-NIT) - P(Gc2-BST) | > Threshold	Forbid VNS opening.	S/WC	i.e.	TBA
10	i.e.	Vc1(WIT) **OR** Vc1(BST) Are closed **OR** | P(Gc2-WIT) - P(Gc2-BST) | > 10mbar **OR** d/dt| P(Gc2-WIT) - P(Gc2-BST) | > Threshold	Forbid VWS opening.	S/WC	i.e.	TBA
11	i.e.	Vc1(MCT) **OR** Vc1(IT) Are closed **OR** | P(Gc2-MCT) - P(Gc2-IT) | > 10mbar **OR** d/dt| P(Gc2-MCT) - P(Gc2-IT) | > Threshold	Forbid VLI opening.	S/WC	i.e.	TBA

3.6. Gate valves (Diameter 1000)

The VNI is the gate valve at the beginning of the north arm between the pumping benches of the NIT and PN01 (Pumping North 1).

The VNE is the gate valve at the end of the north arm between the pumping benches of the NET and PN11 (Pumping North 11).

The VWI is the gate valve at the beginning of the west arm between the pumping benches of the WIT and PW01 (Pumping West 1).

The VWE is the gate valve at the end of the west arm between the pumping benches of the WET and PW11 (Pumping West 11).

The differential pressure measured by the differential gauge between the left and the right side of a gate valve is dP(name of the gate valve); V1(name of the gate valve) and V2(name of the gate valve) are the valves which give the access of the tube to the differential gauge.

NTP(Gc2i) is a linear combination of the pressure measured by the 6 Gc2 gauges along the North Tube.

WTP(Gc2i) is a linear combination of the pressure measured by the 6 Gc2 gauges along the West Tube.

The alarms used on the 2 air compressed bottles are well described in the “LINK AND GATE VALVE Control system” document. The (d) signal activate the first safety (see below).

N°	Goal	Triggering status	Action	Type	Remarks	Status
1	Avoid to not be able to close the gate valve in case of low level of compressed air.	Compressed Air Pressure ((d) signal) < Pressure Threshold	Close the gate valve.	H/W	True for all the gate valves.	AI
2	Avoid to open a gate valve if the differential pressure exceeds 0.5 mbar.	V1(VNI) is closed **OR** V2(VNI) is closed **OR** | dP(VNI) | > 0.5mbar	Forbid VNI opening.	H/W	Use of a differential gauge with a relay threshold.	AI

3	i.e.	V1(VNE) is closed **OR** V2(VNE) is closed **OR** | dP(VNE) | > 0.5mbar	Forbid VNE opening.	H/W	i.e.	AI
4	i.e.	V1(VWI) is closed **OR** V2(VWI) is closed **OR** | dP(VWI) | > 0.5mbar	Forbid VWI opening.	H/W	i.e.	AI
5	i.e.	V1(VWE) is closed **OR** V2(VWE) is closed **OR** | dP(VWE) | > 0.5mbar	Forbid VWE opening.	H/W	i.e.	AI
6	Redundancy on the differential pressure protection.	Vc1(NIT) is closed **OR** Va1(NTS1) is closed **OR** | P(Gc2-NIT) – P(Gc2-PN1) | > 5mbar **OR** d/dt| P(Gc2-MCT)-NTP(Gc2i)| > Threshold	Forbid VNI manual opening.	S/WC	Only active in remote control with VTT.	TBA
7	i.e.	Vc1(NET) is closed **OR** Va1(NTS6) is closed **OR** | P(Gc2-NET) – P(Gc2-PN11) | > 5mbar **OR** d/dt| P(Gc2-NET)–NTP(Gc2i) | > Threshold	Forbid VNE manual opening.	S/WC	i.e.	TBA
8	i.e.	Vc1(WIT) is closed **OR** Va1(WTS1) is closed **OR** | P(Gc2-WIT) – P(Gc2-PW1) | > 5mbar **OR** d/dt| P(Gc2-WIT)–WTP(Gc2i) | > Threshold	Forbid VWI manual opening.	S/WC	i.e.	TBA
9	i.e.	Vc1(WET) is closed **OR** Va1(WTS6) is closed **OR** |P(Gc2-WET) – P(Gc2-PW11)| > 5mbar **OR** d/dt| P(Gc2-WET)–WTP(Gc2i) | > Threshold	Forbid VWE manual opening.	S/WC	i.e.	TBA

In the “LINK AND GATE VALVE Control system”, an algorithm has been proposed to close a gate valve automatically when the pressure increase in the tube. The algorithm will be implemented only if it is required explicitly in a new version of this document.

Figure 1. UHV tower pumping system scheme.

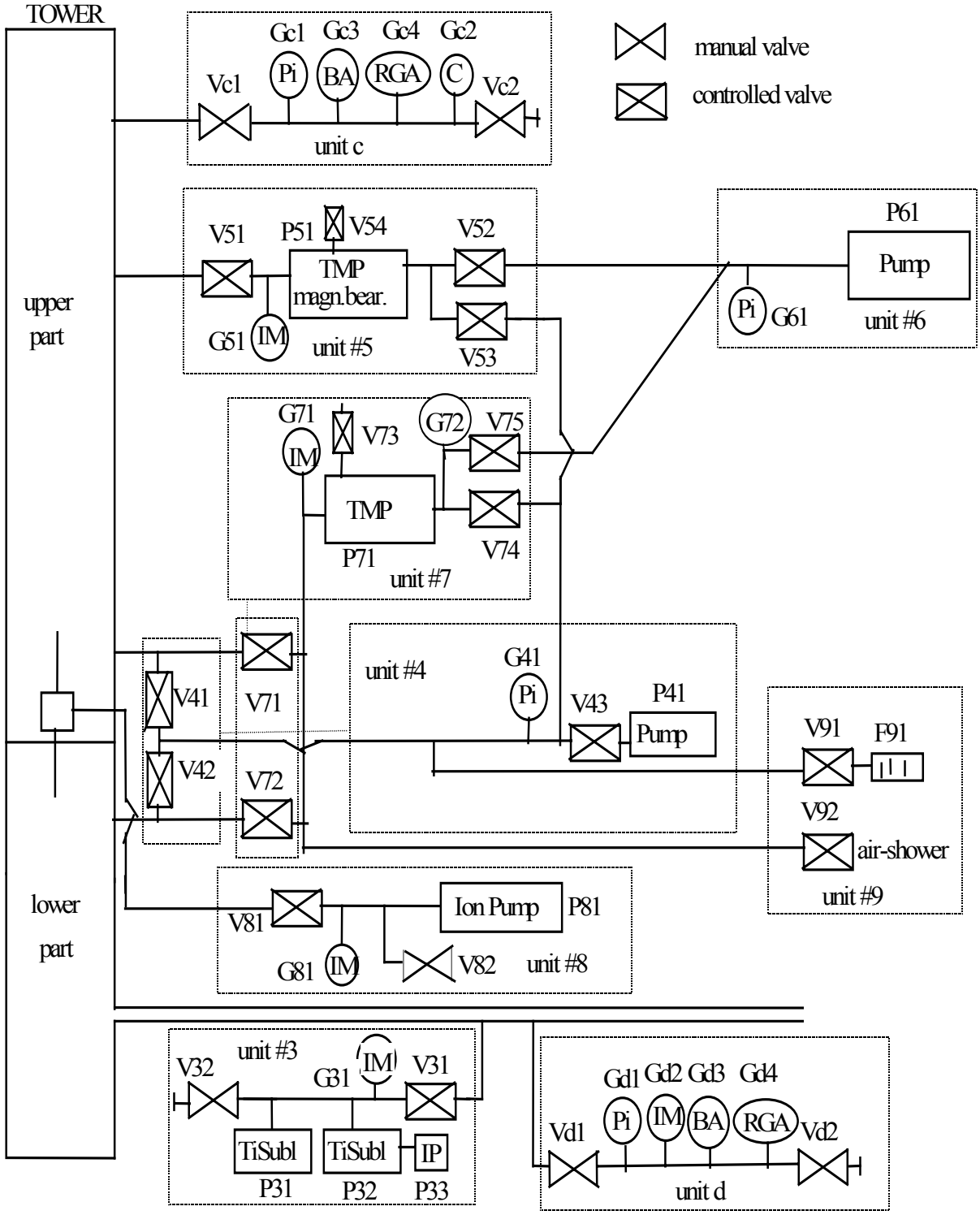

Figure 2. HV tower pumping system scheme.

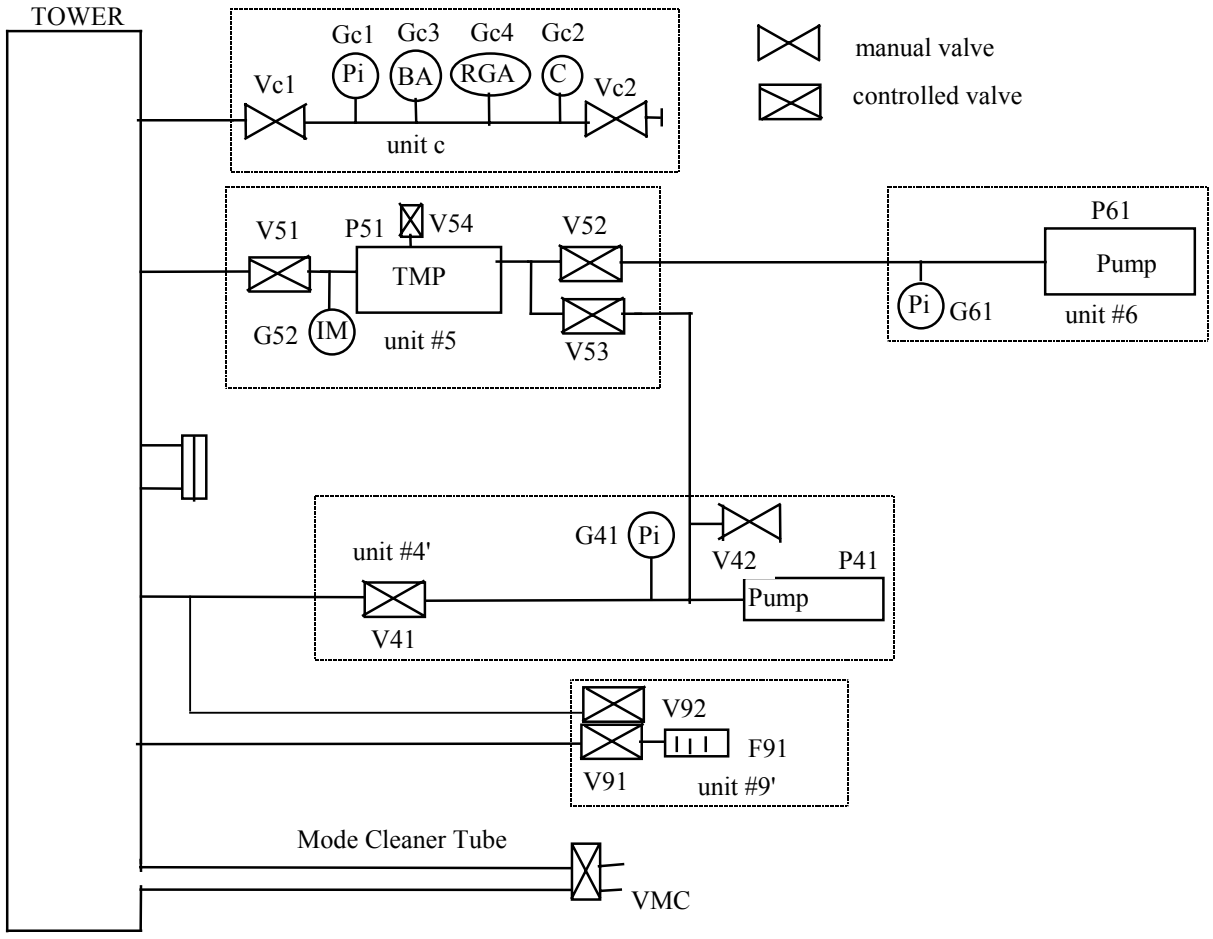

Figure 3. Tube intermediate pumping group.

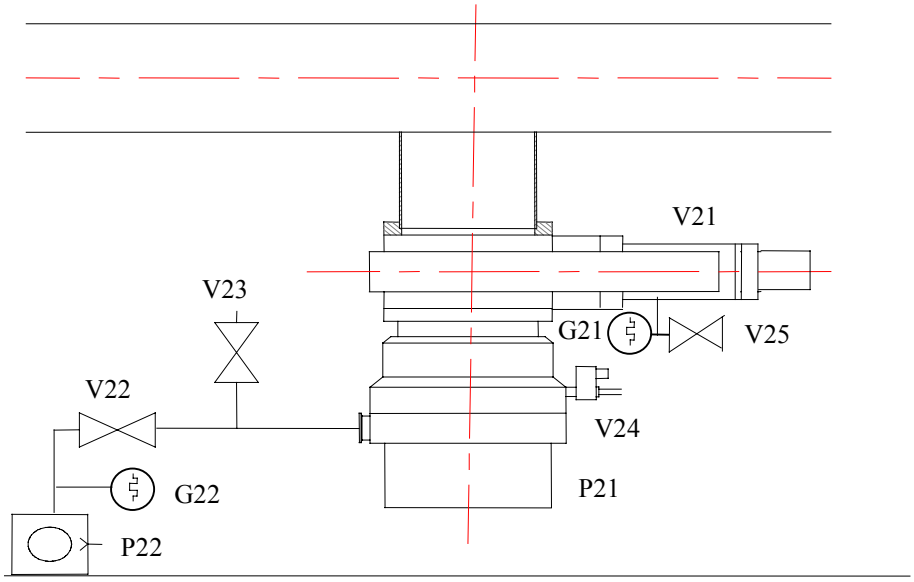

Figure 4. Tube permanent pumping group.

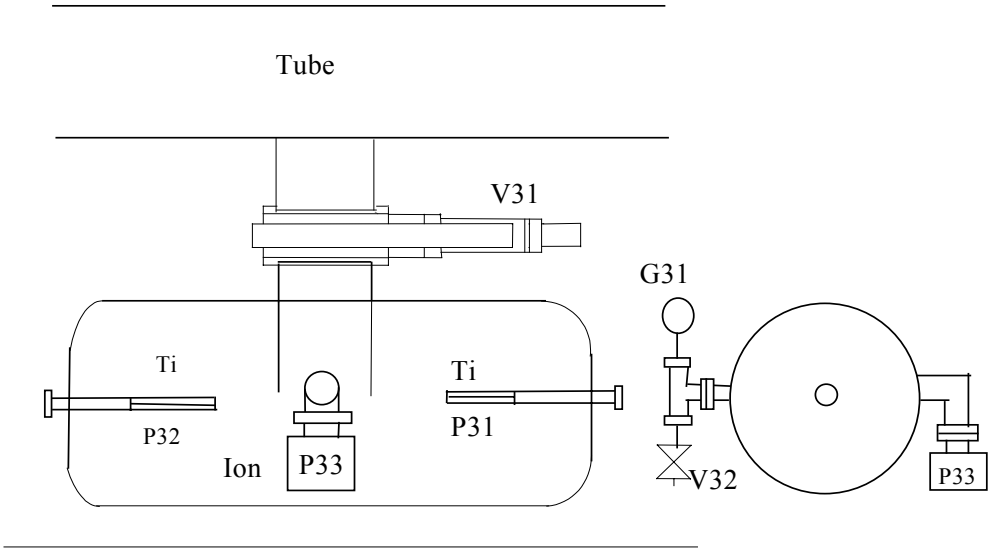

Figure 5. Scheme of safety measures for the valves between towers.

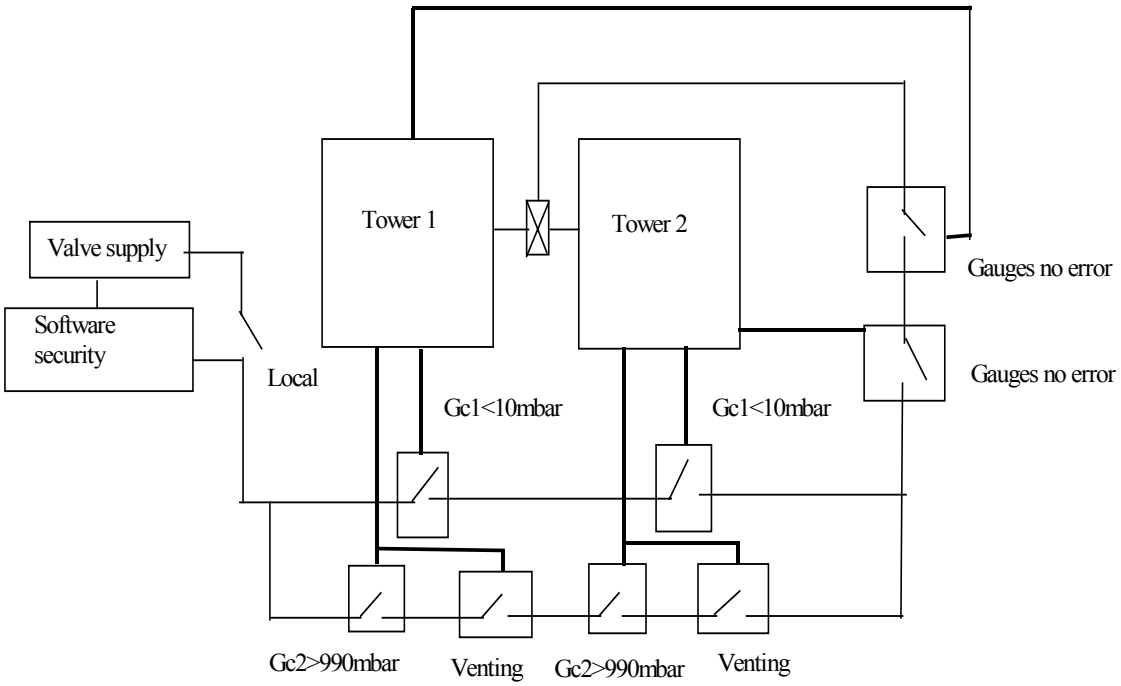

Figure 6. Scheme of safety measures for the large valves on the tubes.