Fermilab

$\bar{p}$ Note #303

An Alternative Design for the Accumulator Ring Vacuum System

A. Poncet

6/4/83

6.4.83
A. Poncet.

303

AN ALTERNATIVE DESIGN FOR THE ACCUMULATOR RING VACUUM SYSTEM

1) Introduction (and summary)

The accumulator design pressure is proclaimed to be 1 to 3 $\times 10^{-10}$ Torr.*
$\bar{p}$ note # 286 describes a vacuum system based on massive ion pumping, largely inspired by the successful electron cooling ring vacuum system, which achieved apparently very low outgassing rates ($q < 1.10^{-13}$ Tl sec^{-1} cm^{-2}) after months of pumping.
This note presents an alternative design where ion pumping is largely replaced by titanium sublimation pumps, down at low pressures, and based on the following arguments:

ion pump pumping speed is relatively small at pressure below 10^{-9} Torr (low efficiency thus very high cost)

achieving very low pressures like on the cooling ring requires long pumping times and heavy bake out temperatures: both features which are not acceptable on a reliable, long life machine which has to be opened frequently for improvement of equipment.

titanium sublimation pumps, if there are a burden when operated at pressures above 10^{-8} Torr, provide at low pressures a very cheap mean of achieving high pumping speeds, with virtually no operational problems and very long life times. As already said in $\bar{p}$ note # 246, they are of widespread use at CERN's ISR, AA, SPS and LEAR.

*Note: Gauge pressure.

2) - Sectors & Sector valves

The choice has to be made as a compromise between antagonists requirements :

large number of sectors for operationnal ease : arranged around critical equipment likely to be removed or modified.

keeping the price down, which means few sectors and/or valves of smallest possible diameter, and fewer roughing stations.

Figure 1 shows a possible arrangement. The number of valves has been minimized, as well as the diameter.
Unfortunately, there is only one manufacturer : VAT. These gate valves are new products : they are cheaper than pendulum valves and have an essential safety feature : they are self locking.

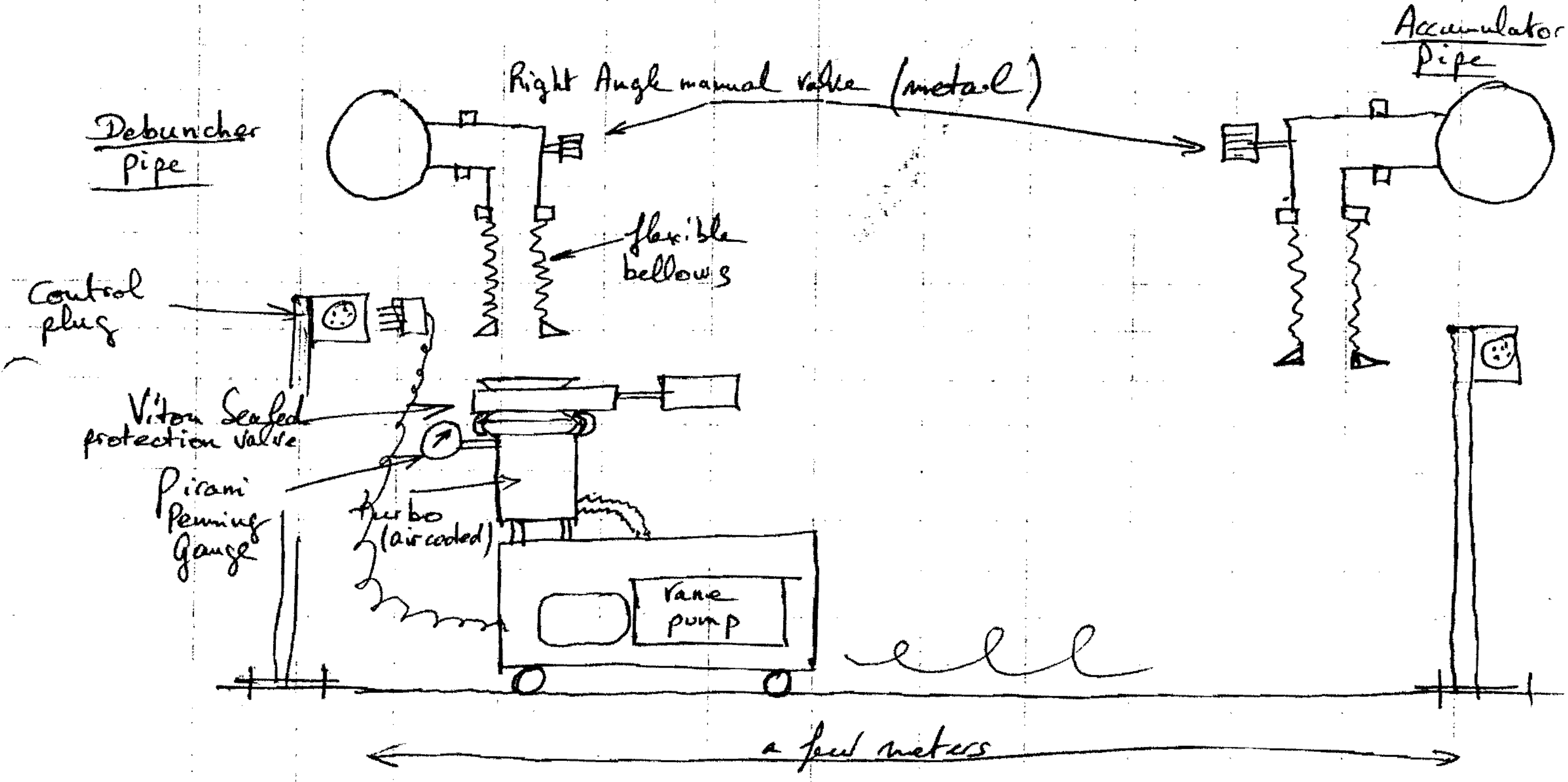
Valves are standardized at 4" I.D., but for one 10" I.D., on the injected beam path.
Total price should be about 50'000 $, European prices.

3) - Roughing stations :

$\bar{p}$ note n° 297 has already studied the problem for the debuncher, and came out with the argument that, due to conductance limitations and long sectors, one would need either a large number of fixed stations, or some fixed and mobile carts. The argument is even stronger for the accumulator which has an even smaller conductance : about half that of the debuncher ($\sim 90\ \ell m\ sec^{-1}$ against $180\ \ell m\ sec^{-1}$).

Mobile roughing stations are usually fine on paper ; on the field they are a real burden if one has to travel on large distances with the carts, rolling on pipes, wires etc. Also they complicate somewhat the controls. On the other hand fixed stations make the roughing expensive.

Fortunately there is a peculiar thing about debuncher and accumulator which should make possible some compromise. Matching azimuthally the roughing groups of the debuncher and accumulator seems possible, allowing the same semi mobile group to pump alternatively facing sectors, moving it by only a few meters. If one provides a flexible hose onto which the turbo valve can be attached without lifting it, and a plug for the controls, then much of the burden of a mobile group is avoided:



The control plug provides remote command (from the service building) of the group's functions: ON/OFF, HIGH VACUUM VALVE OPEN/CLOSE and acquisition of corresponding status, and interlocks. Interlocks are normally built in the pumping group and are rather standard, but if FNAL has already developped its own control unit, this can as well be located in the service buildings.

Figure 2 shows a schematic of both Debuncher + Accumulator sectors and pumping groups, consistent with $\bar{p}$ note # 297.

The need is thus for 8 Groups (+1 spare), with turbos in the range 330 - 450 l/s, air cooled, backed by two stages rotary vane pumps of 12 m^3/h pumping speed.

4) Pumping down to low pressures:

Normally the system is baked at 300°C for 24 hours while pumping with the roughing stations, so that the system may eventually reach quickly (24 to 30 hours) UHV outgassing rates (1.10^{-12} Tl $sec^{-1} cm^{-2}$) thus making the pumping at low pressures easier and less costly. This is very sensible if one relies only on ion pumps, since there is virtually no reserve in pumping speed. If one uses instead Ti sublimation pumps, with their large & cheap pumping speeds, one relies less on the high temperature bake (150°C instead of 300°C), and there may be even cases where bake outs are not strickly necessary if one has time ahead to reach the ultimate low pressure. The argument is though usually not strong enough to relax completely on the necessity of planning a 300°C bake out system, when one designs a UHV machine. But it certainly gives a tremendous amount of operational flexibility.

4.1. Ion pumping:

Ion pumping has still to be provided for the following reasons:

Ti Sublimation pumps do not pump non active gases such as Ar, He, CH_4 which are present in UHV systems.

ion pumps are needed to reduce the system's pressure down to 10^{-8} Torr, pressure at which Ti Su pumps really start to be efficient.

The second argument, when it is fullfilled, largely covers the first one, since Ar, He, CH_4 outgassing rates are usually very small (a few percent), in a clean UHV system.

Also, since one of the goals is to pump rare and non active gases with ion pump, triode type pumps are largely preferred to diodes.

4.2. Titanium Sublimation pumps

These have been described in p̄ note 246 with their advantages. One should stress again that since they are consumable items, with "wear rate" proportional to the operating pressure, their real addantage is at low pressures where they provide large constant pumping speeds. For this reason, one usually starts them at pressures below 10^{-8} Torr, and when the outgassing has been sufficiently reduced by bake out. Figure 3 gives a typical pumping down cycle on the AA machine, showing their operating range.

4.3. Pumps sizes and spacings

Rather than following the usual reasoning (see p̄ note #297), we shall base the system on "a priori" known pumps sizes, and try to find the optimum spacing, for the following reasons:

- # the accumulator is even more conductance limited than the depuncher ($90\ \ell m\,sec^{-1}$ against $180\ \ell m\,sec^{-1}$),
- # gas loads are lower due to bake outs
- # Ti Su pumps have anyway such large pumping speeds that it hardly influences the average pressure on a conductance limited system.
- # There is a big interest (price wise & P. Supplies) to standardi[ze] ion pumps for both the debuncher and the accumulator, 270 l/s triode being a good compromise (p̄ note 297).

Annex 1&2 gives the conductances and gas loads which should be used in the calculation.

The average pressure between 2 pumps of equal pumping speed S is:

$$\bar{P} = AL\left(\frac{1}{S} + \frac{L}{12C}\right)$$

A: linear outgassing [$Tl\ sec^{-1} m^{-1}$], L [m] distance between pumps and C the conductance [$l\ m\ sec^{-1}$]

the minimum pressure that one can achieve is $\bar{P}_{min} = \frac{AL^2}{12C}$ giving the maximum distance that one can afford between 2 pumps:

$$L_{max} = \left(\frac{\bar{P}_{min} \times 12C}{A}\right)^{\frac{1}{2}}$$

Annex 3 gives the results for both ion and Ti pumping for the accumulator. As already said, the ion pumping assumption is that one should be able to reach 10^{-8} Torr with it, for the unbaked outgassing rate of 1.10^{-11} $Tl\ sec^{-1} m^{-1}$, obtained on a clean system after one month of pumping, or obtained at 150°C at the end of the bake out.

For the bending magnets, the optimum distances fit perfectly with the magnet lengths. The scheme would then be a TiSu pump in between every bending magnet, coupled to a 270 l/s triode ion pump every 2 magnets. In straight sections the same scheme applies, but with a spacing of between 7 to 8 meters between pumps. This gives some security margin as far as the ion pumping in straight sections.

Figure 4 shows the location of pumps for one sector.

5). Pumping of special equipment.

Special equipment like stochastic cooling PU's and kickers, injection ejection kickers, although not yet well known, can be anticipated to be sources of heavy gas loads. This brief survey aims at showing that Ti Su pumps can do the job in all cases, and should permit an estimation of the required number of pumps.

5.1. Stochastic cooling Pick Ups: $\bar{p}$ note #294

These are 18" I.D, 2.5 meters long tanks with a 8.9×10^{-7} Tl sec^{-1} gas load (after bake out) at Room temperature. Although they will be cooled at LN temperature, it is safe to design the pumping system so that it can cope with the RT figure: if this may be considered as expensive with only ion pumping, the cost surplus with Ti Su pumps is only very marginal.

<u>ion pumps</u>: we shall use the same argument as for the bending arcs: ion pumps should evacuate the system to 10^{-8} Torr without bake.

Assuming an outgassing rate without bake of 10 times the after-bake one:

$$q = 8.9 \times 10^{-6} \text{ Tl sec}^{-1}$$

the pumping speed has to be $S = \frac{q}{p} = 890$ l/sec, value which is too much for a single pump.

If one instead standardizes on 270 l/s triode pumps, the use of 2 such pumps will result in a pressure of 1.6×10^{-8} T, enough eventually to start firing Ti Su pumps in an emergency pump down without bake (See §4.).

Ti Sublimation pumps:

There the gas load is 8.9×10^{-7} Tl sec^{-1}, to be coped down to 10^{-10} Torr with standard 2000 l/s Ti Su pumps:

$$1 \cdot 10^{-10} = \frac{8.9 \times 10^{-7}}{x \cdot 2000} \Rightarrow x = 4 \text{ to } 5 \text{ pumps}$$

4 being probably sufficient.

To summarize, each stochastic cooling PU as defined in $\bar{p}$ note #294 could be safely pumped down to 10^{-10} Torr without the necessity of LN cooling, with

{ 2 × 270 l/s triode ion pumps
  4 × 2000 l/s Ti Su pumps

If one assumes that the price of 2 × 270 l/s ion pumps with power supplies is (see $\bar{p}$ note #286) 11'350 #, and a Ti Su pump with PS 2000 #, the total cost would thus be

19'350 #

compared to (see $\bar{p}$s # $\frac{294}{286}$) ~16'000 # for a 1000 l/s ion pump + PS and ≤10^{-9} Torr design pressure. Thus the difference in cost is only marginal between the two schemes, the former one giving a factor of 10 in pressure, down to $1 \cdot 10^{-10}$ Torr.

Finally one should say that the pumping speed can be further increased at no extra cost if one can sublimate directly into the PU tank. As indicated in $\bar{p}$ note # 296, care should only be taken not to sublimate titanium directly onto screens, insulators, etc. The practical rule to avoid this is: there should be no direct optical path between filament and the sensitive device. One to two optical reflexions are enough to make it safe in all known cases. Also proper care should be taken so that µwave emission from the filament acting as an antenna, into the PU's, is avoided.

Now, assuming to first approximation that all stochastic cooling equipments have the same gas load per meter of vacuum tank than the ones described above, the number of pumps can be extrapolated:

A60: 16 m of Stack Tail & core PU's:

Ti Su pumps: 1.6 pump per meter

⇒ 25.6, i.e. 26 Ti Subl. pumps

270 l/s triode pump: 1 pump per 1.25 meter

⇒ ~ 12 ion pumps.

A10: 2 x 2.5 m of core PU's:

⇒ 8 Ti Su pumps

⇒ 4 ion pumps

A20: 2 x 2.5 m of tail kickers, plus injection and extraction kickers. As can be seen in annex 4, the gas load per meter is just about the same than that of stochastic equipment.

thus ⇒ 4 x 4 = 16 Ti Su pumps

⇒ 4 x 2 = 8 ion pumps.

A30: ~16 m of tail and core kickers: this going to be probably at least the gas load per m of A20 PU's:

thus: ⇒ 26 Ti Su pumps

+ 12 ion pumps

As an alternative to 270 l/sec ion pumps, one could consider, at some expence of standardisation, having fewer but larger ion pumps, for instance of 500 l/sec nominal pumping speed. That would reduce to 18 the number of pumps, with the following advantage in price (prices taken from p̄ note # 28.6.)

Alternative 1
$$\begin{cases} 36 \times 270\ l/s = 36 \times 5875 = 211\ k\$ \\ +36\ \text{power S.} = 36 \times 2500^{*} = 90 \end{cases}$$
300 k$

Alternative 2
$$\begin{cases} 18 \times 500\ l/s = 18 \times 8750 = 157.5 \\ +18\ PS = 18 \times 2500^{*} = 45 \end{cases}$$
202.5 k$

Scheme 2 gives an almost 100 k$ in price. But this has to be modulated: FNAL is likely to build the power supplies, and the advantage for them may drop out. Also, one is not going to have a series price for 18 × 500 l/s pumps. Therefore, the two alternatives should be offered to manufacturers when asking for bids.

As a summary for the Accumulator special equipment, one has:

47 meters in total of 18" diameter tanks, with a 1.9×10^{-5} Tl sec^{-1} total gas load, pumped by 76 titanium sublimation pumps, and
36 270 l/s triode ion pumps
or 18 500 l/s " " ".

* Note: ~ Varian catalog price for multistandard Power Supply.

6). Pressure measurements - Gauges - RGA.

6.1 - High Pressure (10^{-1} - 10^{-7}). Pump down monitoring and interlocks.

This is usually done with coupled Pirani (thermocouple) - Penning heads. Apart of the ones necessary to interlock the high vacuum valves separating the roughing stations, some are needed (at least one per sector, preferably two for long sectors) on the vacuum chamber for the following purpose:

monitor the pump down. Once a normal, leak free pumpdown curve has been established with this high pressure gauge, it serves as a reference for later pumpdowns. Early detected deviations from the reference, serve in tracing quickly an eventual leak or closed valve (or open!).

as interlock to prevent switching on sublimation and ion pumps at atmospheric pressure.

Taking a minimum of one per sector, plus 8 units for the roughing stations, this gives a total of

14 Penning - Pirani units for the whole accumulator.

6.2. Ionization gauges ($> 5 \cdot 10^{-11}$ Torr)

For a nominal pressure of 10^{-10} Torr, there is no need for the X ray modulation gauge type, but care must be taken in providing some mass spectrum analysers. Gauges have to be located such that they give a good idea of the average pressure in the ring (for instance stochastic cooling equipment, kickers etc.). In UHV they are often used to locate leaks quickly, using Argon as tracer, taking advantage of its large ionisation cross section and corresponding Argon high sensitivity,

6.3 - Residual Gas Analysers (RGA)

these are also very useful on a UHV system. For 10^{-10} Torr total residual pressure, a minimum detectable partial pressure of 1×10^{-14} Torr has to be specified for the RGA. RGA's are used to assess on the cleanliness of the system, to detect leaks, and to provide essential data for improvement of the system. A multi head multiplexer scheme is being foreseen. Heads should be located preferentially on high degassing items.

Figure 5 shows a possible pressure measurement scheme for the accumulator. Gauges and RGA should be mounted on the Ti Sublimation pump manifold, where flanges are likely to be provided.

7. Bake out and controls

these will be the object of a separate study.

The following table gives a summary of the necessary pumps and measuring devices for the accumulator.

ACCUMULATOR RING UHV SYSTEM

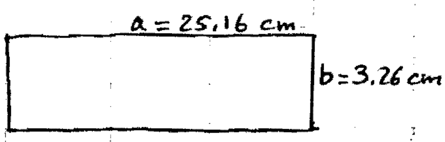
PARAMETER LIST

DESIGN PRESSURE :	1.10^{-10} TORR
SPECIFIC OUTGASSING :	1.10^{-12} $T\ell\,sec^{-1}\,cm^{-2}$
AVERAGE CONDUCTANCE :	90 $\ell m\,sec^{-1}$ for AIR
DESIGN BAKEOUT TEMP :	300 °C
NORMAL BAKEOUT TEMP :	150 °C
4" I.D ALLMETAL VALVE :	4
10" I.D. ALLMETAL VALVE :	1
ROUGHING STATIONS :	8 SEMI FIXED
TURBO SPEED :	330 - 450 $\ell\,sec^{-1}$
VANE PUMP :	12 $m^3 h^{-1}$
VALVE :	6" I.D. VITON SEALED
TRIODE ION PUMPS :	
270 l/sec :	72
OR :	
270 l/sec :	36
500 l/sec :	18
TITANIUM SUBLIMATION PUMPS : (1500 - 2000 l/sec)	142
PIRANI - PENNING GAUGE UNITS :	8 ON ROUGHING GROUPS + 6 ON VAC CHAMBER
IONISATION GAUGES :	12
RESIDUAL GAS ANALYSER HEADS :	6

ANNEX 1 : ACCUMULATOR CONDUCTANCES AND GAS LOADS

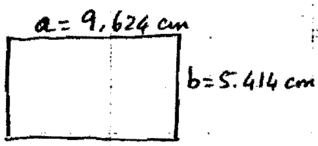
(specific outgassing : $q = 1.10^{-12}$ $T\ell\, sec^{-1} m^{-1}$)

LARGE BENDING MAGNETS :



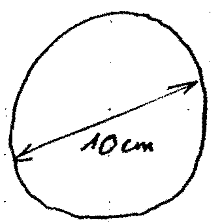
	Perimeter	Conductance*	Gas Load
LARGE BENDING MAGNETS	57 cm	110 $\ell m\, sec^{-1}$	$A = 5.7 \cdot 10^{-9}$ $T\ell\, m^{-1} sec$

SMALL BENDING MAGNETS :



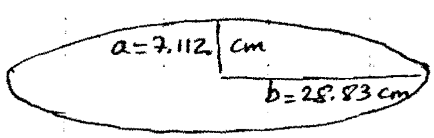
	Perimeter	Conductance*	Gas Load
SMALL BENDING MAGNETS	30	64	3×10^{-9}

SMALL QUAD & STRAIGHT SECTIONS :



	Perimeter	Conductance*	Gas Load
SMALL QUAD & STRAIGHT SECTIONS	31.4	121	3.14×10^{-9}

LARGE QUAD :
~(ELLIPTICAL)



	Perimeter	Conductance*	Gas Load
LARGE QUAD	66	300	7×10^{-9}

---

*See P note 297 for formulae - FOR AIR !

CERN's experience for outgassing
ON A UHV CLEANED-BUT-NOT-BAKED*
VACUUM SYSTEM (LEAR + AA)

10 hours of pumping	$\longrightarrow$	$2 \cdot 10^{-9}$ Tl sec^{-1} cm^{-2}
1 day	$\longrightarrow$	7×10^{-10} "
3 days	$\longrightarrow$	2×10^{-10} "
2 weeks	$\longrightarrow$	2×10^{-11}

After several months, one may expect, for a clean system:

$$\sim 7 \times 10^{-12}$$

*: Means all chamber parts vacuum fired at 950 °C under good vacuum $p \leq 10^{-5}$ Torr.

Annex 3: Optimum distances between pumps AND AVERAGE PRESSURES

			$q = 1\cdot10^{-12}$ T l sec^{-1} cm^{-2}		$q = 1\cdot10^{-11}$ T l sec^{-1} cm^{-2}	
			2000 l/s		270 l/s	
	PERIMETER (CM)	CONDUCTANCE (l m sec^{-1})	L_{MAX} Ti Su PUMPS (m)	$\overline{P}$ average Ti Su (Torr)	L_{MAX} ION PUMPS (m)	$\overline{P}$ average ion pumps (Torr)
1) LARGE BENDING MAGNET CHAMBER	57	110	4.8	$1.1\cdot10^{-10}$	15.2	$1.3\cdot10^{-8}$
2) SMALL BENDING MAGNET CHAMBER	30	64	5.06	$0.97\cdot10^{-10}$	16	$0.85\cdot10^{-8}$
3) SMALL QUAD & STRAIGHT SECTIONS	31.4	121	6.8	$1.33\cdot10^{-10}$	21.5	$0.7\cdot10^{-8}$
4) LARGE QUADS	70	300	7.17	$1.25\cdot10^{-10}$	22.7	$1\cdot10^{-8}$

$$\overline{P}_{av} = AL\left(\frac{1}{S} + \frac{L}{12C}\right); \quad \overline{P}_{min} = \frac{AL^2}{12C}; \quad L_{max} = \left(\frac{\overline{P}_{min}\cdot12\cdot C}{A}\right)^{1/2}$$

- Annex 4 -

INJECTION / EJECTION KICKERS -
ROUGH ESTIMATION OF THE GAS LOAD

Each tank is 250 × 45 cm long, stainless steel, with 3 magnets + shutter.

1 Magnet: 36 ferrite blocks Ø6".25 : 17'687 cm²

18 Ceramic plates 12" × 5.5" + insulators : 14'000 cm²

27 Stainless steel plates : 17'757 cm²

49'444 cm²

1 tank:

3 Magnets → 3 × 49'444 = 148'332 cm²

+ St. Steel tank 250 × π × 46 = 35'908 cm²

+ Aluminium shutter 250 × 20 = 5'000 cm²

189'240 cm²

+ contingencies → 200'000 cm²

(a) If Ceramics, Ferrites, Stainless steel are all degassed at 950°C 10^{-5} Torr:

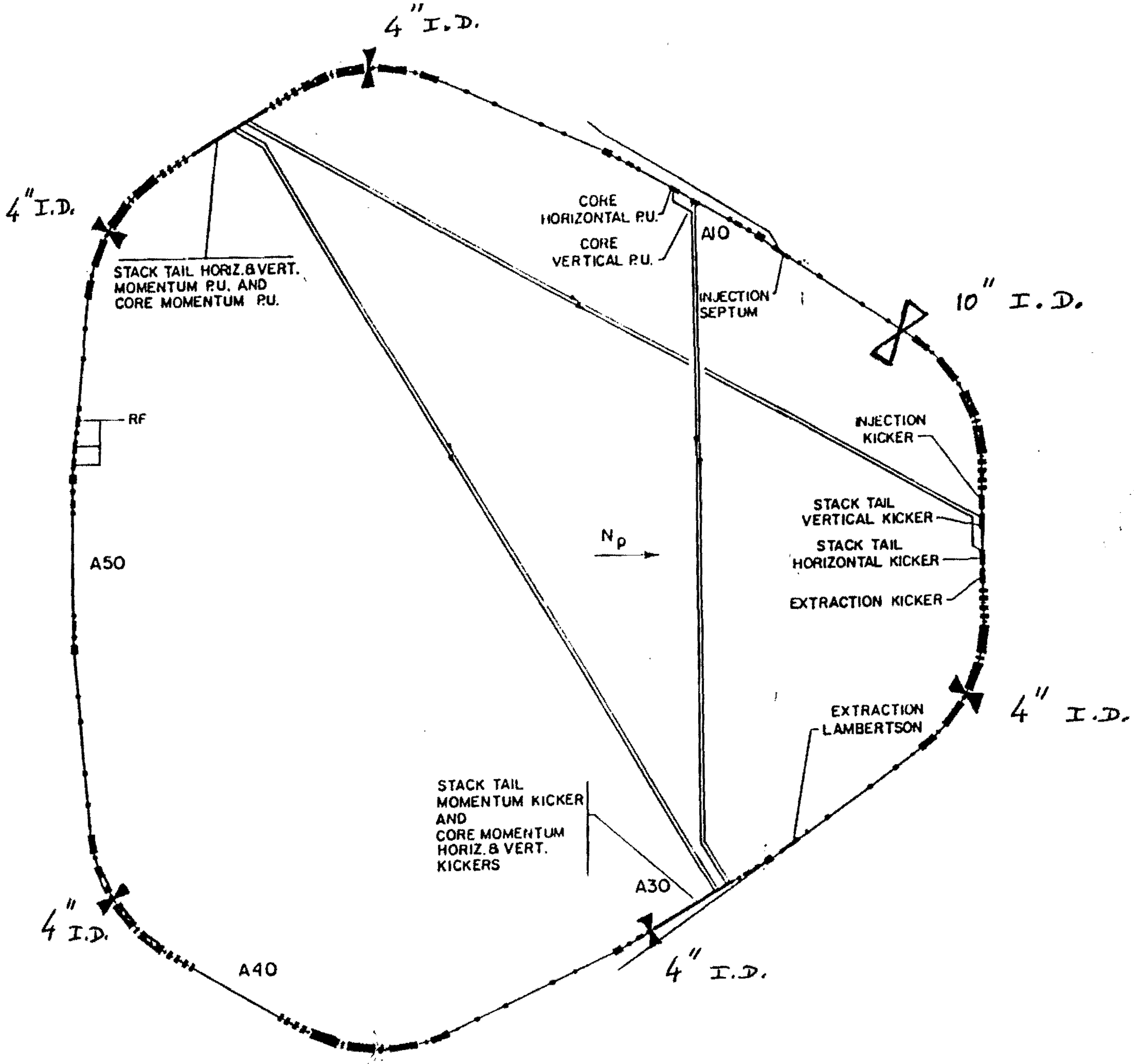
$$q = 1 \times 10^{-12}\ \text{Tl sec}^{-1}\ \text{cm}^{-2}$$

then total gas load $Q = 2 \times 10^{-7}\ \text{Tl sec}^{-1}\ \text{cm}^{-2}$

(b) If ferrites are not degassed → $q_{ferrite} = 1 \cdot 10^{-11}\ \text{Tl sec}^{-1}\ \text{cm}^{-2}$ and one has to add: $17'687 \times 3 \times 1 \times 10^{-11} = 5.3 \times 10^{-7}\ \text{Tl sec}^{-1}\ \text{cm}^{-2}$

so that the total gas load is $\underline{7.3 \times 10^{-7}\ \text{Tl sec}^{-1}\ \text{cm}^{-2}}$

That value should be taken, from AA experience (there is some hint that ferrite would eventually catch back its gas load with time and air exposures)



- FIGURE 1 :

LOCATION OF ALL METAL BAKEABLE GATE VALVES (VAT)

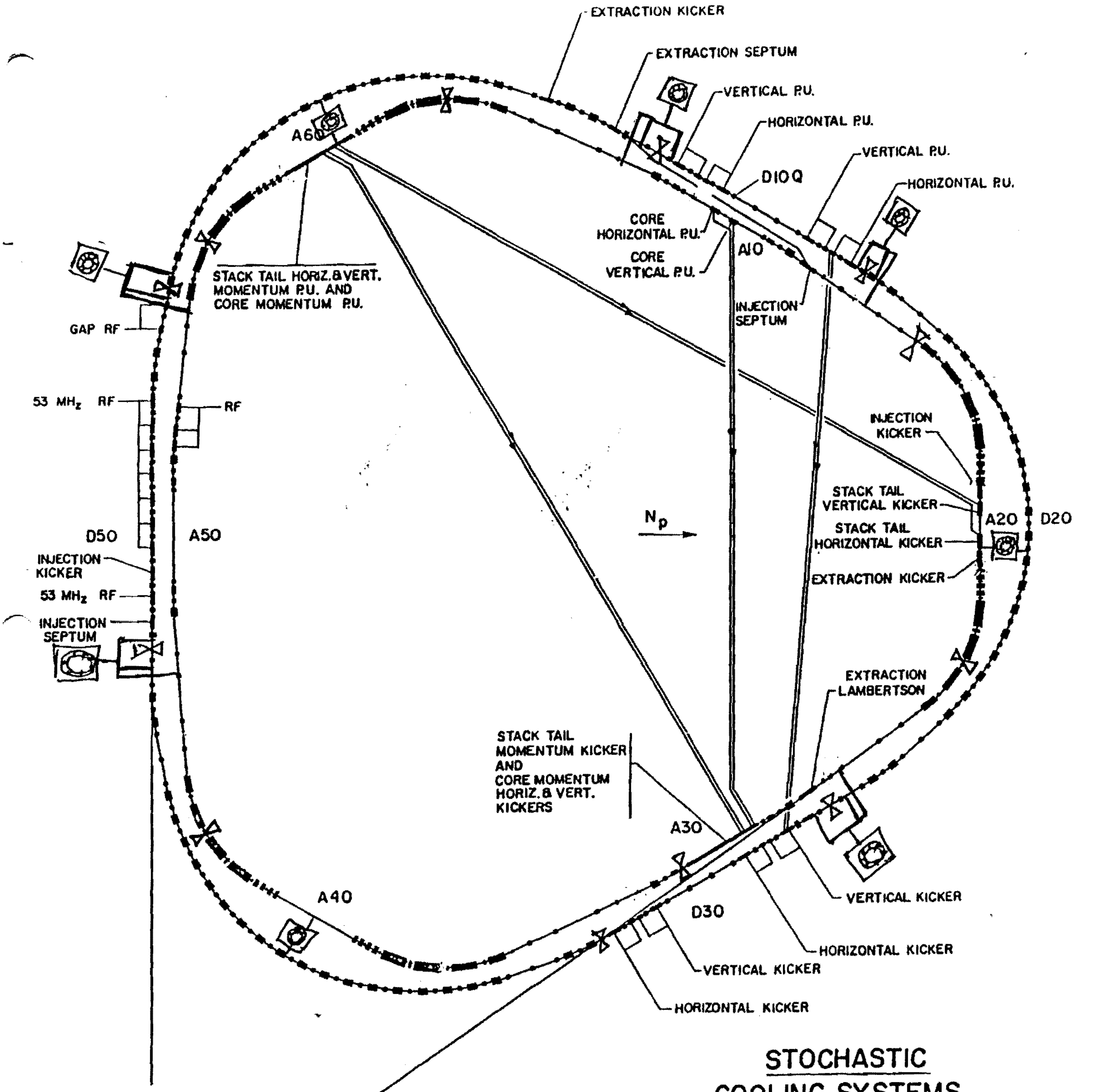
6 Sectors

5 x 4" GATE VALVES = 5 x 6'000 = 30'000 $ *

1 x 10" GATE VALVE = 1 x 18'000 = 18'000

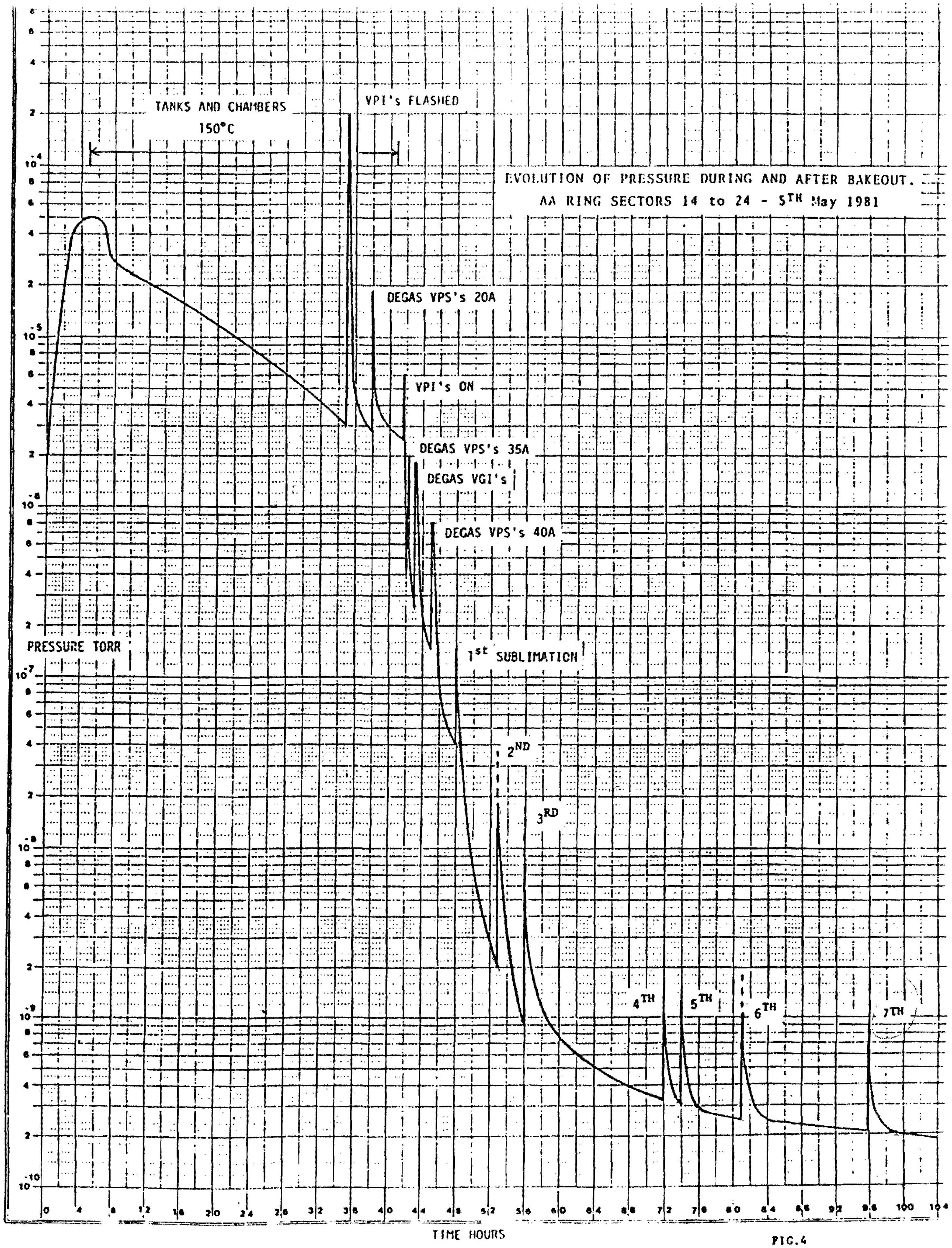
Σ = 48'000 $

* EUROPEAN PRICES.



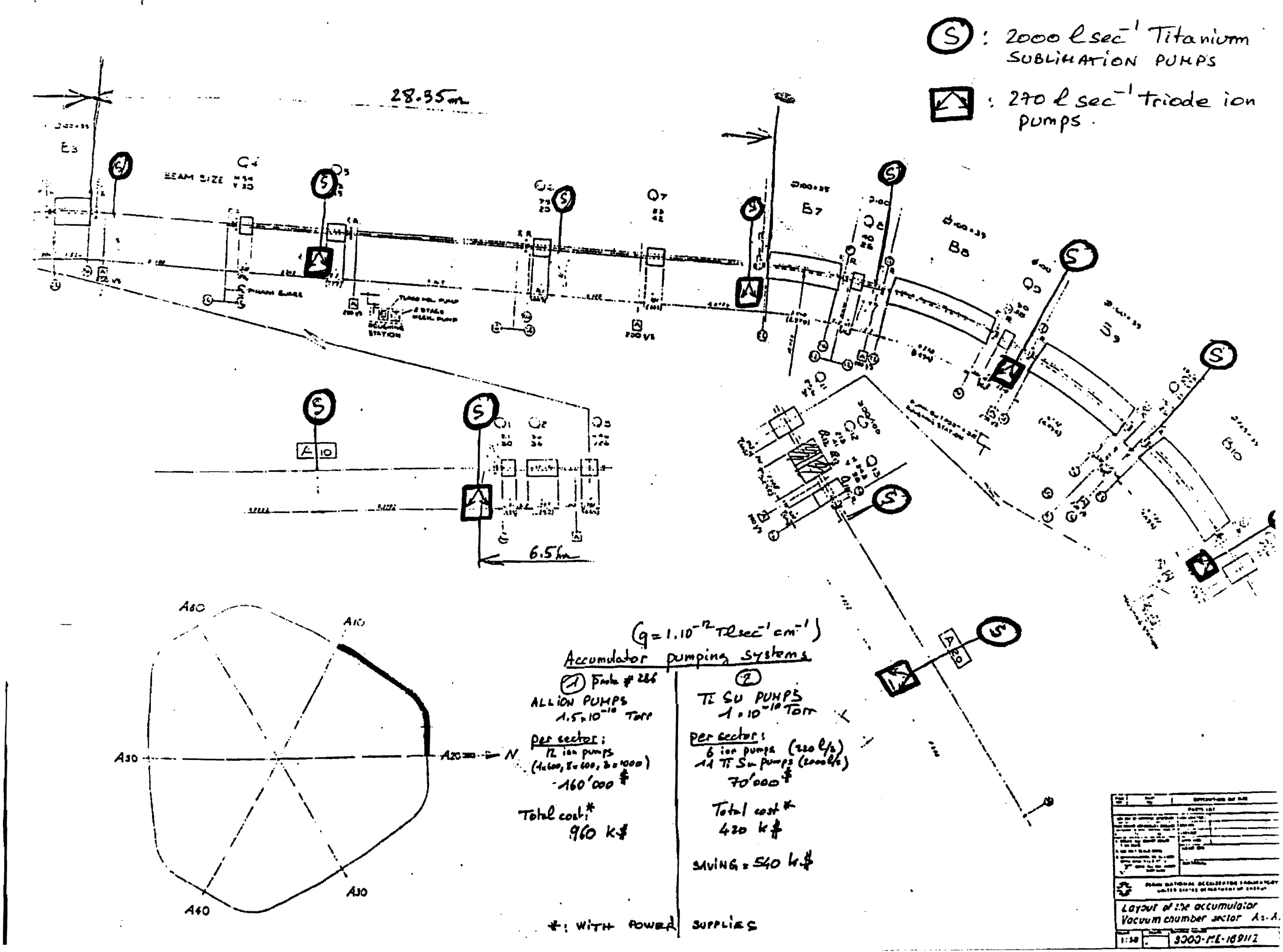
- FIGURE 2: POSITION OF COMMON SEMI FIXED ROUGHING STATIONS

8 GROUPS { Turbo: 330 – 450 l/s
2 stages Vane pump: 12 m^3/h
+ VITON SEAL VALVE 6" I.D.


EVOLUTION OF PRESSURE DURING AND AFTER BAKEOUT.
AA RING SECTORS 14 to 24 - 5TH May 1981
TANKS AND CHAMBERS
150°C
VPI's FLASHED
DEGAS VPS's 20A
VPI's ON
DEGAS VPS's 35A
DEGAS VGI's
DEGAS VPS's 40A
1st SUBLIMATION
2ND
3RD
4TH
5TH
6TH
7TH
PRESSURE TORR
TIME HOURS
FIG.4

— Figure 3 —

FIGURE 1: Accumulator pumping System



12 x O : IONISATION GAUGE
6 x D : RESIDUAL GAS ANALYSER HEAD
6 x □ : PIRANI-PENNING GAUGE UNITS

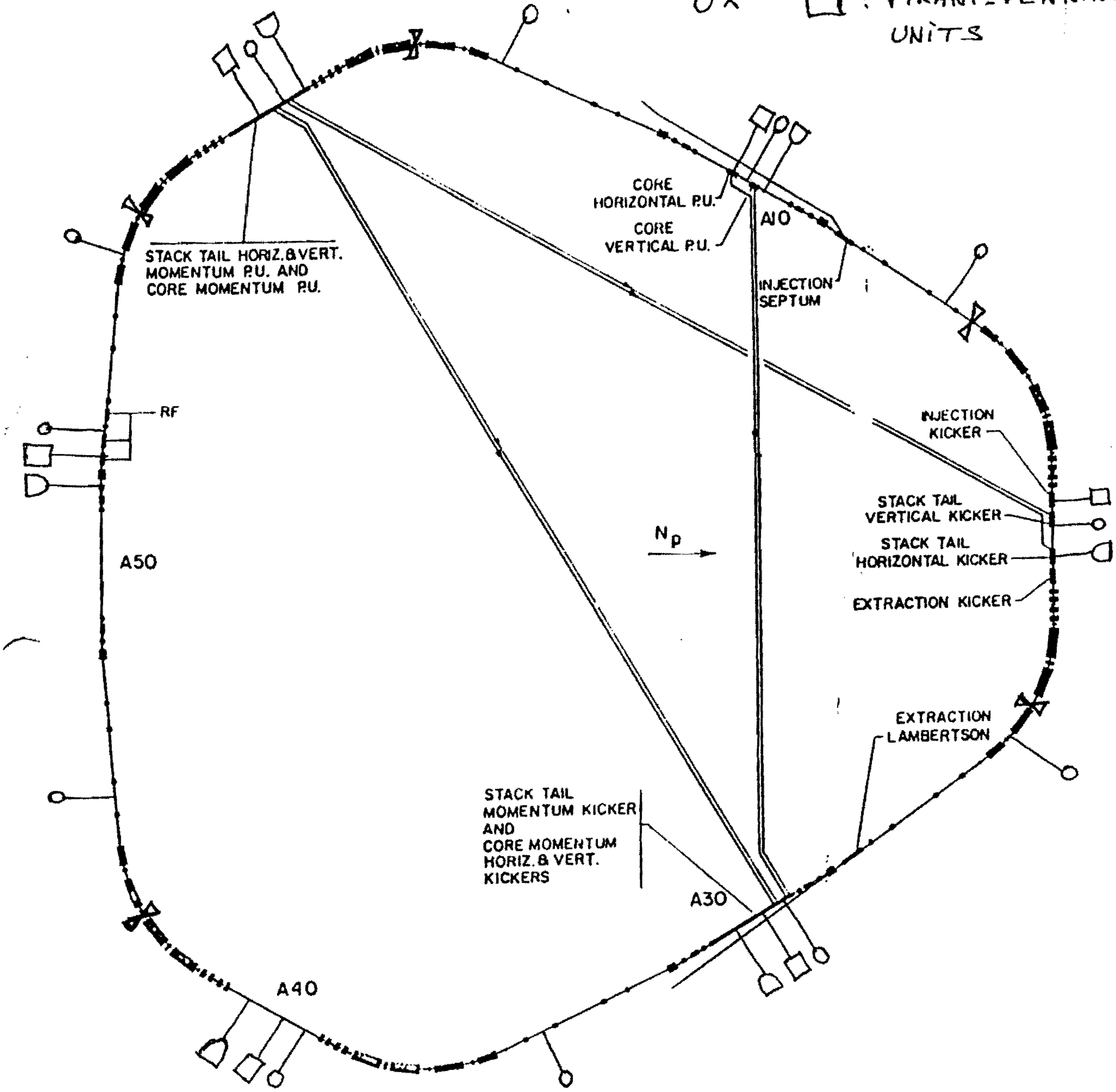


FIGURE 5

GAUGES AND ANALYSER HEADS LOCATION