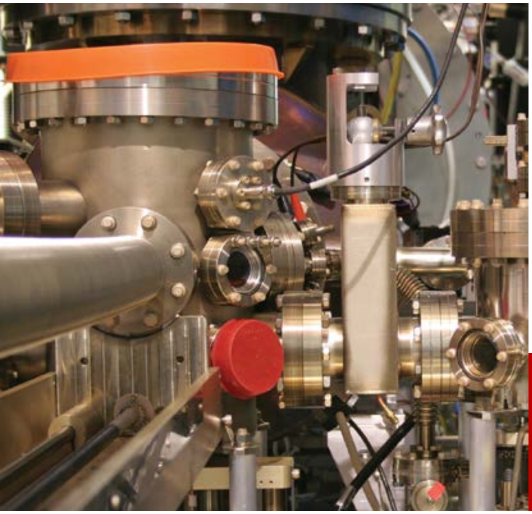


Table of Contents

SESSION 4.3: Getters

- Getters pump gases by chemically bonding molecules to surfaces upon impingement
- Two definitions of pumping capacities:
  - → Activation capacity
  - → Termination capacity
- Based on activation manner, there are two types of getters:
  - → Titanium sublimation pumps (TiSPs)
  - → Non-evaporable getters (NEGs)
- Both TiSPs and NEGs are widely used in accelerator vacuum systems

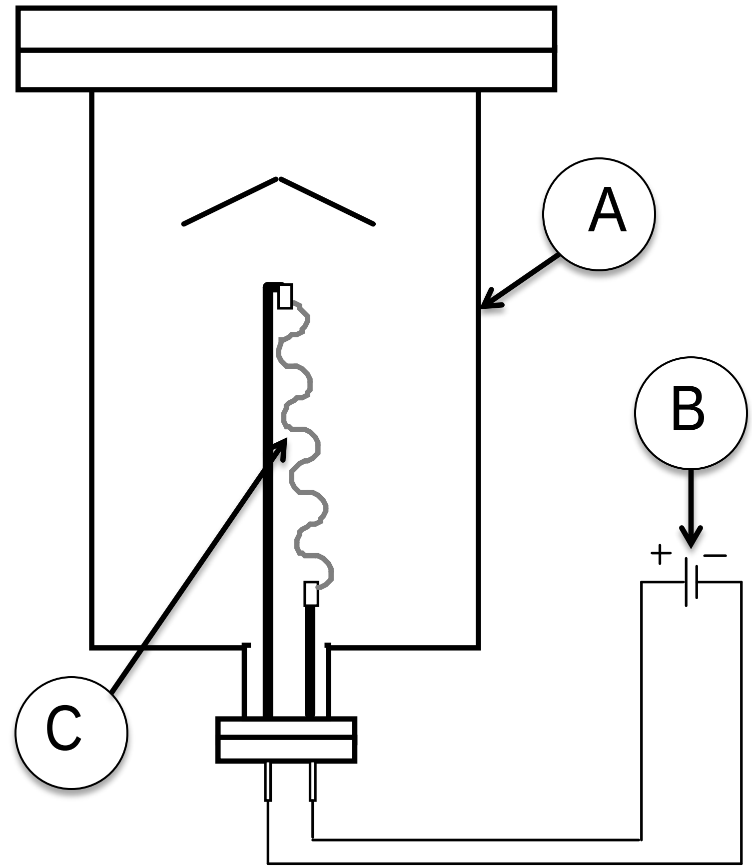
Session 4.3A
Titanium Sublimation Pumps

Titanium Sublimation Pumps – Basics

- A TiSP simply consists of three basic elements:

  → A source from which titanium is sublimed (C)
  → A power supply to heat the source (B)
  → A surface onto which the titanium is sublimed, and is accessible to the arriving active gas. (A)

- Thus no manufacturer sells a TiSP 'pump', only the Ti sources (and a power supply)



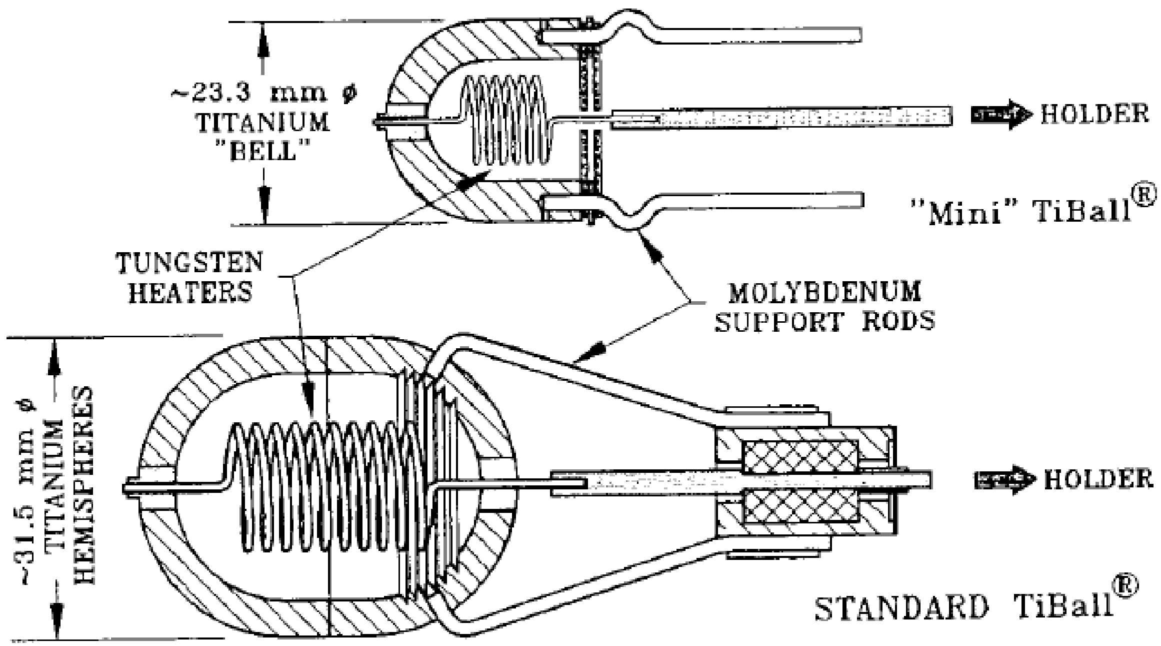
Example of a TiSP System

Titanium Sources – Filamentary Types

- *Filaments made of 85%Ti-15%Mo are most common sources of titanium used in TiSPs.*
- *The filament is resistively heated during sublimation process.*
- *In most cartridges, multiple filaments are loaded.*

Titanium Sources – Radiated Heating

More suitable for very high throughput pumping application.



Varian Vacuum

Ref. "A Radiant Heated Titanium Sublimator," Proc. 5th Int. Vacuum Congress, 1971, JVST 9 (1), 552 (1972)

- ***Sources require operation at some level of standby power to maintain Titanium temperature above 900°C.***
- ***Very inefficient heating, and require relatively high heating power.***

TiSPs – Pumping Speed

A TiSP is simply a surface conductance limited pump. The pumping speed depends on ***unit surface conductance (C_i)*** *to the Ti-covered* ***surfaces (A)*** *and* ***gas sticking coefficient****.*

$$S_i\left(m^3/s\right) = \alpha_i C_i A = 36.24\sqrt{\frac{T}{M}} \cdot \alpha_i A\left(m^2\right)$$

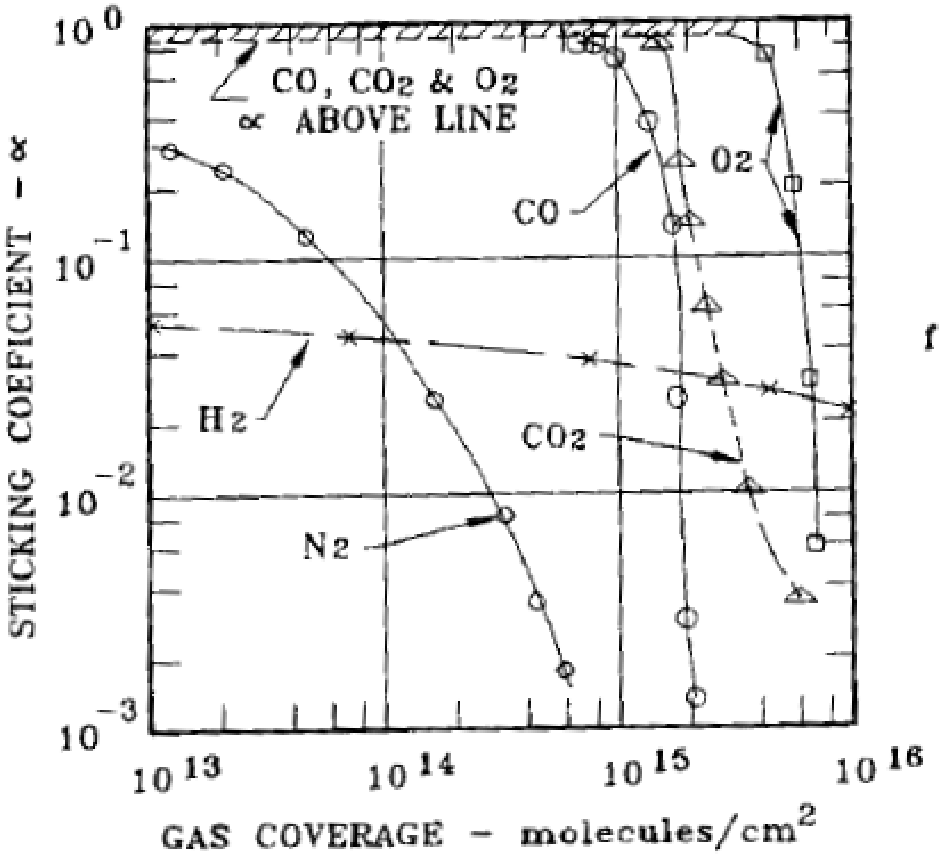
Or

$$S_i\left(L/s\right) = 3.624\sqrt{\frac{T}{M}} \cdot \alpha_i A\left(cm^2\right)$$

T – Temperature of gases (Kevin)
M – Gas molar mass
A – Ti covered area (in m^2 or cm^2)
α_i – sticking coefficient for "i" gas molecules

Sticking Coefficient

- ✓ *Sticking coefficient is strongly gas reactivity dependent*
- ✓ *For most active gases, the sticking coefficient decrease with adsorbed quantity, with various behavior, due to surface deactivation.*
- ✓ *Ti film has very high capacity for hydrogen, indicating 'bulk' diffusion for dissociated H atoms.*



Ti layer: ~10^{16} atoms/cm^2

Factors Influencing Sticking Coefficient

- Thickness of Titanium film
- Ratio of pumping speed to Titanium sublimation rate
- Surface temperature at the time of sublimation
- Surface temperature at the time of gas sorption
- Film deposition process (batch or continuous)
- Gas species
- Gas desorption and synthesis at Titanium source
- Partial pressures of gases at time of sublimation
- Contamination of film by some gas
- Effects of film annealing
- Variations of surface and bulk diffusion processes

Pumped or/and Displaced Gases

Pumped Gas	Displaced Gas				
	CH_4	N_2	H_2	CO	O_2
CH_4		no	no	no	no
N_2	yes		no	no	no
H_2	yes	yes		no	no
CO	yes	yes	yes		no
O_2	yes	yes	yes	yes	
α_m	$<10^{-3}$	0.3	0.05	0.85	0.95

This is controversial and probably only true for CH_4 and H_2.

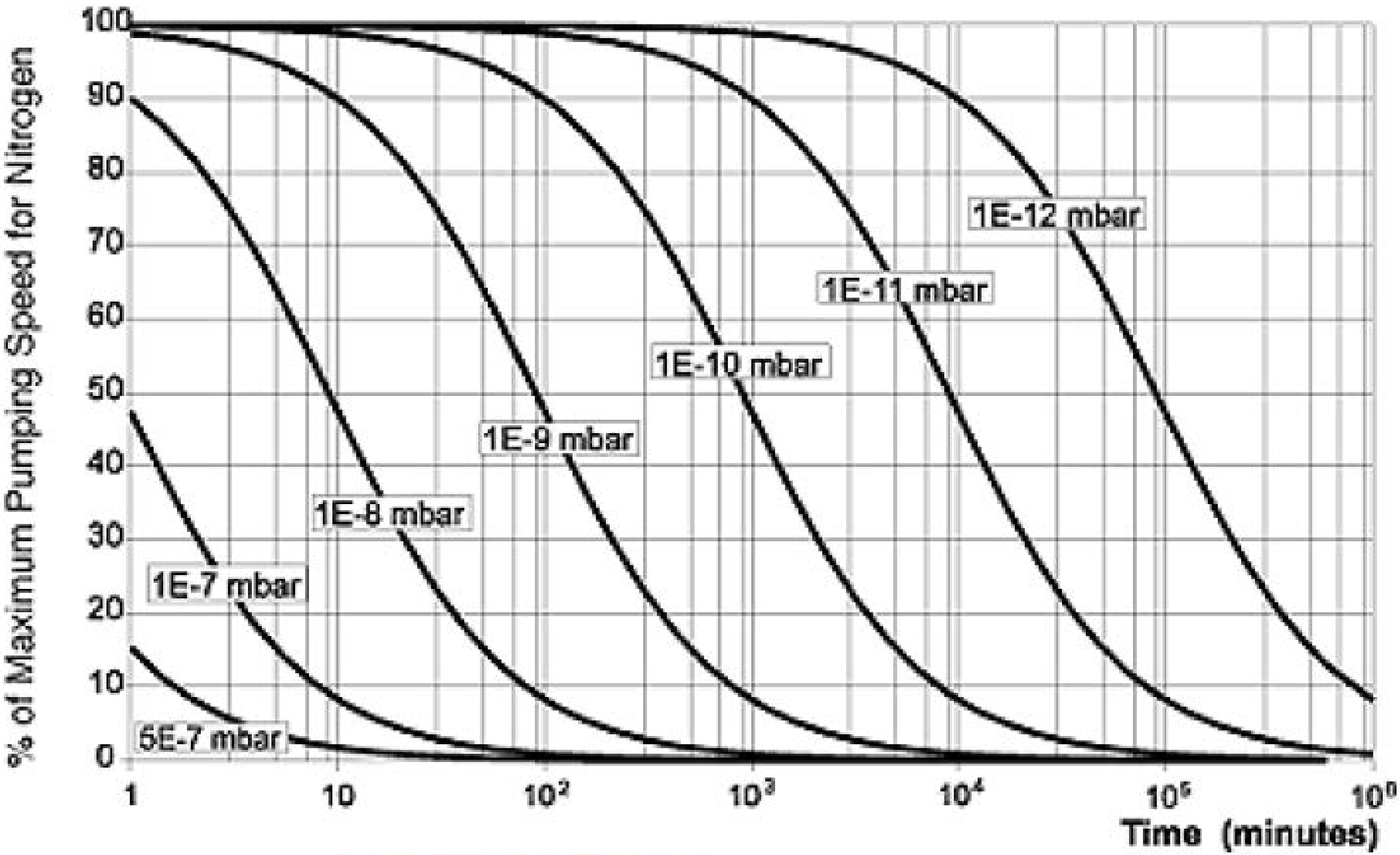
Typical Engineering Values for TiSP

Test Gas	Max. Sticking Coefficient-α_m		Max. Speed[a] (liters/sec-cm^2)		Max. Capacity of Film- x10^{15} (molecules/cm2) [b]	
	300 K	77 K	300 K	77 K	300 K	77 K
H_2	0.06	0.4	2.6	17	8-230[c]	7-70
D_2	0.1	0.2	3.1	6.2	6-11	-
H_2O	0.5	-	7.3	14.6	30	-
CO	0.7	0.95	8.2	11	5-23	50-160
N_2	0.3	0.7	3.5	8.2	0.3-12	3-60
O_2	0.8	1.0	8.7	11	24	-
CO_2	0.5	-	4.7	9.3	4-12	-

a) Speed calculated at RT
b) Wide variations due to film roughness
c) Wide variations due to bulk diffusion into film

(Ref. "Sorption of Nitrogen by Titanium Films," Harra and Hayward, Proc. Int. Symp. On Residual Gases in Electron Tubes, 1967)

Pumping Capacity – Just an Example



Ref. Varian Vacuum

Batch vs. Continuous Sublimation

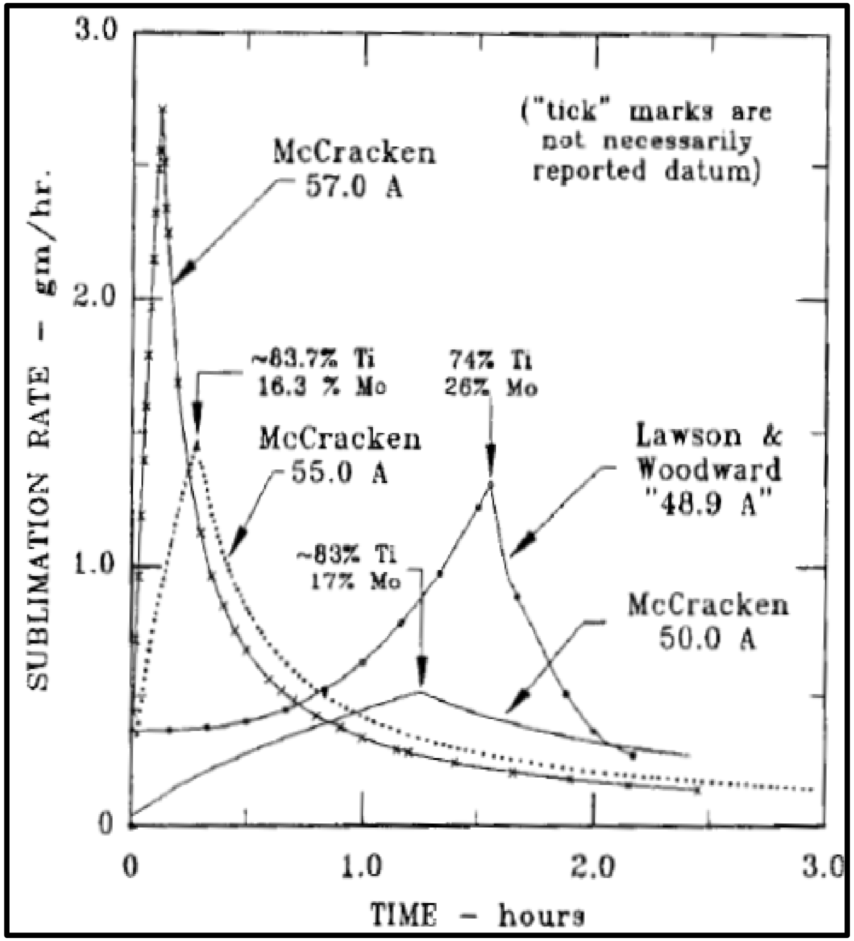
- For some high gas load, high throughout applications, Ti may be continuously sublimated. In the continuous sublimation mode, proper cooling must considered.

- In most applications, Ti is periodically sublimated as the Ti layer is saturated. This is referred as "batch sublimation". In a batch sublimation mode, the timing of the sublimation is usually rely on independent pressure measurement.

- In batch-mode sublimation, one may choose various control modes: constant current, constant voltage or constant power.

Sublimation Mode – Constant Current

- *Constant current operation of Titanium filaments produces increases in sublimation rates early in the filament life.*
- *This is probably due to the progressively leaner mixture of titanium in the filaments.*
- *Filaments develop rougher surface textures as the mixture changes.*
- *Rougher texture*
  = greater surface area
  = higher emissivity
  = lower operating temperature
  = lower sublimation rates.



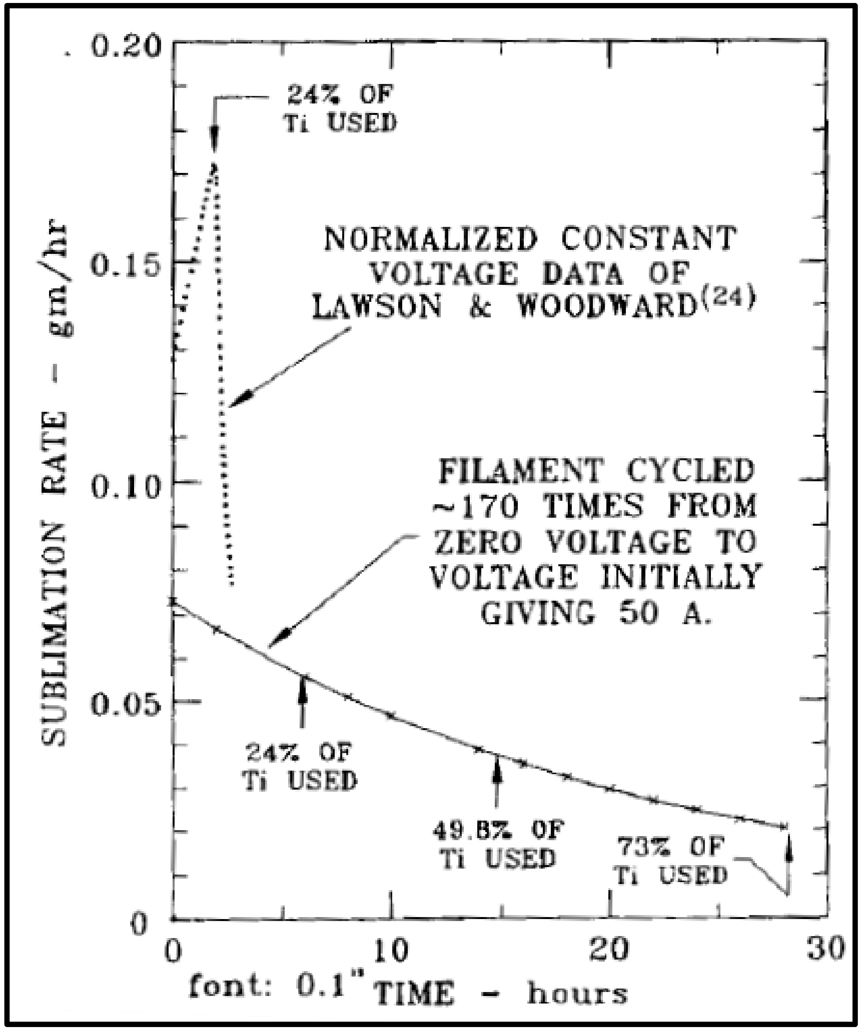
Sublimation Mode – Constant Voltage

- ***Constant voltage operation is rarely done.***
- ***Constant voltage operation in conjunction with RT cycling produces more predictable sublimation rates***

$$R(t) = R_o\, e^{-at}$$

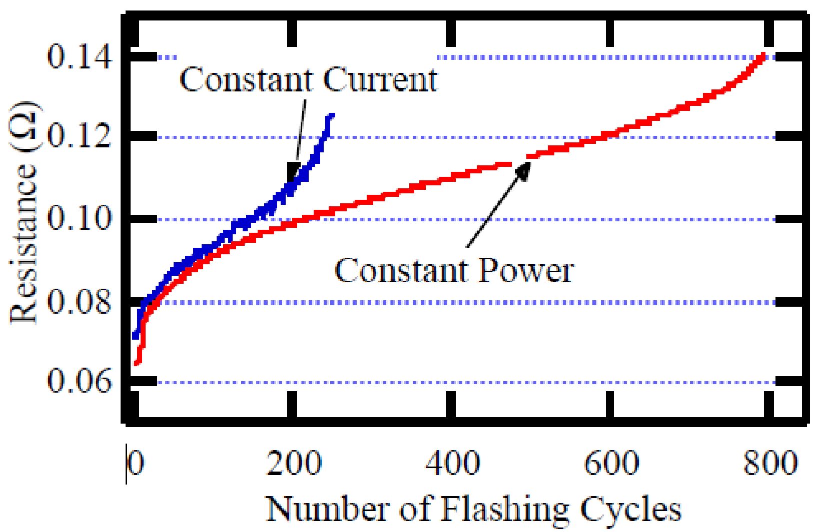
where R_o = ***initial sublimation rate***
a = ***constant***
t = ***cumulative sublimation time***

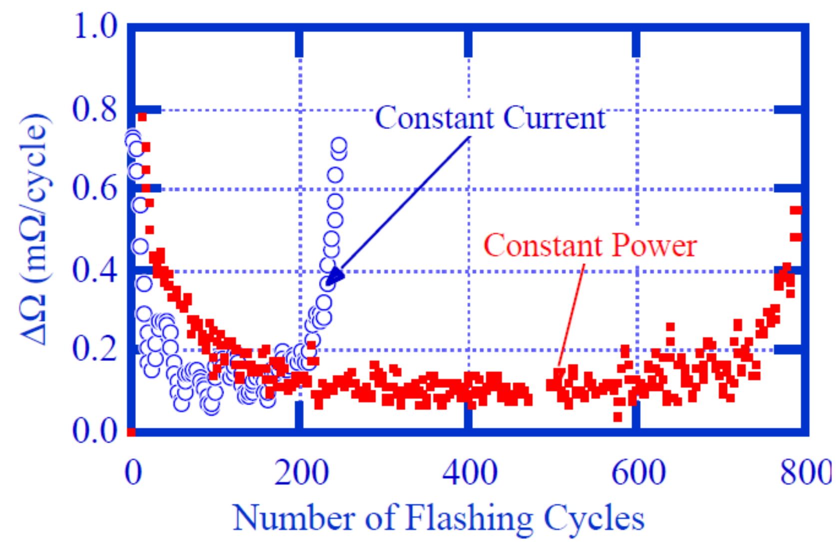
- ***Titanium sublimation rates are dependent on Ti and Mo proportions <u>and</u> the number of temperature cycles through the crystallographic transformation temperature.***



Sublimation Mode – Constant Power

- *At CESR, we choose a constant power approach for Ti sublimation (with a LabView® PID controller).*
- *Using resistance change as a measure of sublimation rate, the constant power mode provide very long term stability of the sublimation rate.*
- *Constant power mode also ensures longer lifetime of Ti filament.*



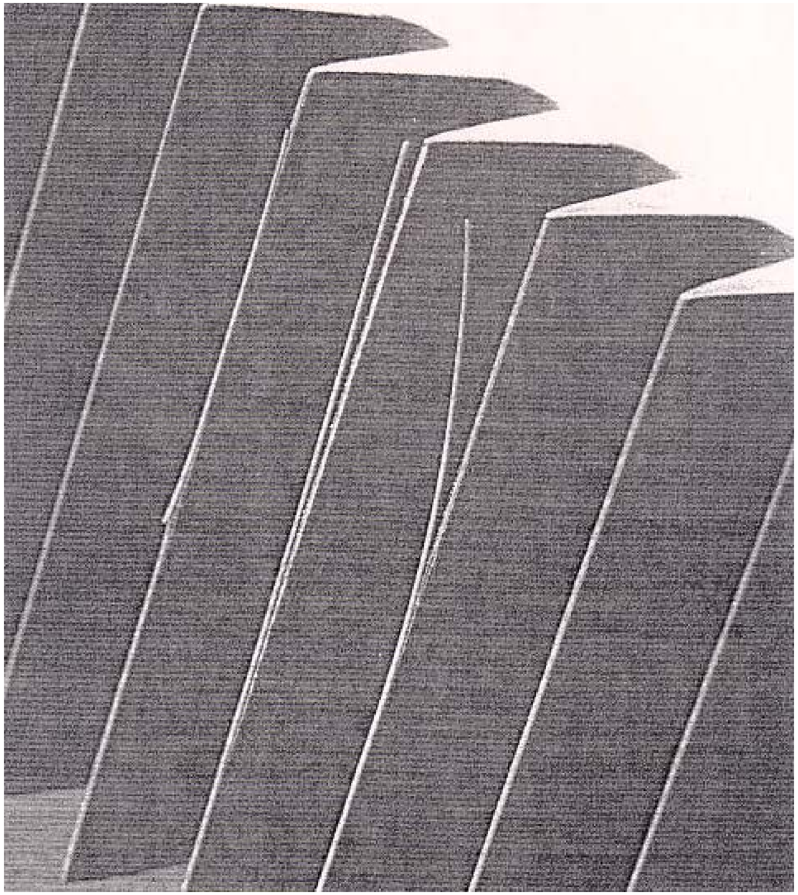


TiSPs for Accelerators – Some Considerations

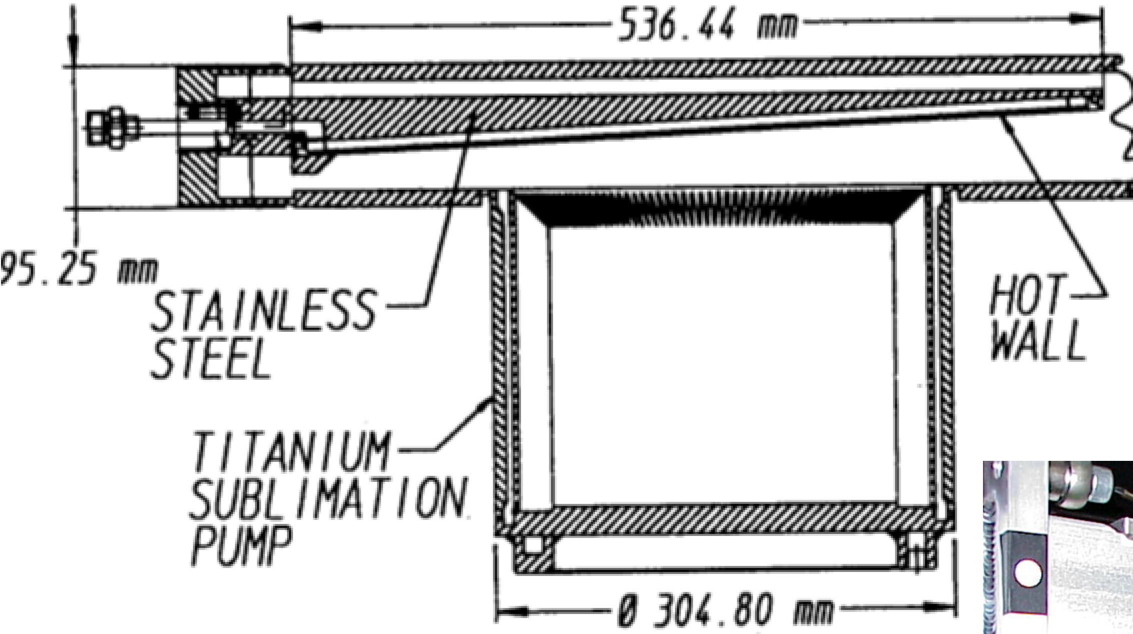
- *Gas throughput must be estimated for use of TiSPs, so that the sublimation period may be reasonable for the accelerator operations. Measures should be taken in design to maximize Ti covered surface area.*
- *Baffles must be in place to block all line-of-sight between the Ti filaments and the particle beam space.*
- *For very long term operations, Ti thin film peeling may be an issue. Orientation and placement of Ti filaments play a role in minimize particle generations to the beam space.*
- *Ti filaments may become EMI antennae when not properly shielded against short bunched particle beam. Sometime RF filtering in necessary.*
- *Adequate protections (mechanical and corrosive) are important for the electric feedthroughs on the Ti cartridges.*

Peeling of Titanium Films

- As Titanium builds-up on a pumping surface, it will begin to peel.
- A typical thickness where peeling begins is 0.05 mm.
- Peeling produces dust particles and increases surface temperatures during sublimation.
- Because of peeling, pumping surfaces may require periodic cleaning (glass bead blasting and/or chemical cleaning).
- If peeling is a problem, a TSP was probably a bad choice or you are misusing the pumps.

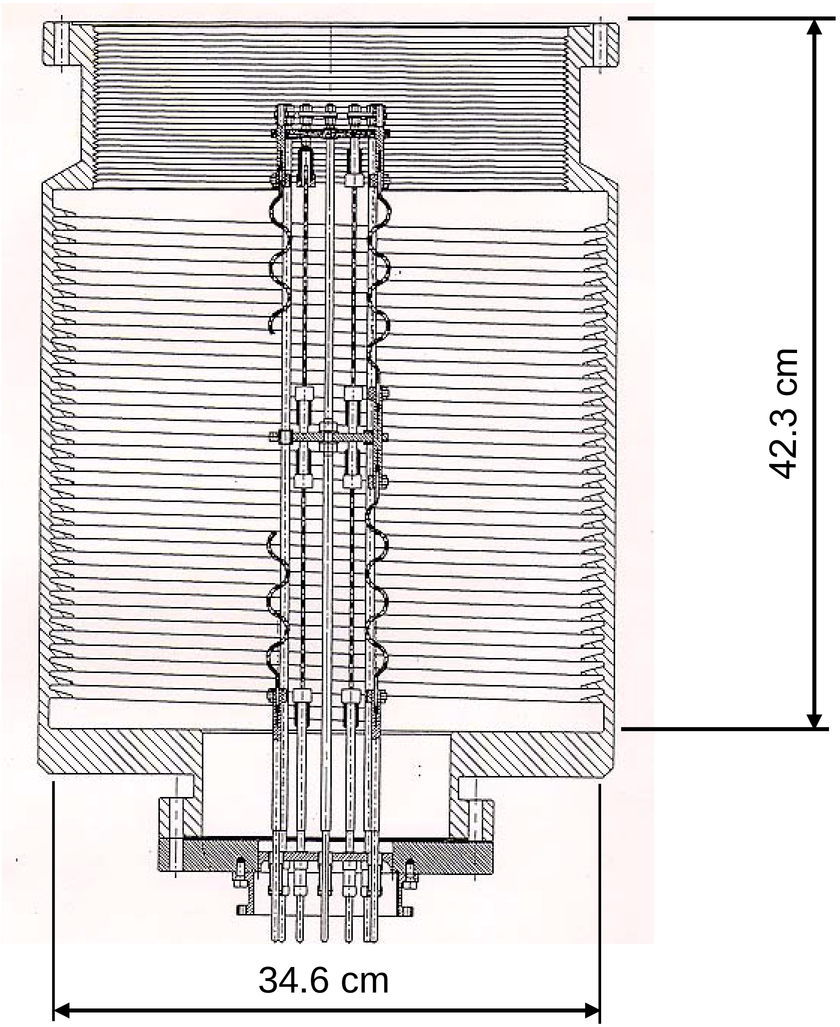


PEP-II LER Arc TSP and Photon Stop



DAFNE Collider TiSP

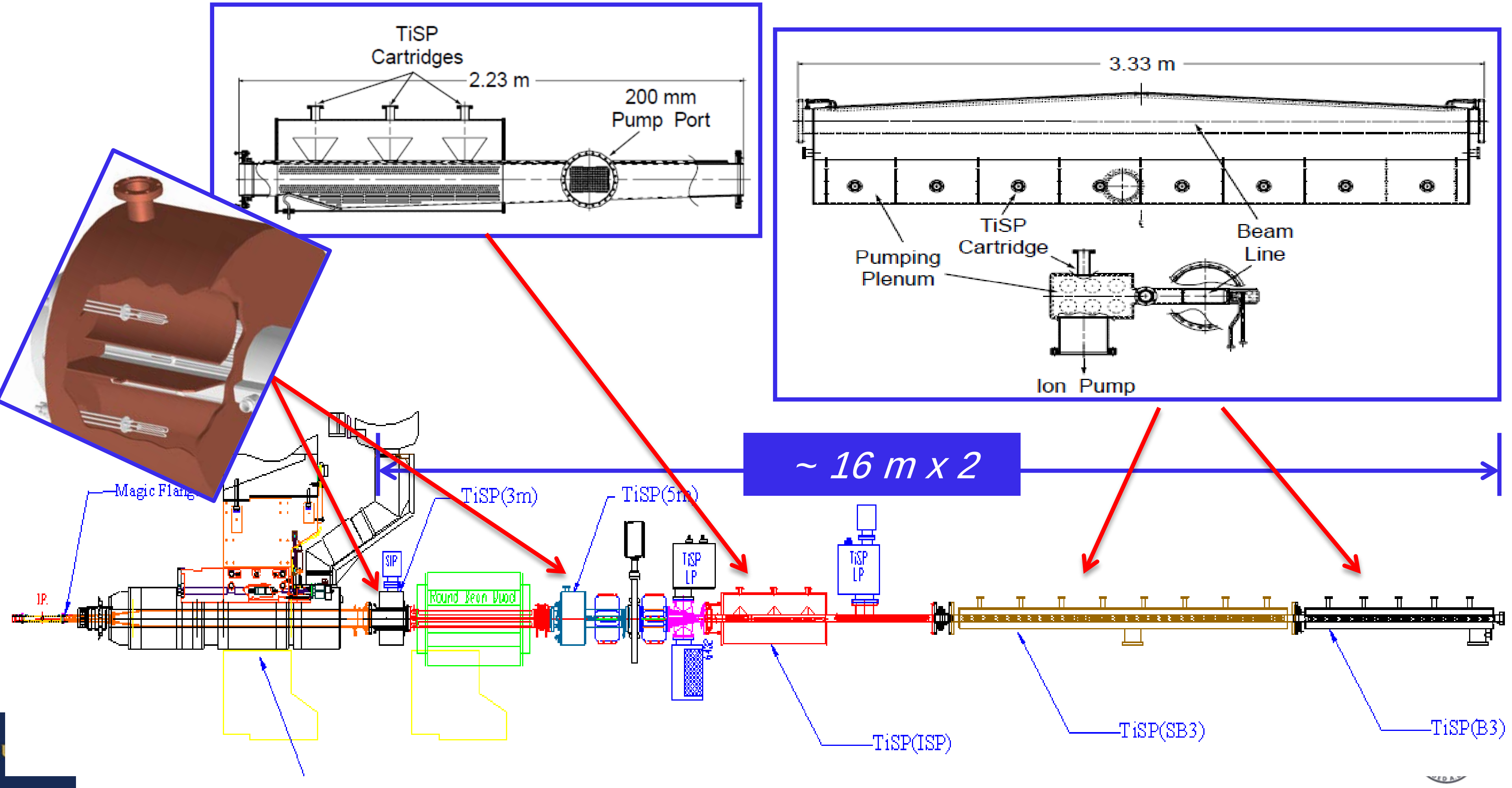
- Used at photon stops
- Specially ordered cartridge with more filaments
- Grooved interior surfaces to increase pumping speed and capacity



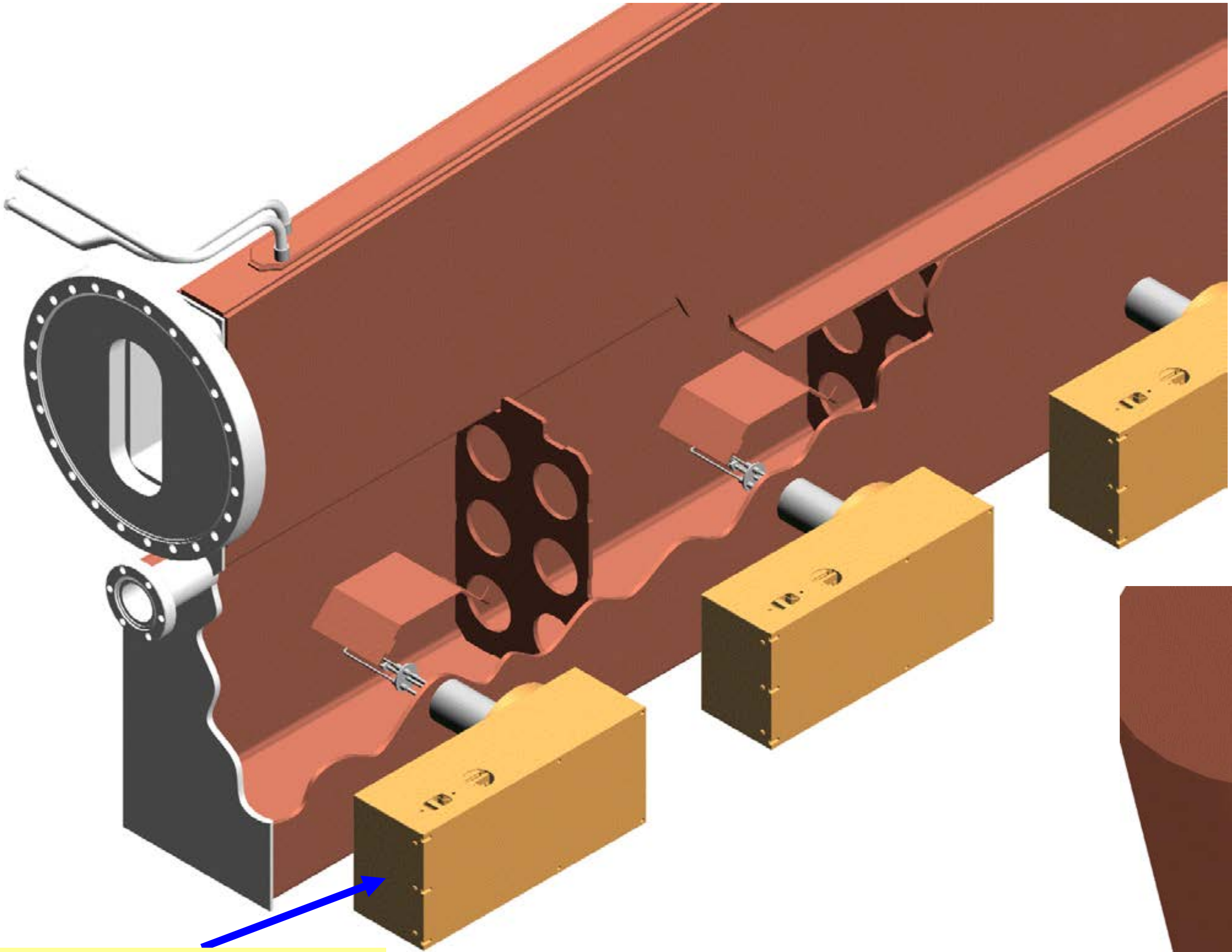
Courtesy: C. Vaccarezza, INFN

TiSPs in CESR Interaction Region

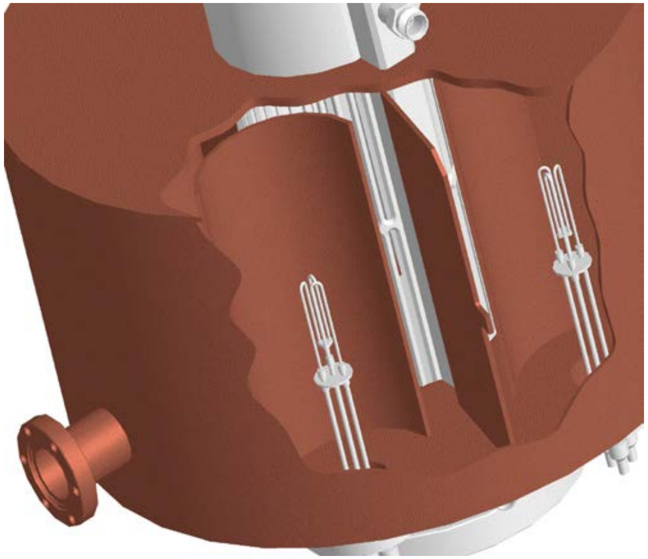
- *During CESR/CLEO III era, distributed TiSPs were implemented as the main pumping system.*
- *2X26 TiSP cartridges populated ~32 m. A RF-filter, multiplexing TiSP control system was also deployed.*



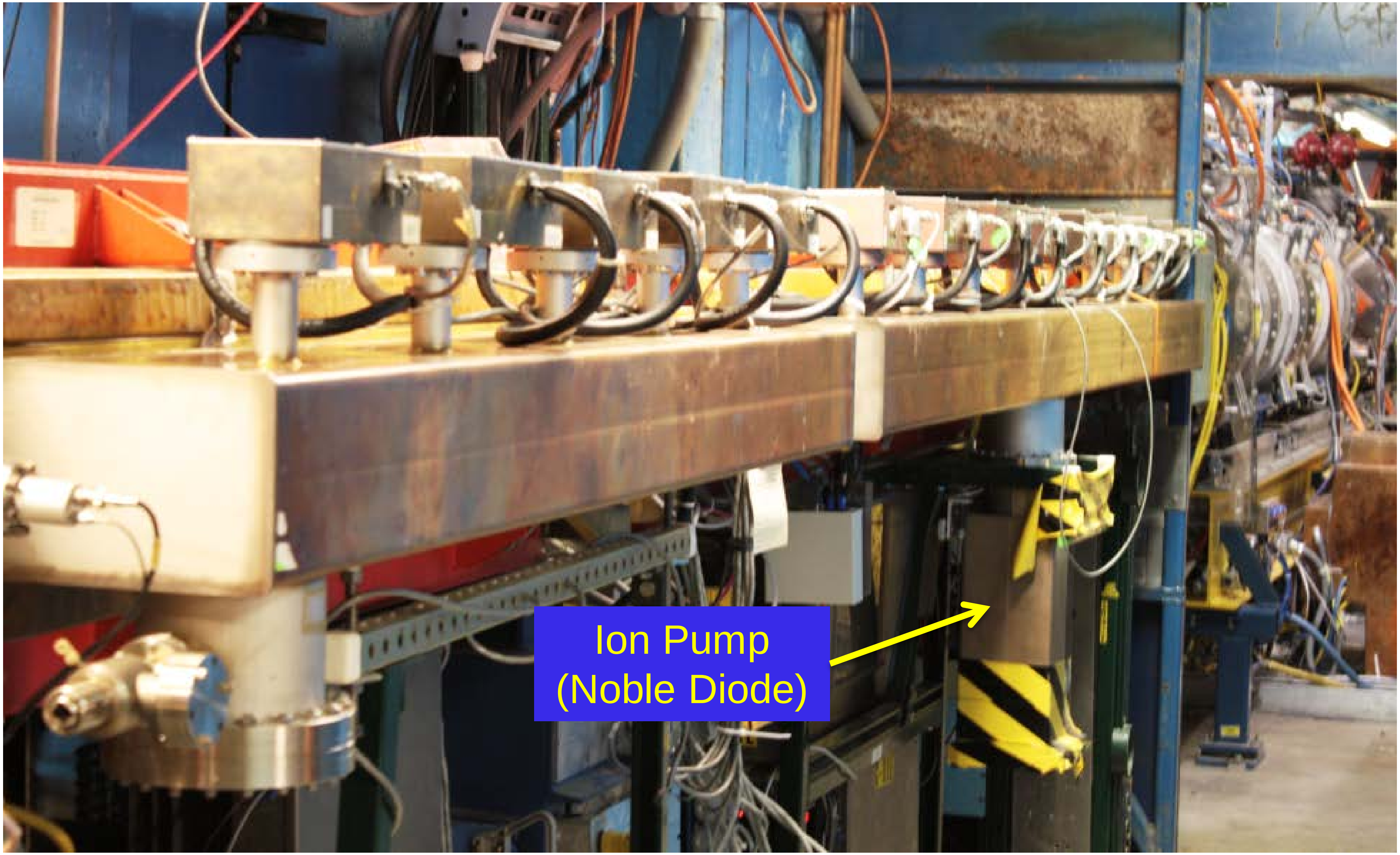
TiSP Chambers in CESR – A Close Look



Relay & EMI Filter Boxes



TiSPs in CESR Interaction Region



TiSPs in CESR IR – Performance History

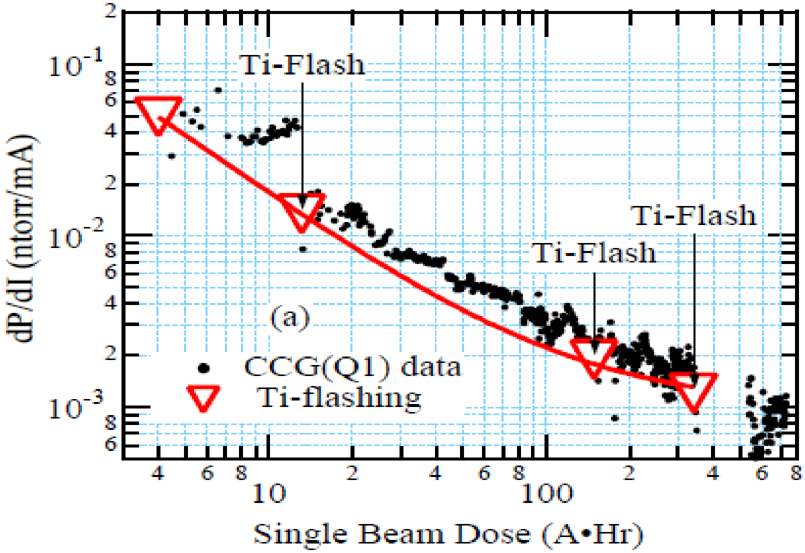
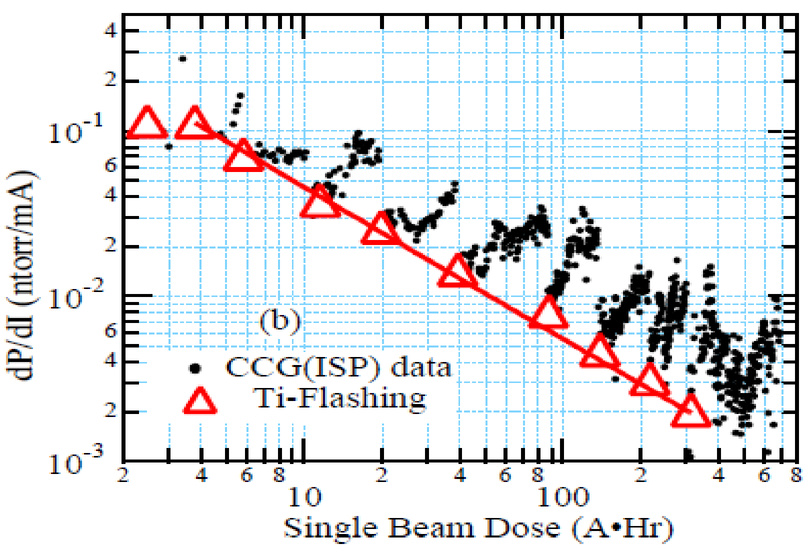
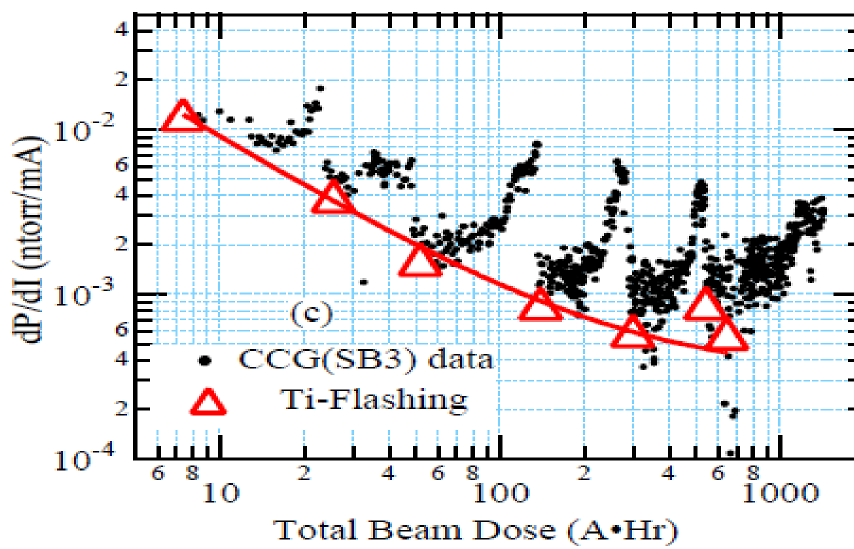


TABLE I. Synchrotron Radiation Flux and Gas Load in the CESR IR for 300 mA $e^{\pm}$ Stored Beams.

Location	Flux Density (Photon/s/m)	Total Flux (Photons/s)	CO GasLoad [Torr-l/s]
Q1-Pump	$1.3\cdot10^{18}$	$2.5\cdot10^{17}$	$7.9\cdot10^{-8}$
ISP absorb.	$1.1\cdot10^{19}$	$1.9\cdot10^{18}$	$2.0\cdot10^{-7}$
Soft-Bend	$3.3\cdot10^{18}$	$3.5\cdot10^{18}$	$6.7\cdot10^{-7}$
Hard-Bend	$6.9\cdot10^{18}$	$2.3\cdot10^{19}$	$1.3\cdot10^{-6}$

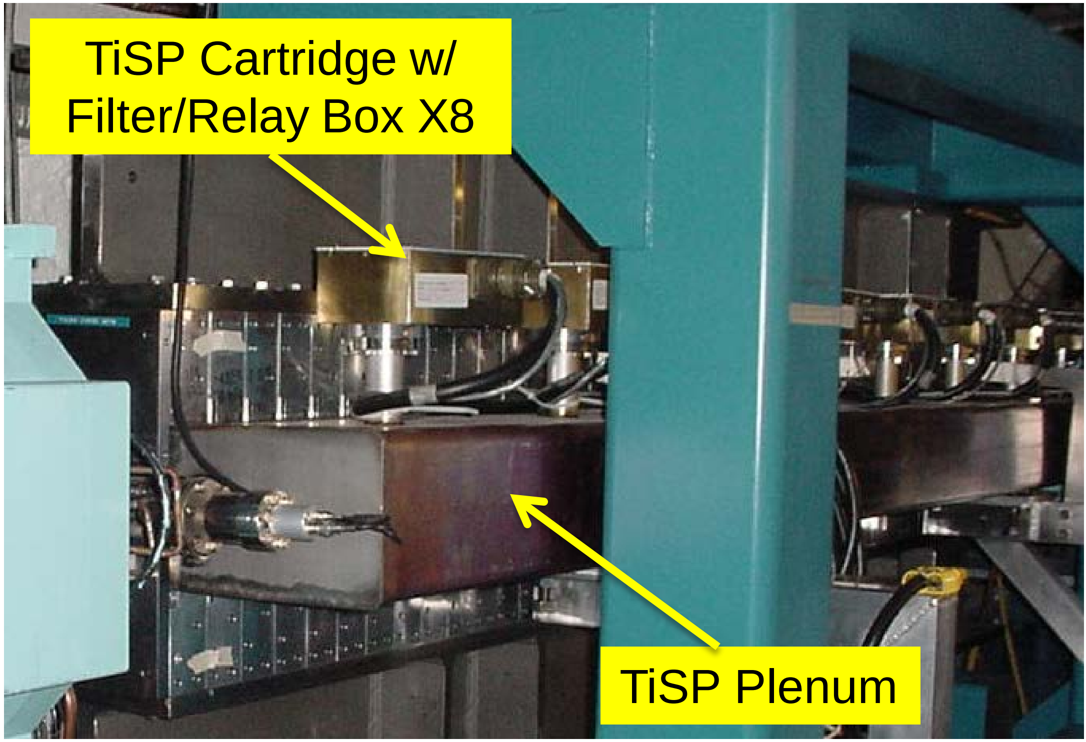


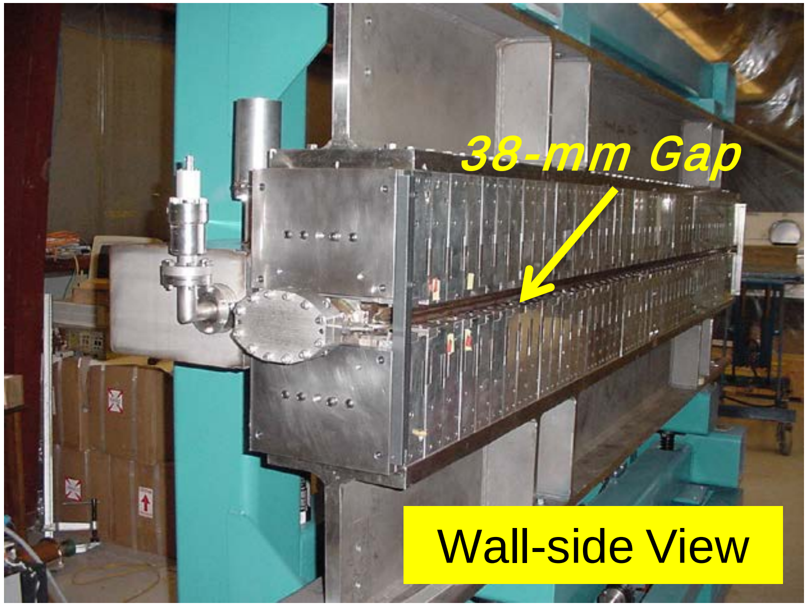


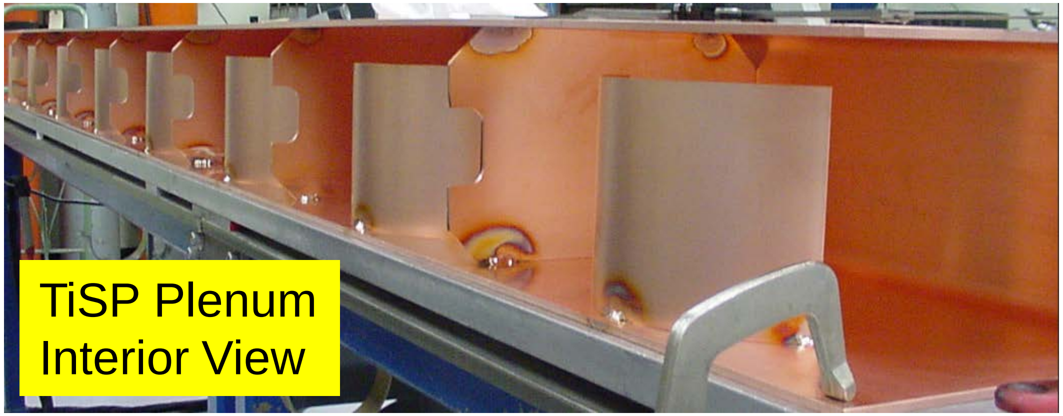
UCDAVIS

TiSPs in a Wiggler Vacuum Chamber

TiSP was incorporated in narrow gapped wiggler chamber for the CHESS G-line

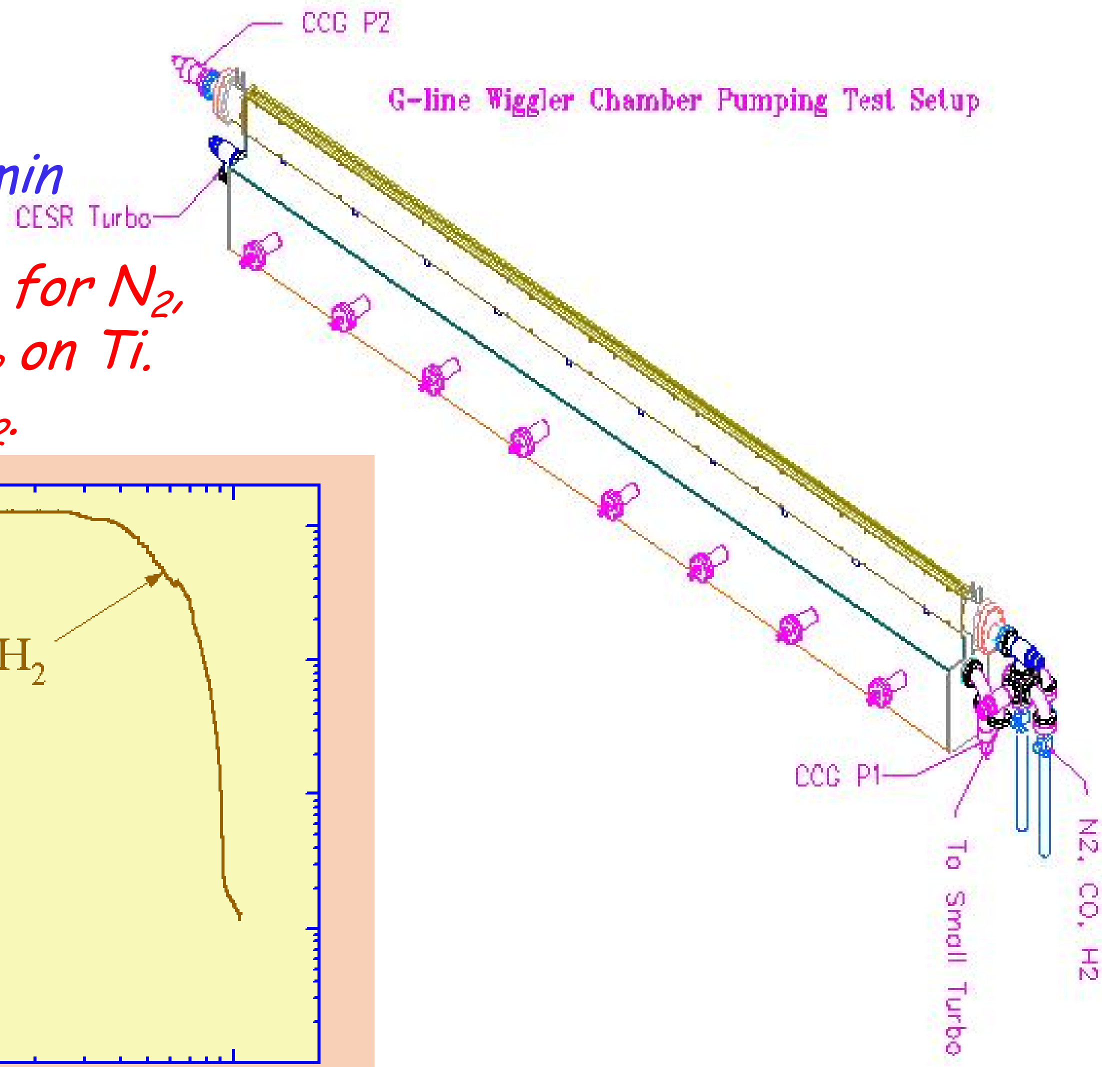


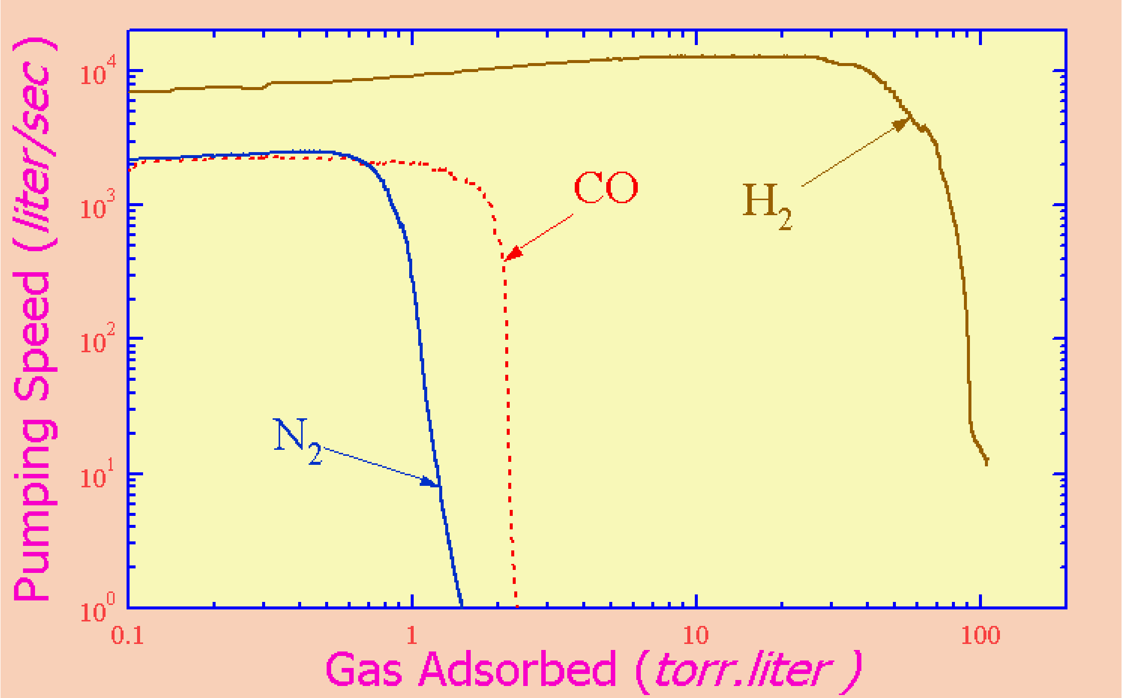




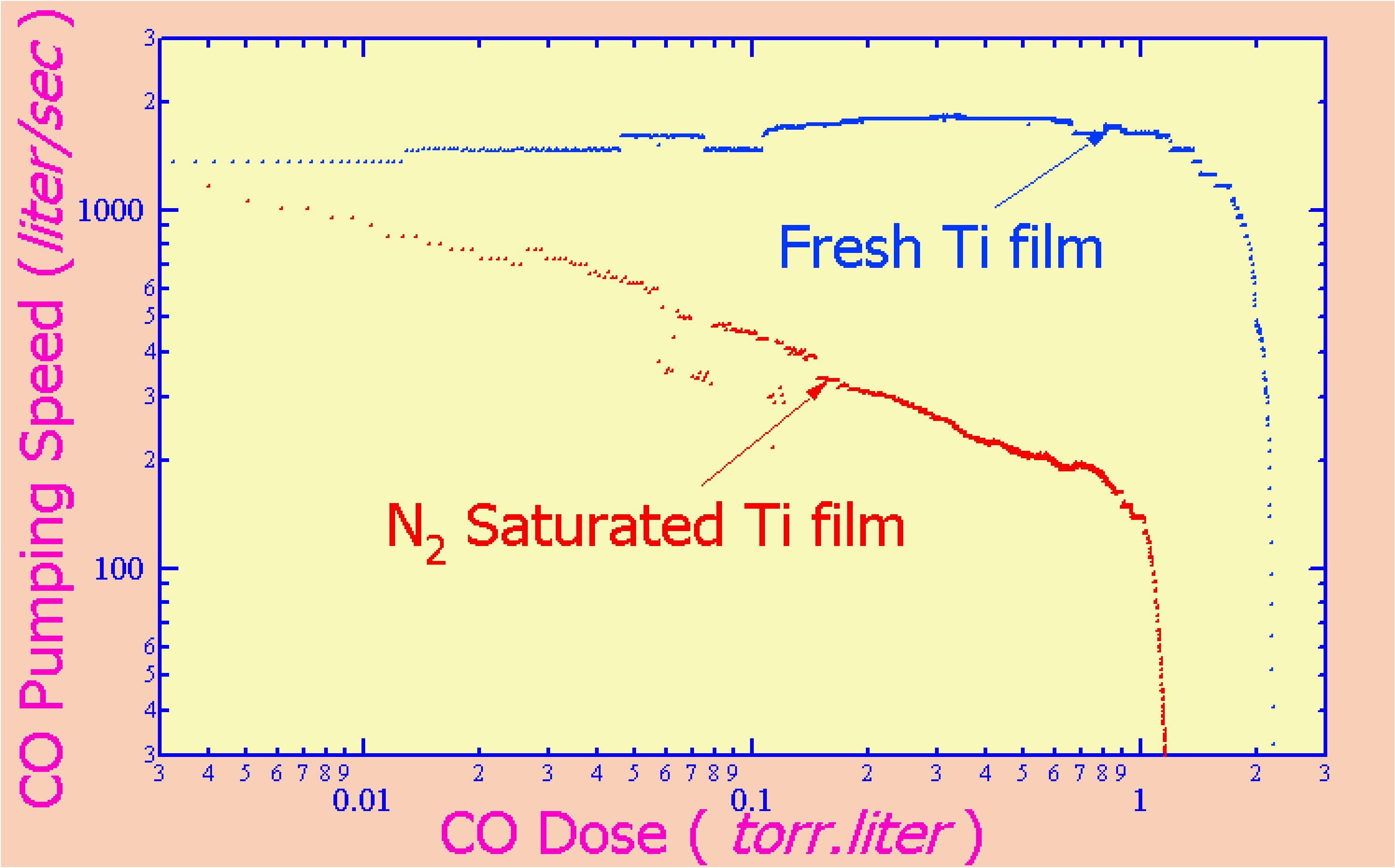
TiSPs in a Wiggler VC – Pumping Speed

- ✓ Calibrated leaks used to measure pumping speed
- ✓ TiSPs sublimation: 200W-2min
- ✓ Twice as capacity for CO as for N_2, indicating dissociation of N_2 on Ti.
- ✓ Much higher capacity for H_2.





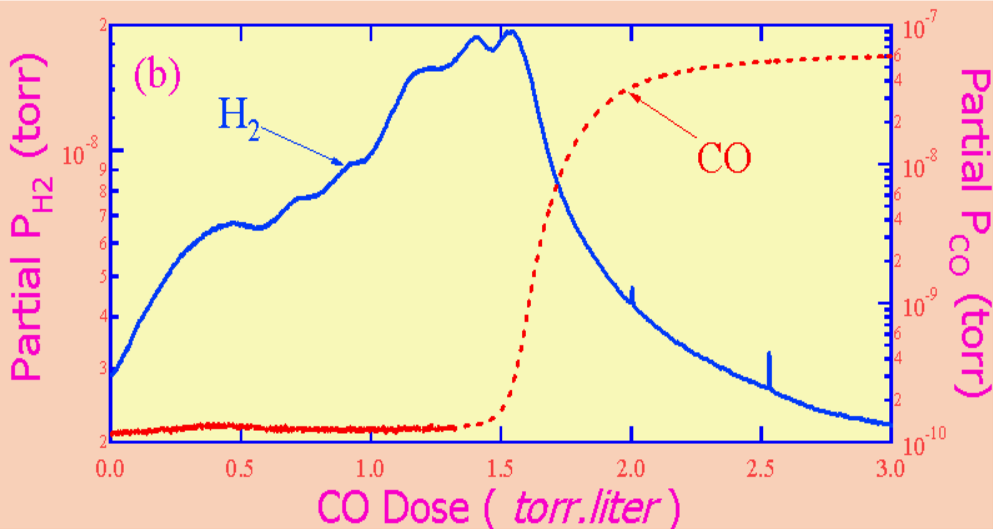
TiSPs Pumping – Another Look

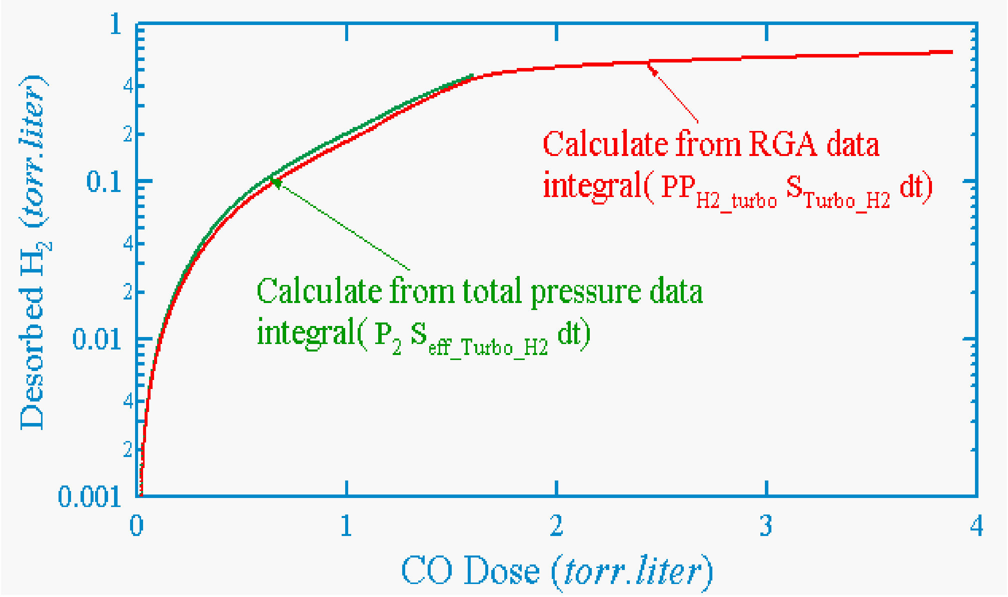


More reactive CO re-arrange adsorbed N atoms on Ti surfaces. Note the (1/2)-capacity for CO

CO Adsorption on Hydrogen-saturated Ti Film

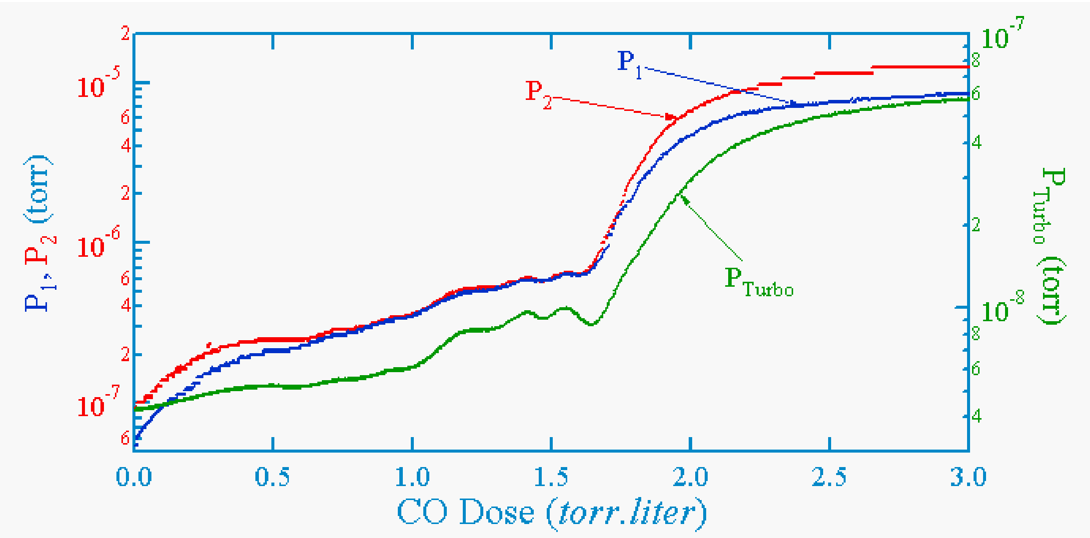
- *After saturating Ti surface with ~ 100 torr-liter H_2, introduce CO.*
- *RGA data clearing indicating further adsorption of CO, and desorption of H_2 simultaneously.*

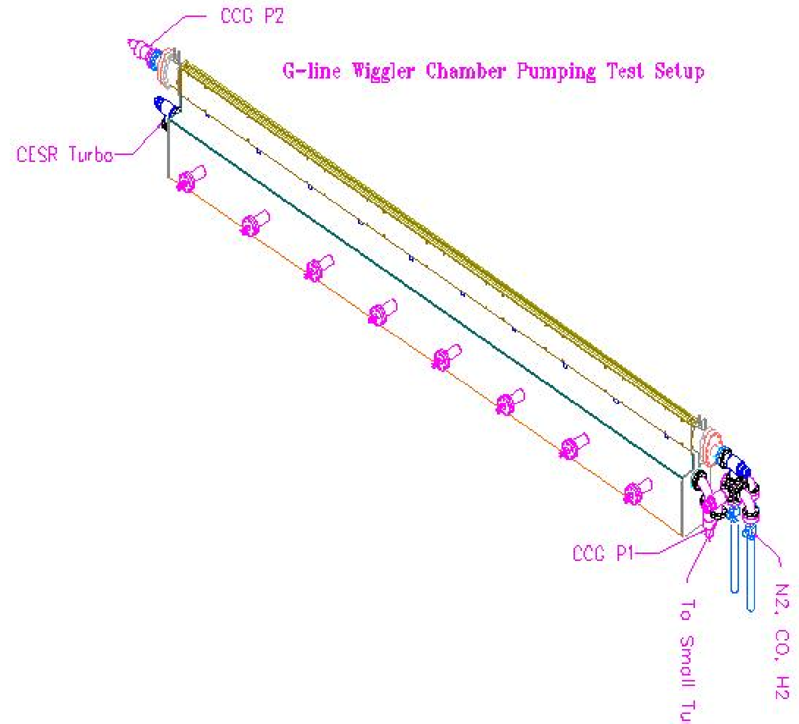




- *Careful quantitative analysis showed CO promoted H recombination desorption.*
- *1.5 torr-liter of CO replaced ~0.7 torr-liter of H_2 !*

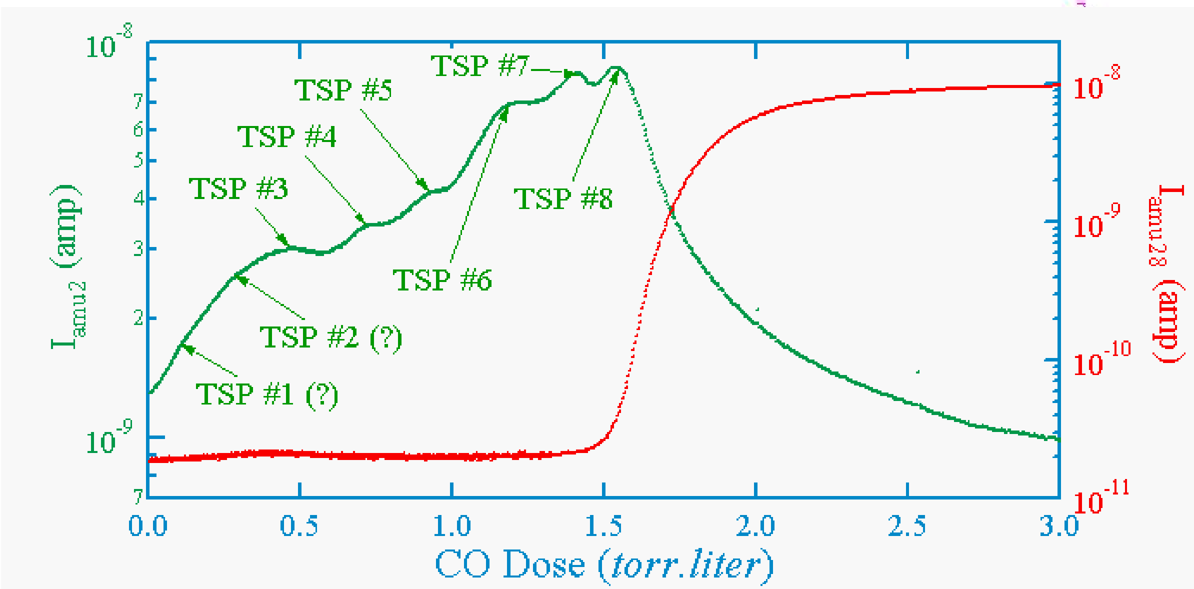
Important Partial Pressure Info





Total pressure gauges data. Hard to tell the displacement of H_2 by CO.

RGA data clearly showing CO replacing H_2.



Session 4.3B
Non-Evaporable Getters (NEGs)

NEGs – The Basics

- Porous alloys with very large active metallic surface area, when activated.

- Bulk Getters - gases diffuse into the interior of the getter material upon heating (activation).

- Gases are categorized into four families based on their interactions with NEGs:
  - ✓1. Hydrogen and its isotopes - adsorbed reversibly.
  - ✓2. CO, CO_2, O_2, and N_2 - adsorbed irreversibly.
  - ✓3. H_2O, hydrocarbons - adsorbed in a combination of reversible and irreversible processes. Hydrocarbons are adsorbed very slowly.
  - ✓4. Noble gases - not adsorbed at all.

Commercial NEGs

- NEGs are primarily available only from:

  SAES Getters S.p.A.
  Viale Italia , 77
  20020 Lainate (Milano) Italy

  SAES Getters U.S.A., Inc.
  1122 E. Cheyenne Mountain Blvd.
  Colorado Springs, CO 80906

- NEGs are also available only from:

  Gamma Vacuum, Edwards Vacuum Inc.
  2915 133rd Street West
  Shakopee, MN 55379 • USA

Hydrogen

- Hydrogen does not form a stable chemical compounds with a NEG alloy. It dissociatively chemisorbs on active NEG surfaces and atomic hydrogen diffuses rapidly into the bulk of the getter and is stored as a solid solution. Thus at ambient temperature, NEGs are very effective pumps for hydrogen.
- Sieverts' Law describes the relationship between H_2 concentration within its NEG and its equilibrium pressure. Usually, high H_2 pressure, ranging 10^{-7} to 10^{-4} torr, is expected during NEG activation.

$$\text{Log } P = A + 2 \log q - \frac{B}{T}$$

q = H_2 concentration in NEG, Torr-Liters/gram

p = H_2 equilibrium pressure, Torr

T = getter temperature, K

A, B constants for different NEG alloys

NEG Pumping Characteristics (2)

CO, CO_2, O_2, N_2, other O-, C-containing molecules

- Active gases are chemisorbed irreversibly by NEGs.
- The chemical bonds of the gas molecules are broken on the surface of the NEG.
- The various gas atoms are chemisorbed forming oxides, nitrides, and carbides.
- At activation temperatures, these chemical bonds do not 'break'. Instead, the elevated activation temperature promotes diffusion into the bulk of the NEG, to 'regenerate' active surface 'sites'.

NEG Pumping Characteristics (3)

H_2O and Hydrocarbons

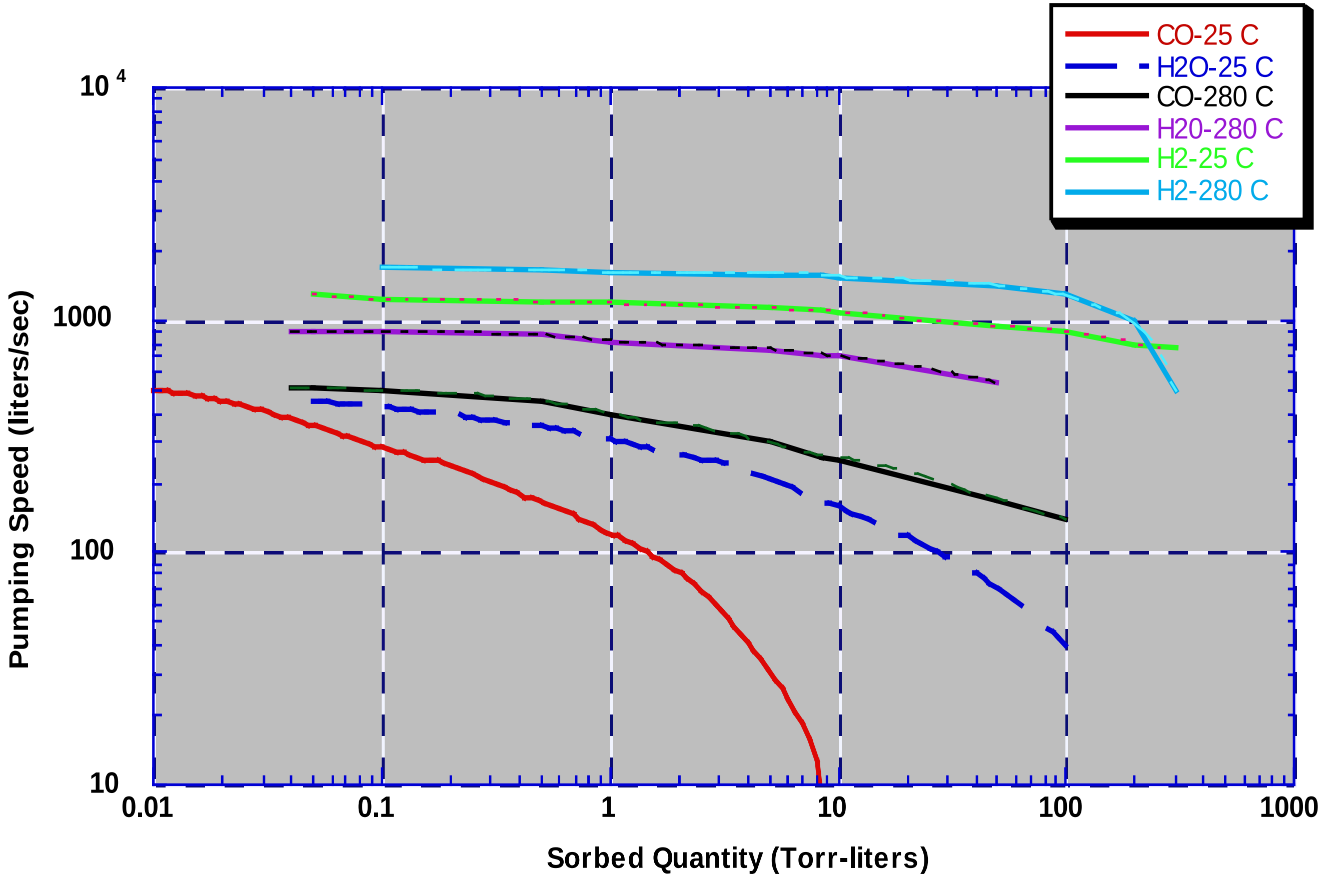
- Water vapor and hydrocarbons are "cracked" on the surface of the NEG.
- H_2 is chemisorbed reversibly.
- O_2 and C are chemisorbed irreversibly.
- However, hydrocarbons sorption efficiency at ambient temperature is extremely low. However, HC pumping may be enhanced with 'hot' NEGs.

NEG Pumping Characteristics (4)

Noble gases

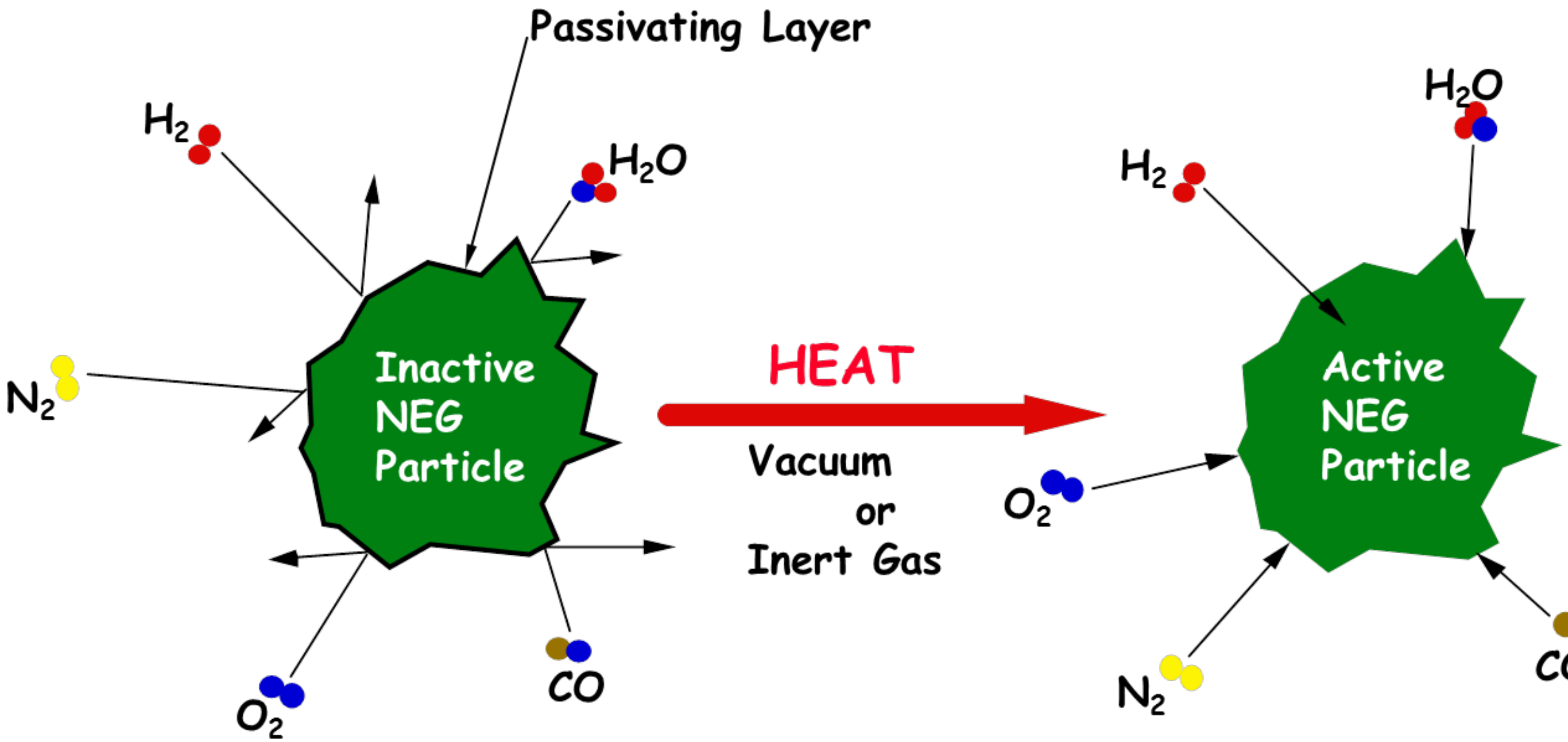
- NEGs do not sorb Ar, He, Kr, Xe.
- Ion pumps are required in combination with NEGs for pumping noble gases.

NEG Pumping Characteristics (5)



- *At low throughput, NEG pumping speeds are constant, independent of pressure.*
- *Pumping speeds usually increase at higher sorption temperature.*

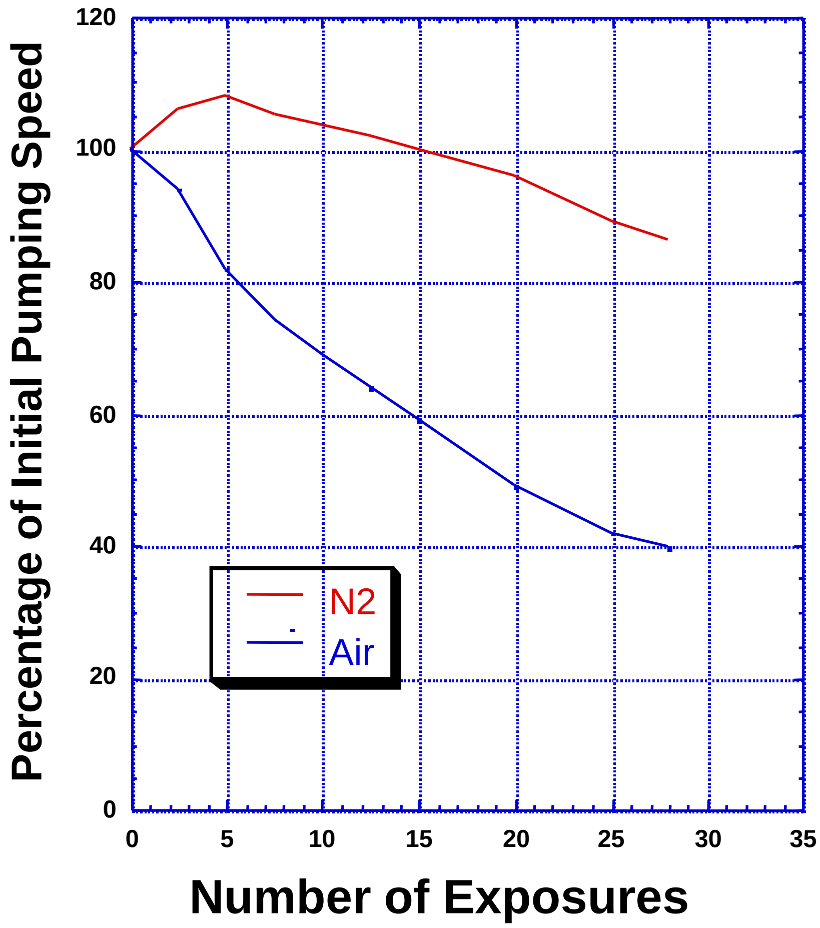
Activation Process for NEG



Ref. SAES Getters

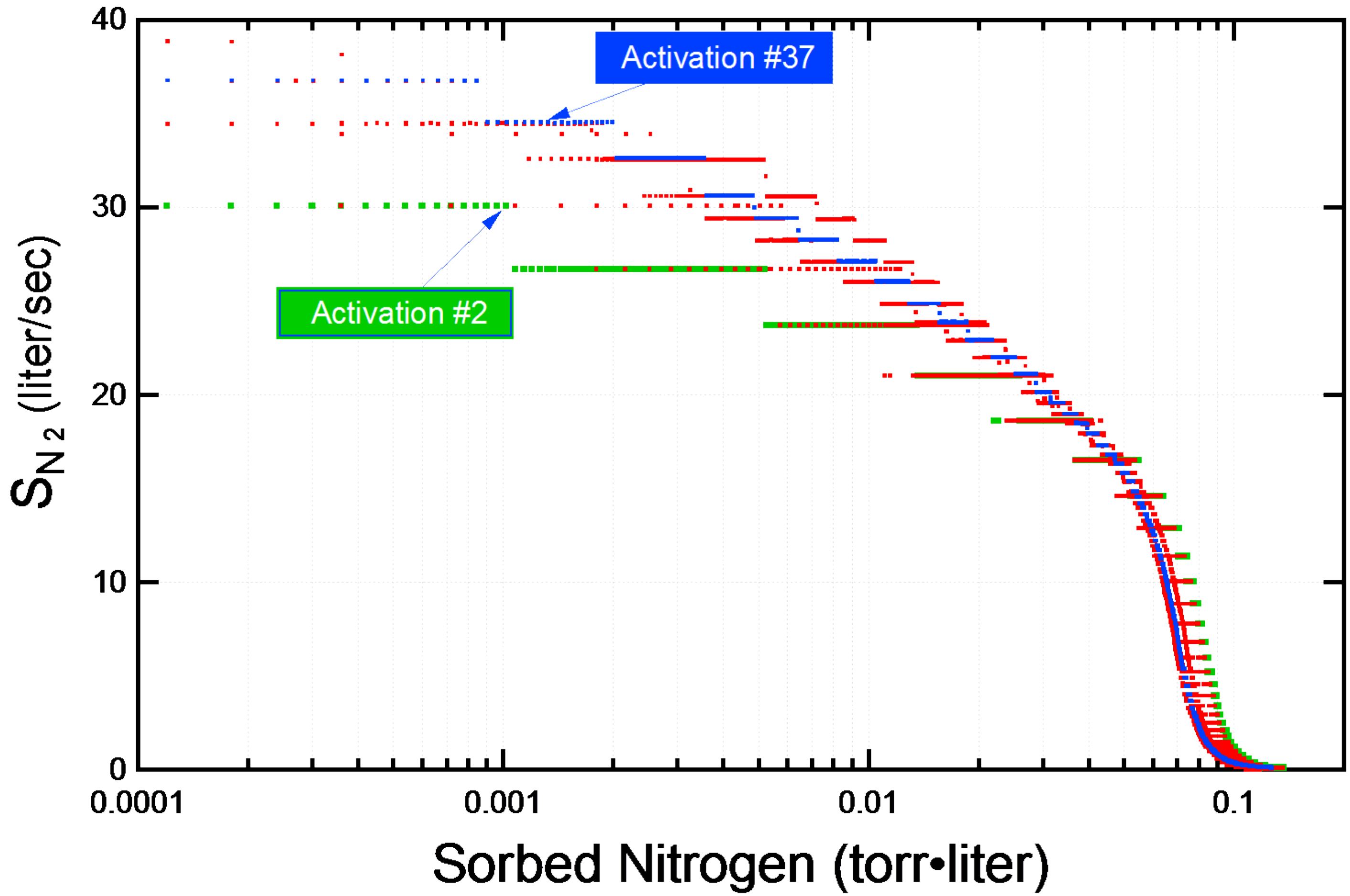
Application Notes for NEGs

- *NEG performance deteriorates due to successive exposures to air (oxygen and water) or N_2.*
- *Further improvement can be obtained if Argon is used as a protective gas, during long term storage .*
- *NEG pumps should never be exposed to air while at temperatures higher than 50°C.*
- *Degassing (or conditioning) of NEGs after initial pump-down.*
- *Whenever practical, activate all NEGs in a system at the same time.*



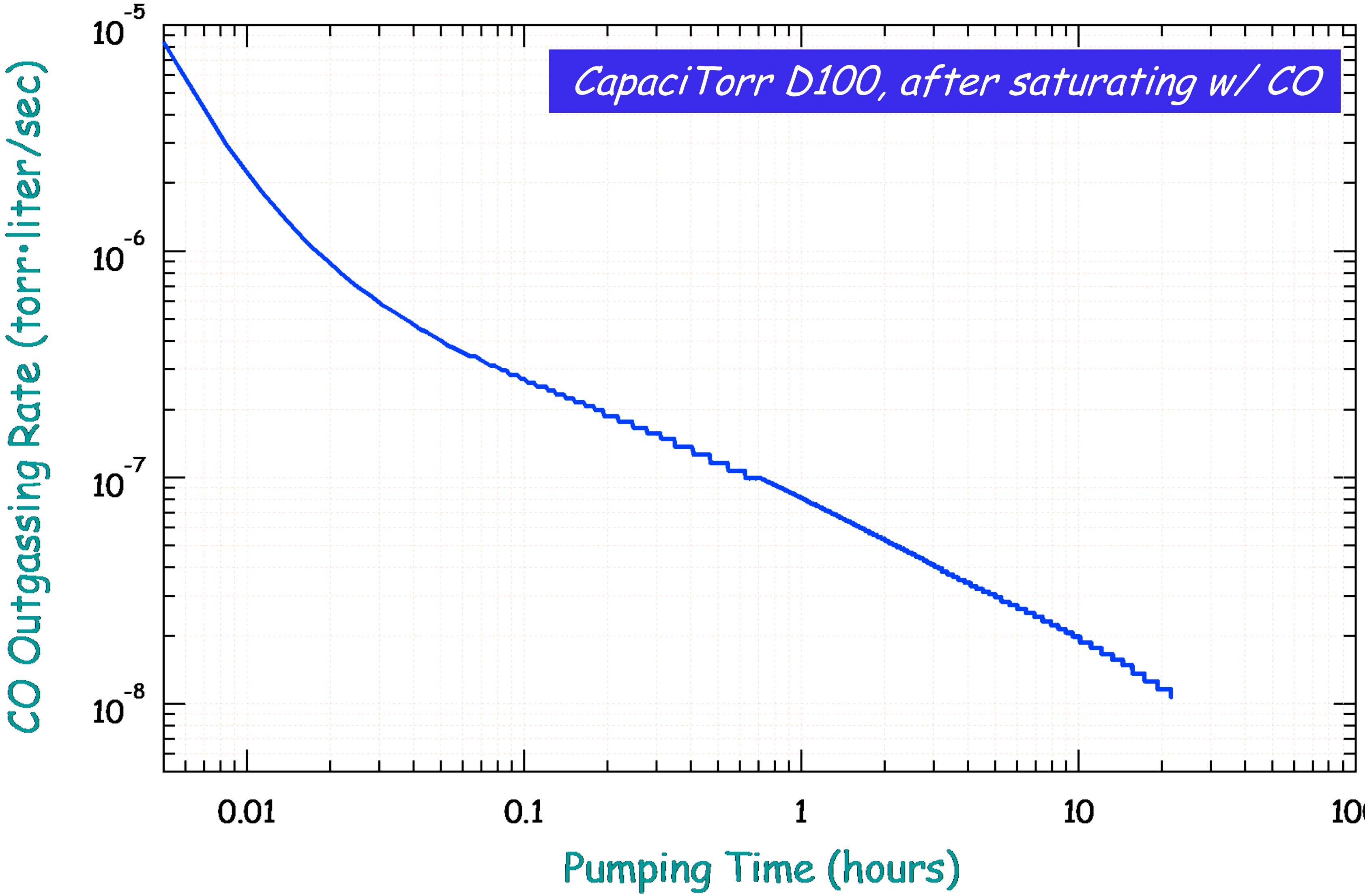
Ref. SAES Getters

Pumping with Repeated Activations

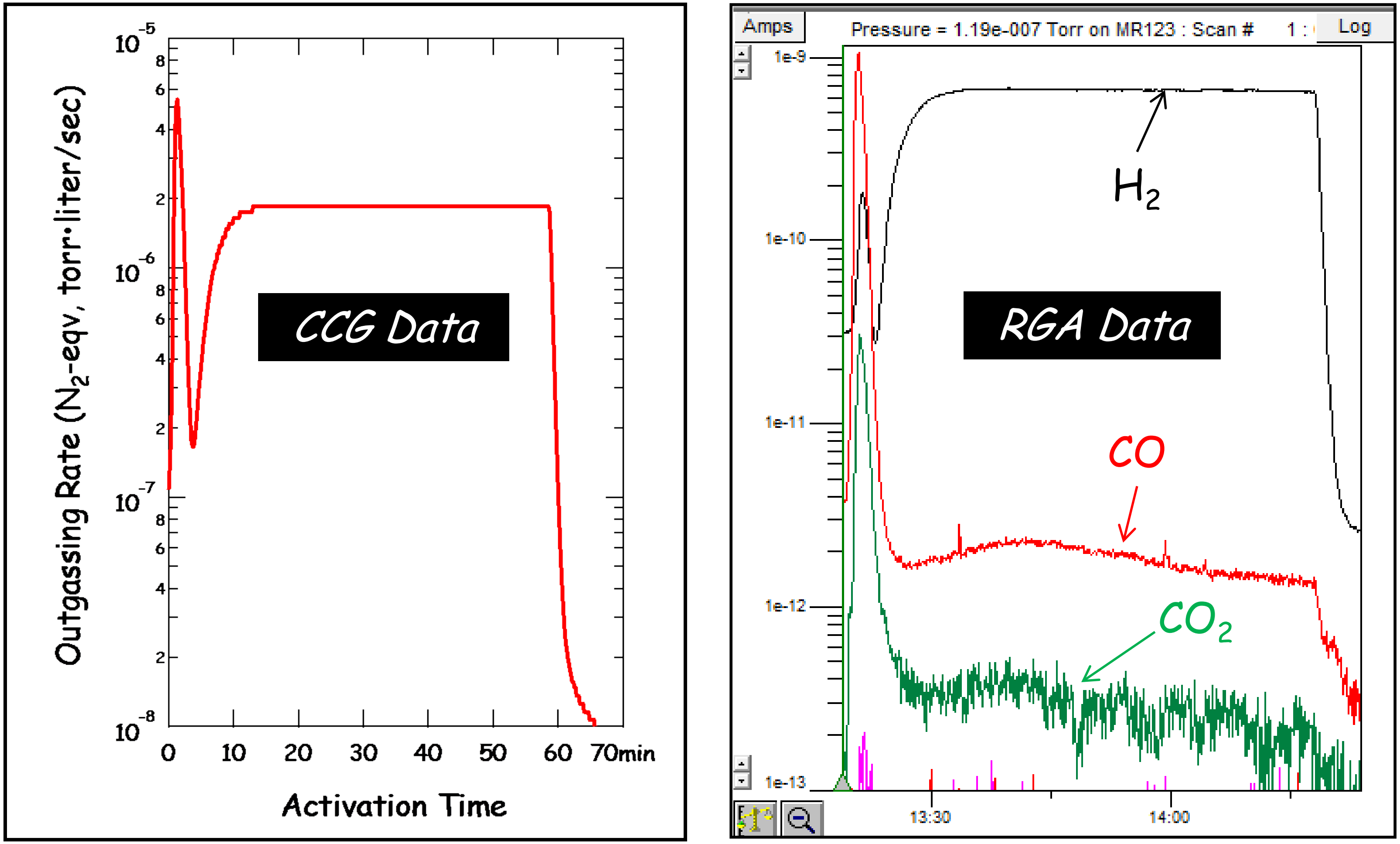


Measured N_2 pumping on a CapaciTorr D100 pump with repeated activation/saturation cycles w/o venting

Outgassing of a fully saturated NEG



Take a look at NEG activation

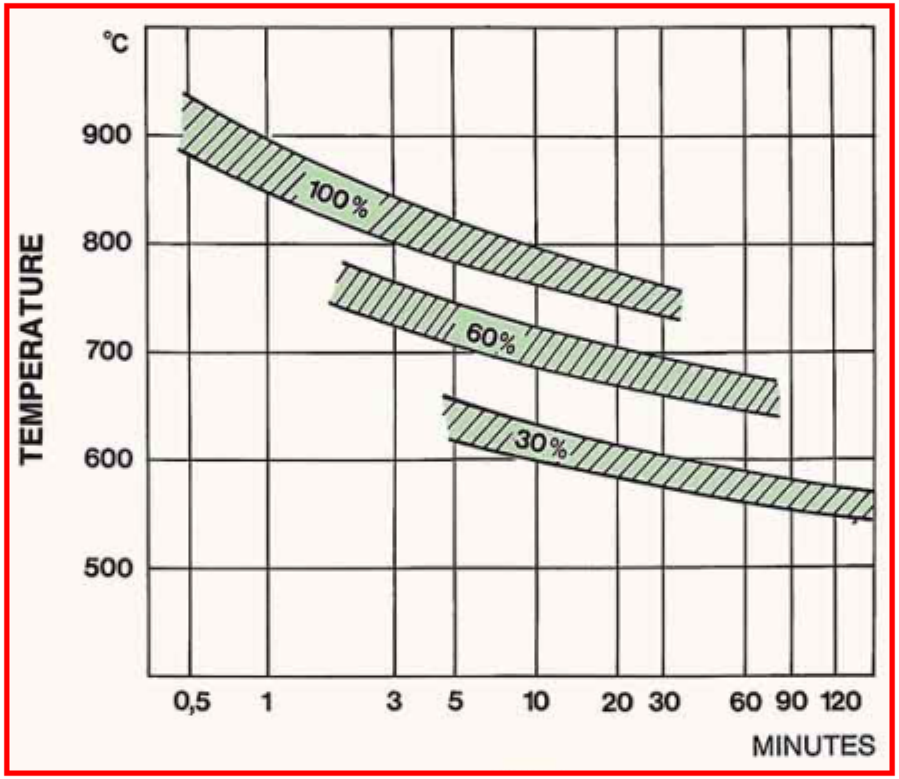


This activation of a SAES' CapaciTorr D100 pump shows typical behavior. (The pump was previously saturated with CO gas, after a 24-hr pumping.)

Examples of SAES Getter's Available NEG Alloys

SAES ST101® Non-evaporable Getters

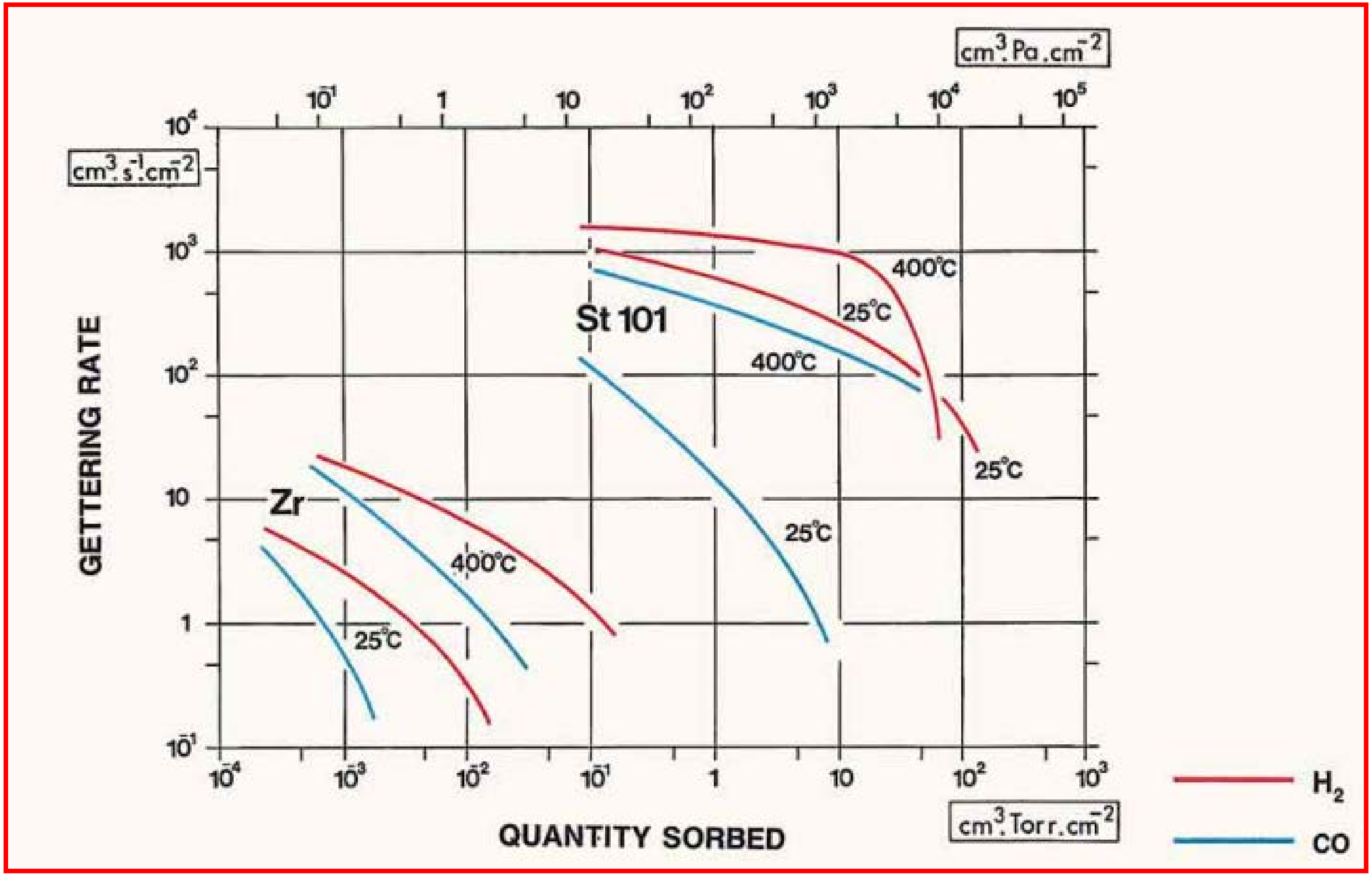
- Metal alloy made up of 84% Zr, 16% Al.
- First Zirconium based getter alloy introduced and still widely used today after 30 years.
- The operating temperature range of ST101 is 0 to 450°C.
- ST101 chemisorbs CO, CO_2, H_2O, N_2, and O_2 at high rates.
- ST101 activates at temperatures from 550 to 900°C.
- ST101 alloy has been replaced by new alloys with lower activation T.



ST 101 Alloy Activation Efficiency

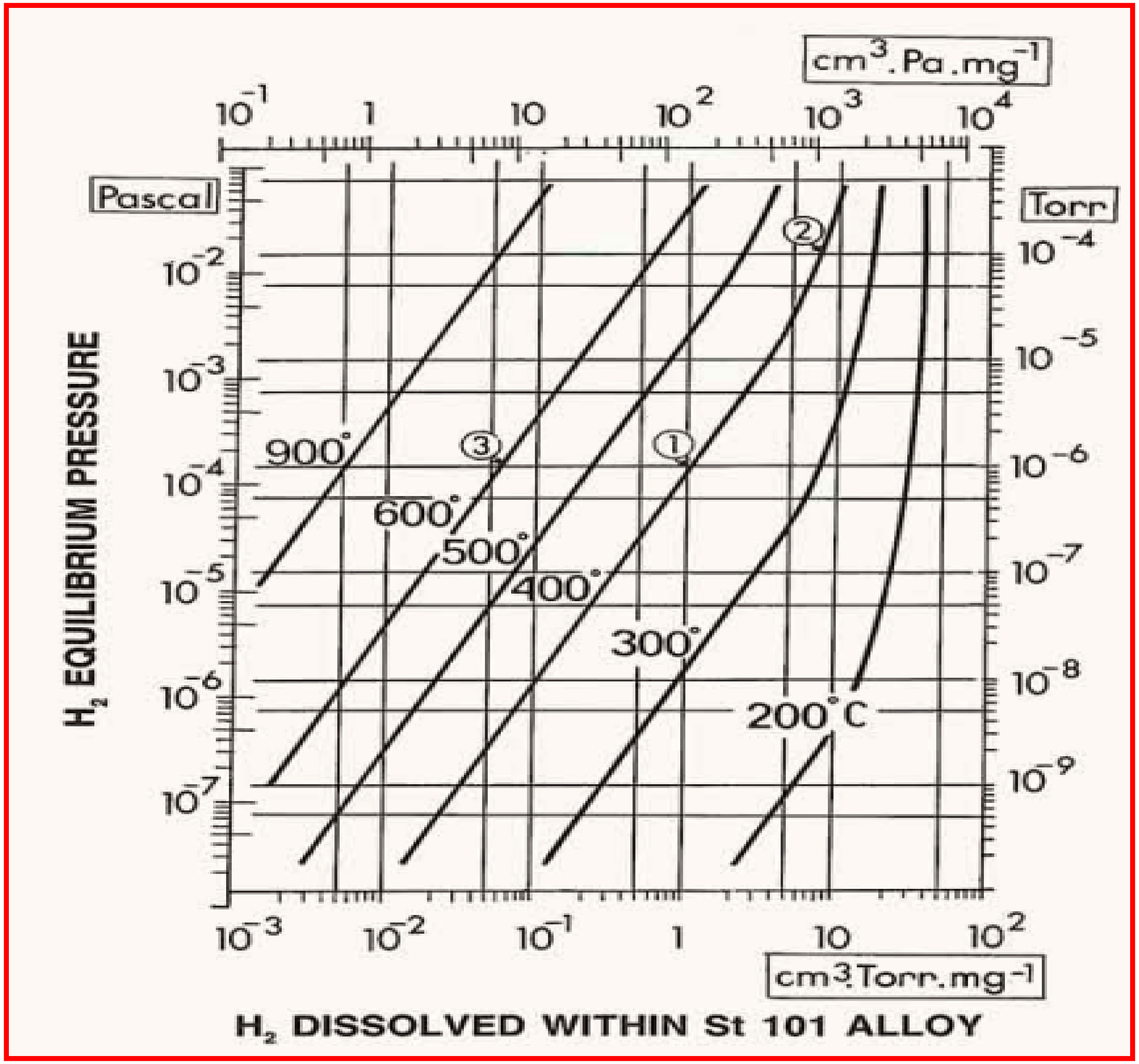
Ref. SAES Getters

SAES ST101® NEG – Pumping

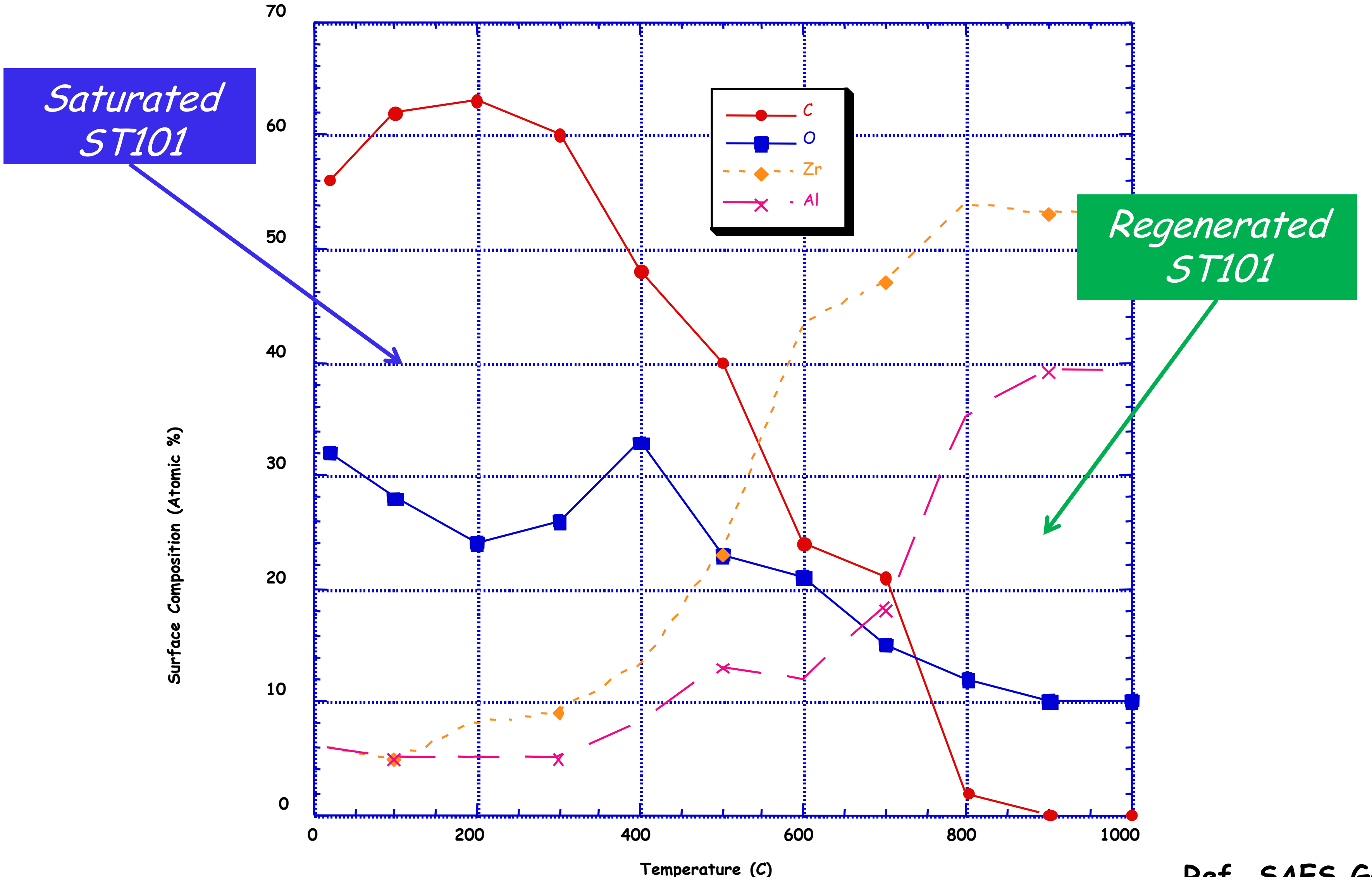


Ref. SAES Getters

SAES ST101® NEG – Hydrogen Solubility



ST101 Surface Composition vs. Temperature



Ref. SAES Getters

SAES ST707® Non-evaporable Getter

- *Metal alloy made up of 70% Zr, 24.6% Va, and 5.4% Fe.*
- *The operating temperature range of ST707 is 20 to 100°C.*
- *ST707 chemisorbs CO, CO_2, H_2O, N_2, and O_2 at high rates.*
- *ST707 has much lower activation temperature.*

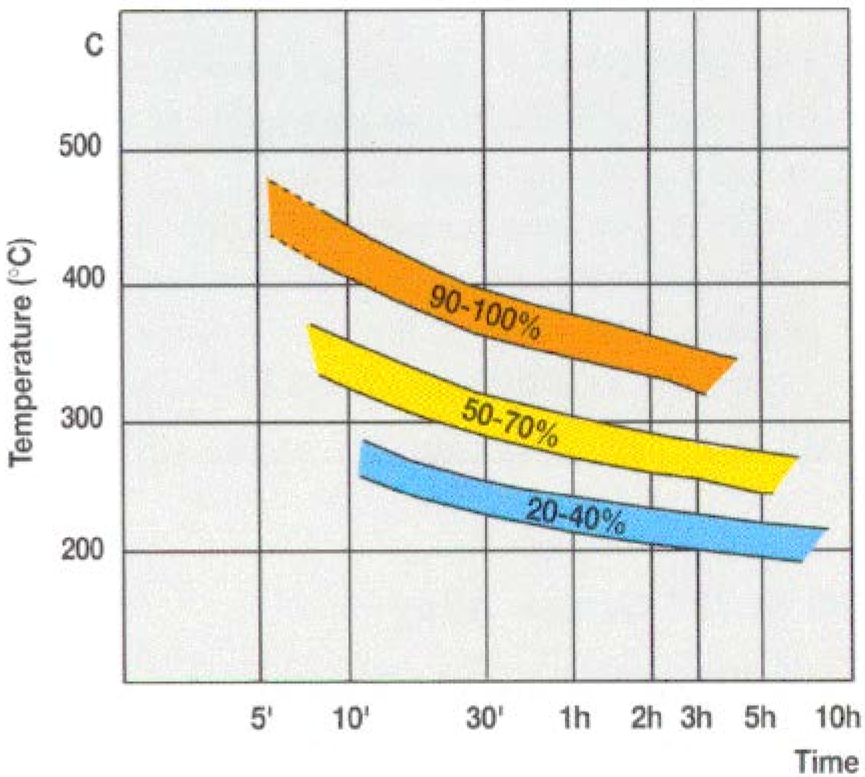
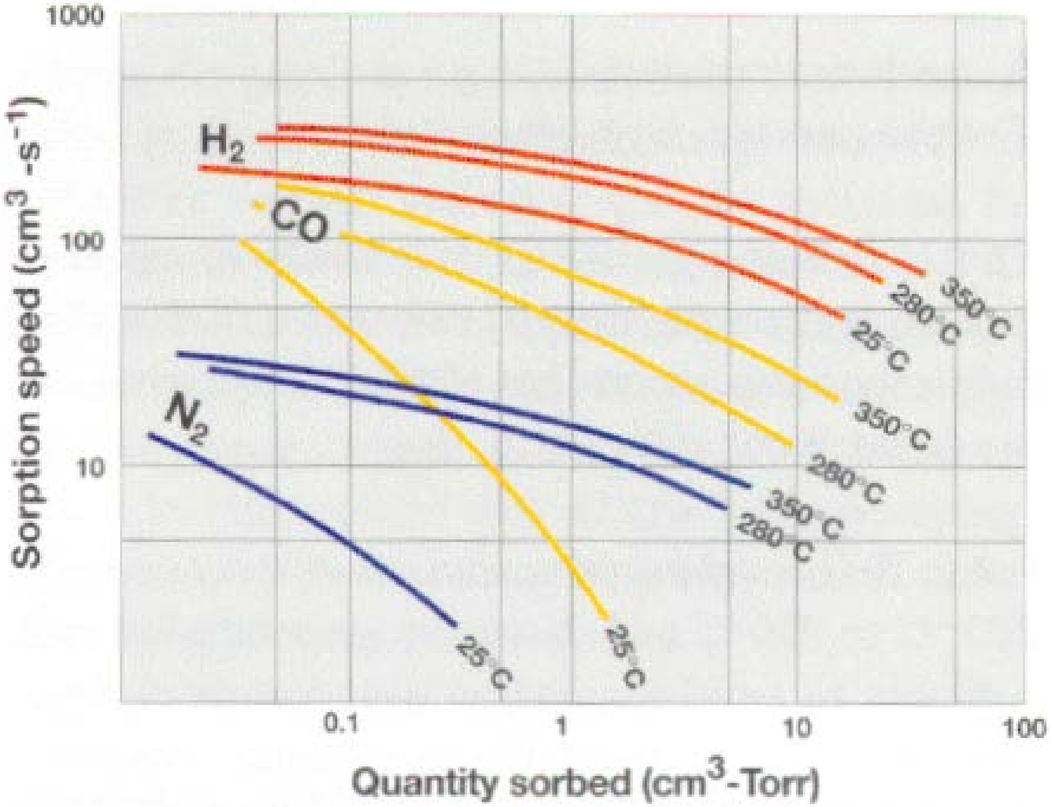


Fig. 1. Activation conditions and gettering efficiency of St 707

SAES ST707® NEG Pumping Performance



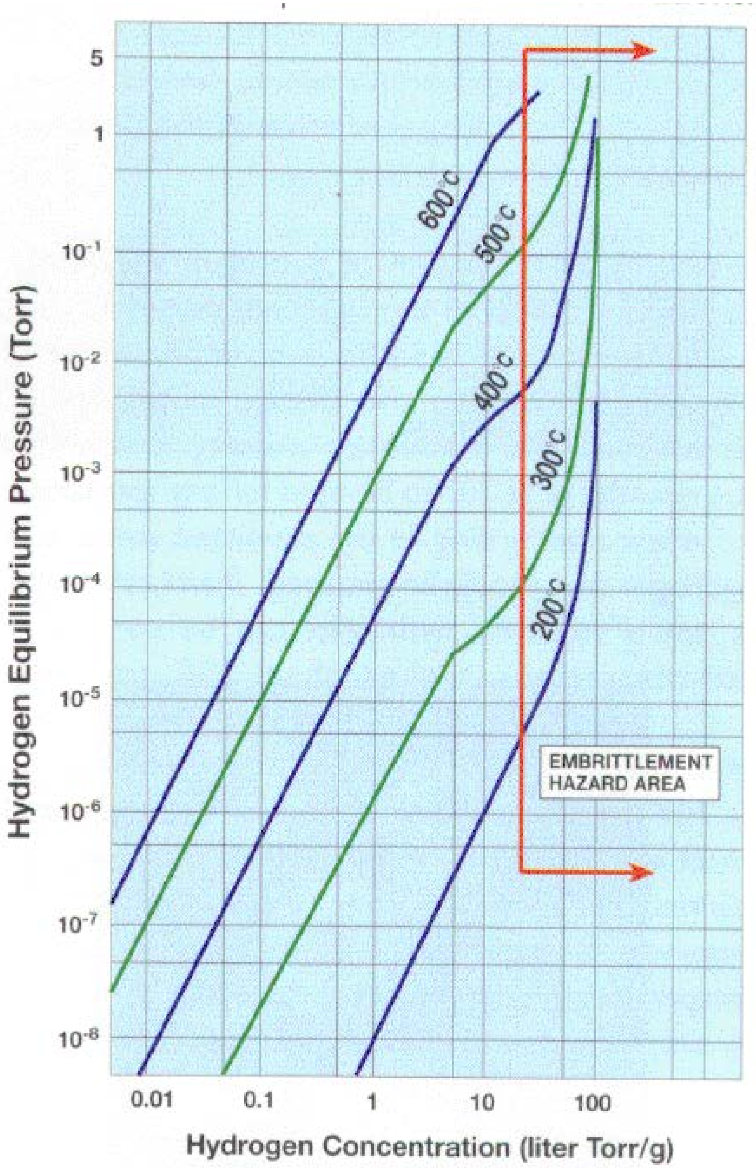
St 707 powder alloy: 100mg

Geometric surface: 50 mm^2

Activation: 450°C for 10 min.

Sorption: At the indicated temperatures

SAES ST707® NEG Pumping – Hydrogen

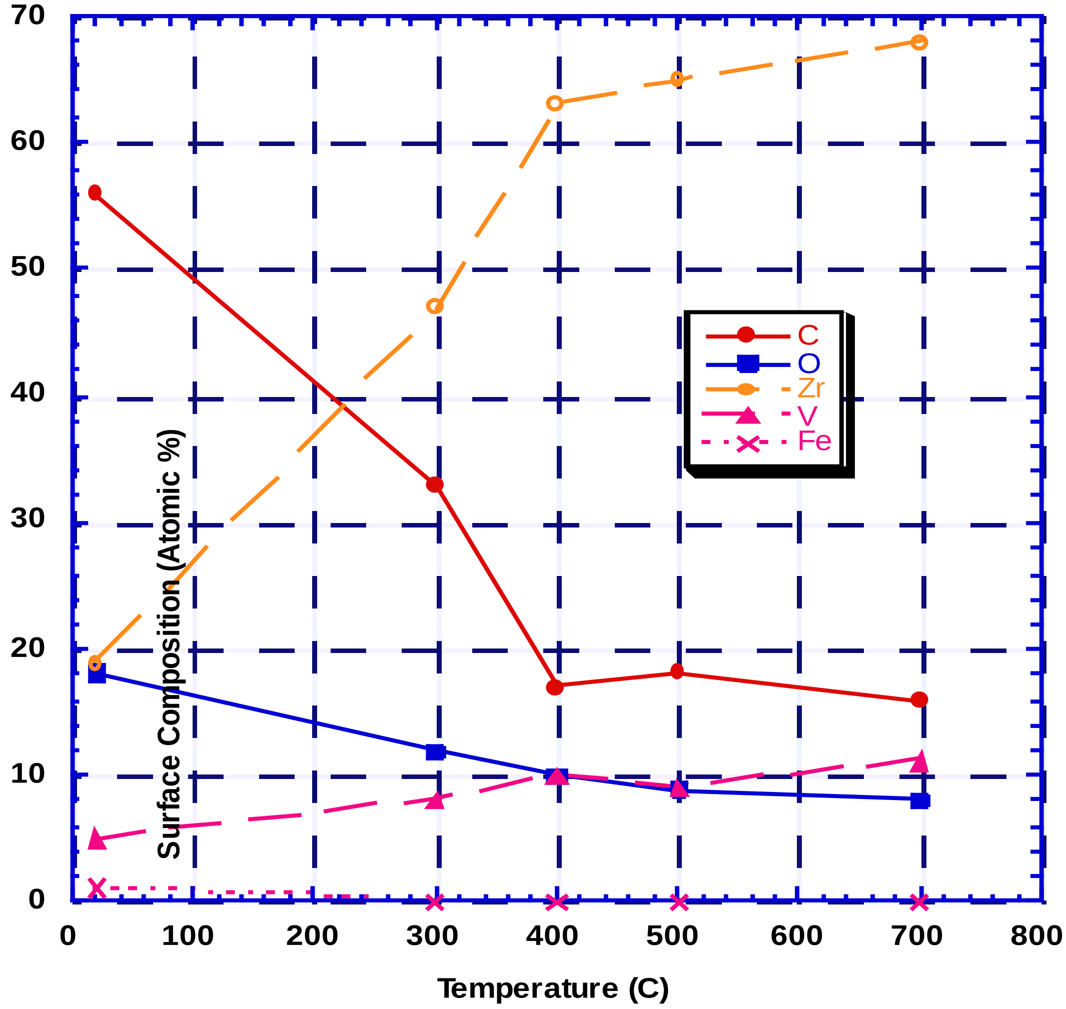


Sievert's Law for ST707

$$\mathrm{Log}\,P = 4.8 + 2\log Q - \frac{6116}{T}$$

- P = H_2 equilibrium pressure (torr)
- Q = H_2 concentration (torr-l/g)
- T = Temperature in °K

ST707 Surface Composition vs. Temperature



Other SAES NEG Alloys

- *ST 172 – ST707 + Zr.*
  One of most used alloys, used in SAES' CapaciTorr and NexTorr pump series.

- *ST175 – Ti and Mo powder mixture, sintered form.*

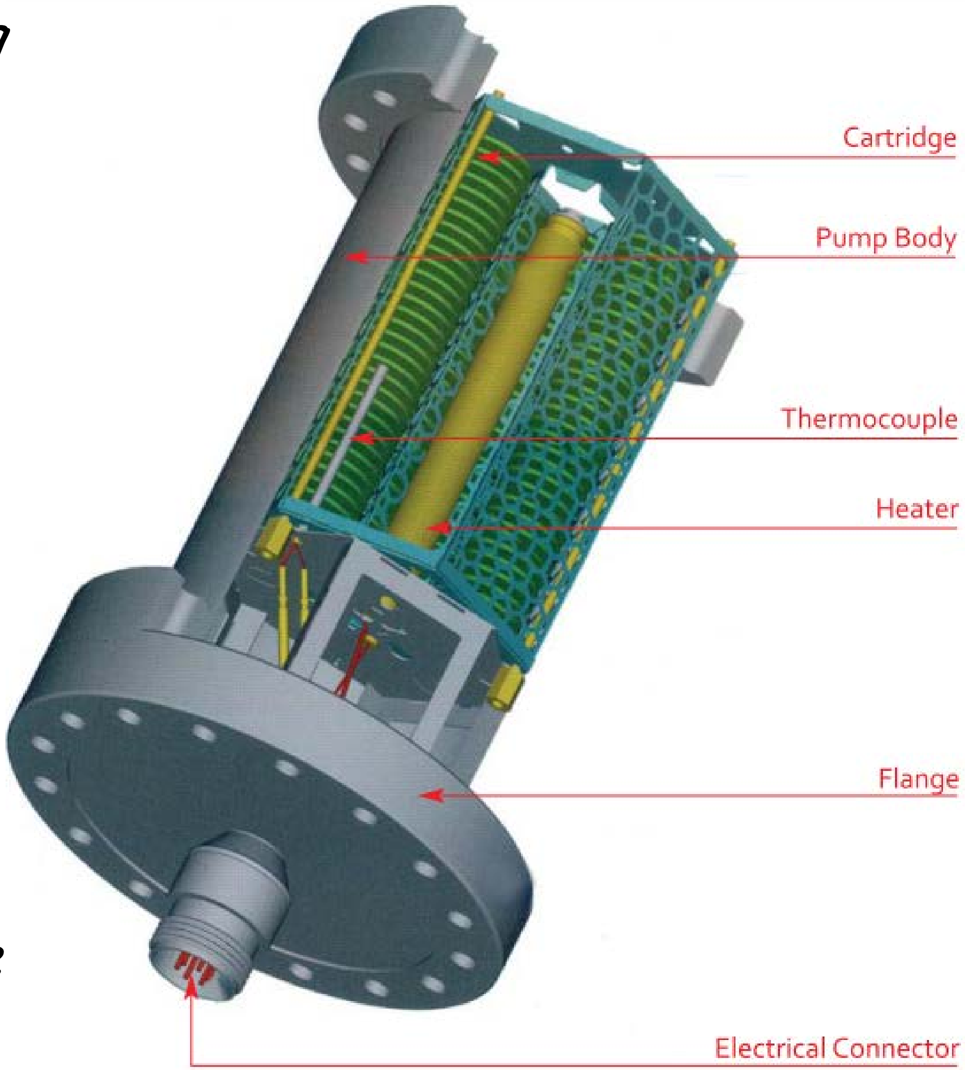
- *ST185 – Ti-V alloy (obsolete !)*

- *ZAO – a new Zr-based alloys, lower gas emissions, higher capacity*

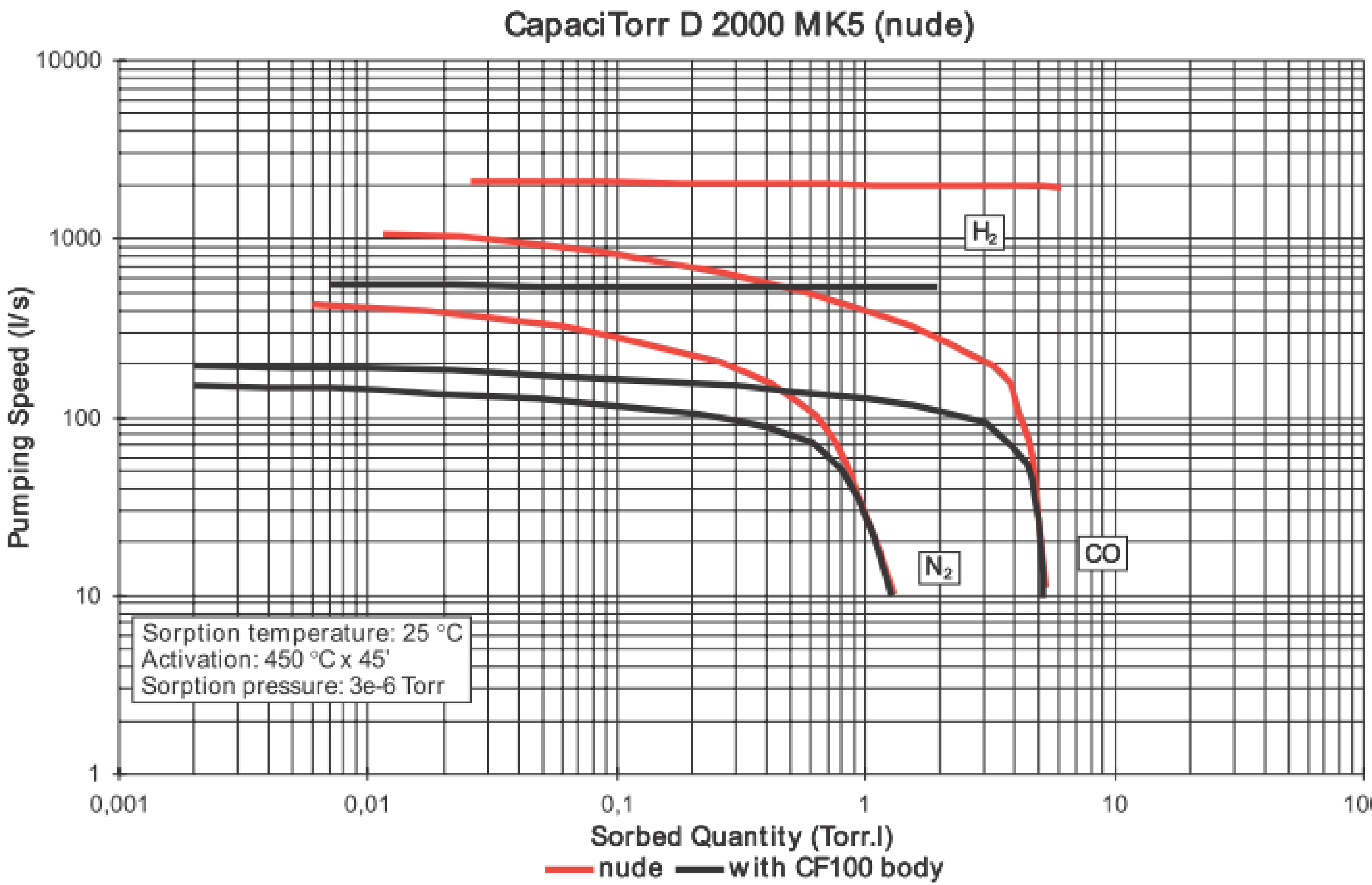
Examples of SAES Getter's Available NEG Pumps

NEG Cartridge Pump Module – CapaciTorr®

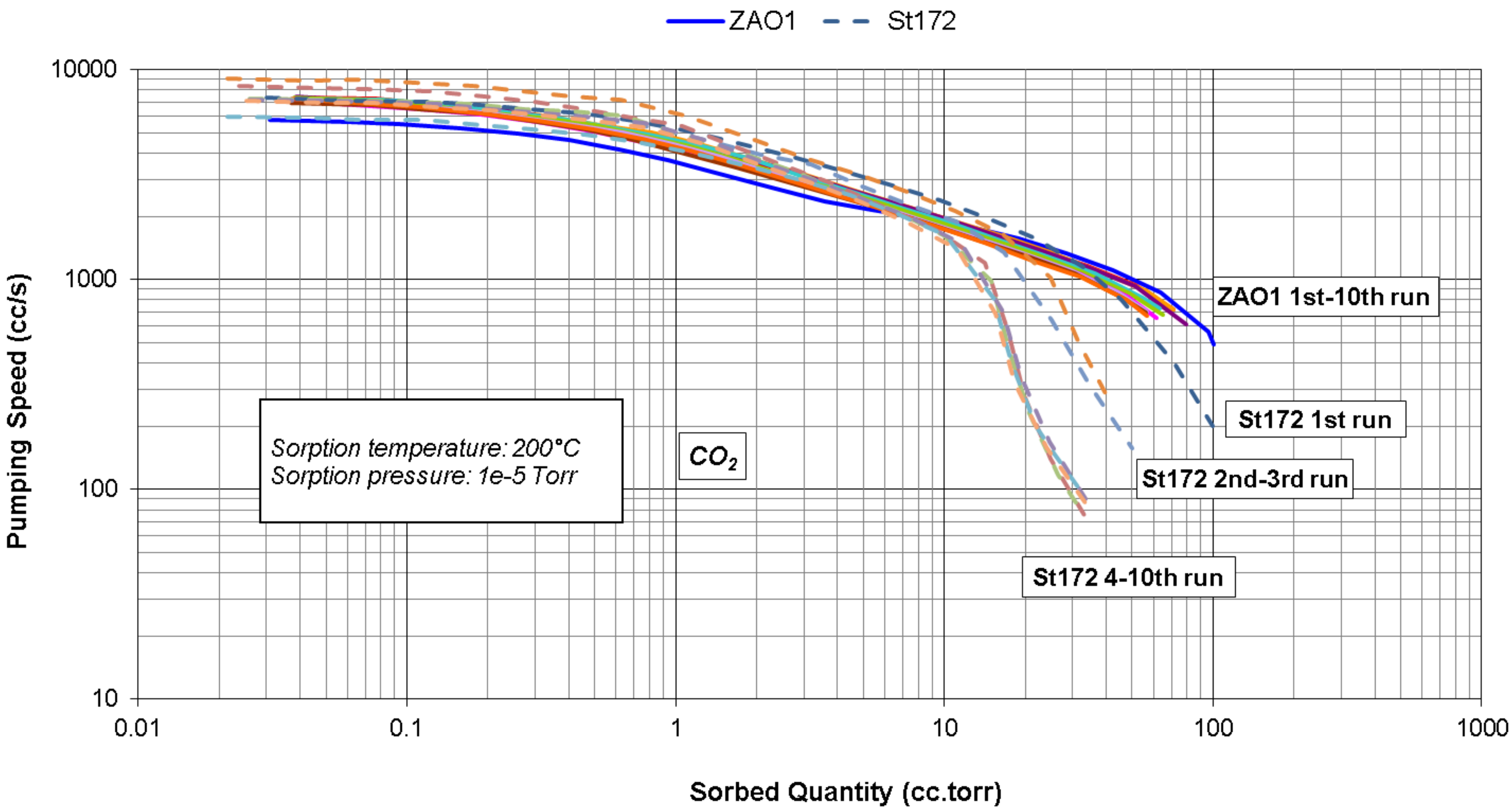
- *Complete compact pumping system, with matching controller for easy activation*
- *NEG materials: st172 sintered blades/disks*
- *Pump sizes from 50 l/s to 2000 l/s, for H_2*
- *For large sizes, the NEG cartridges are replaceable*



CapaciTorr® Pumping Performance

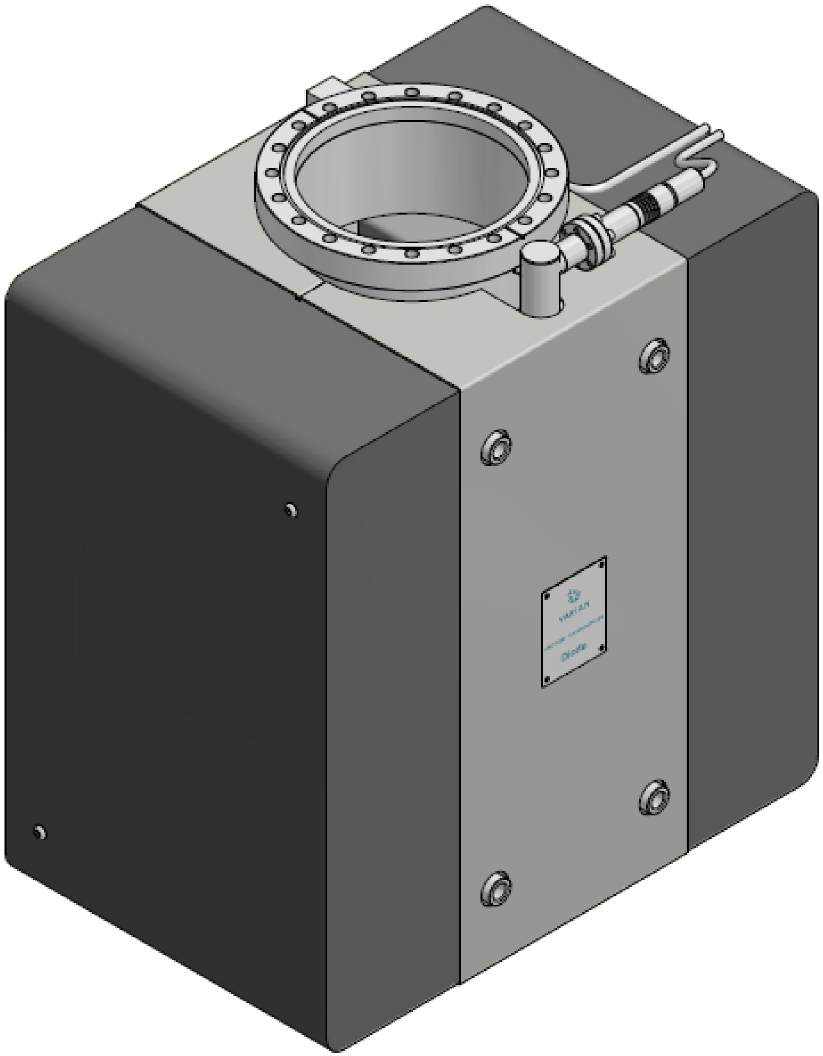


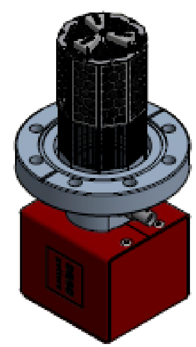
CapaciTorr® st172 vs ZAO HV



F.Siviero AVS 61st, November 2014 Baltimore

NEG – Ion Pump Combination – NexTorr®

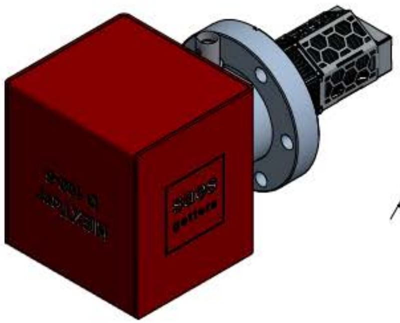


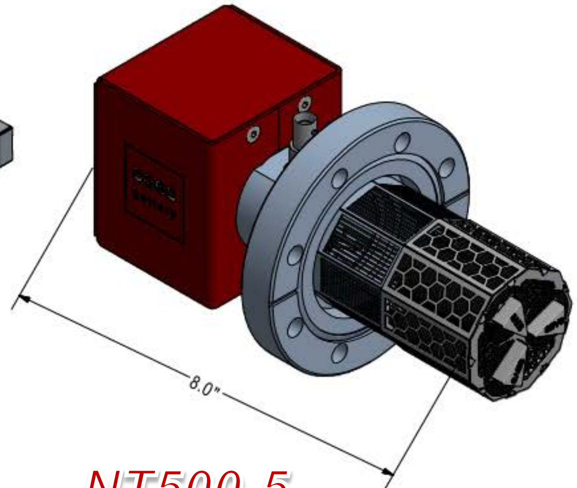


NexTorr D500-5

500 l/s VacIon Plus

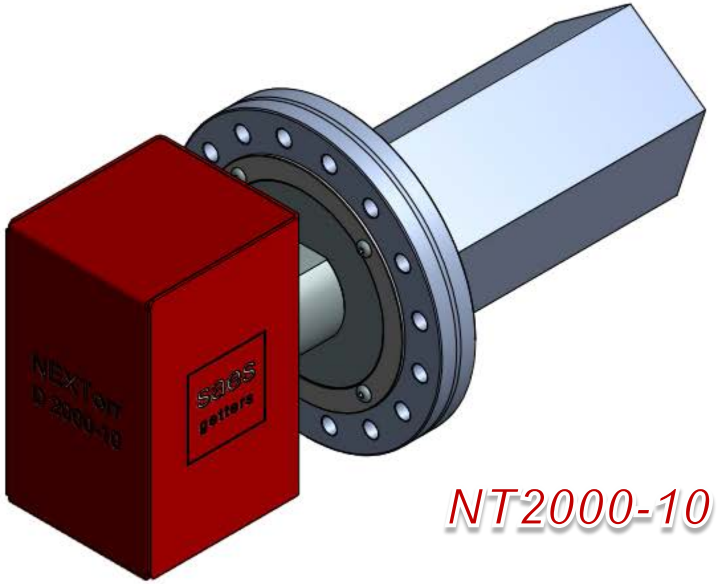
Available NexTorr® Pumps from SAES



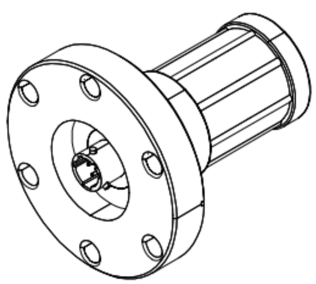


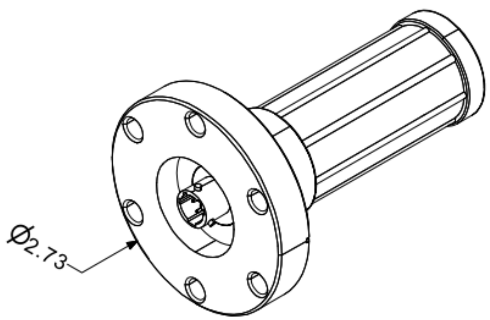
NT100-5

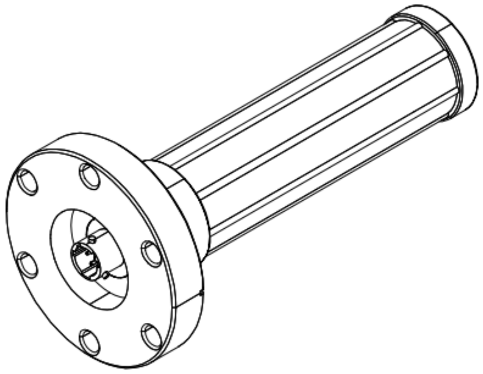
NT500-5



NT2000-10





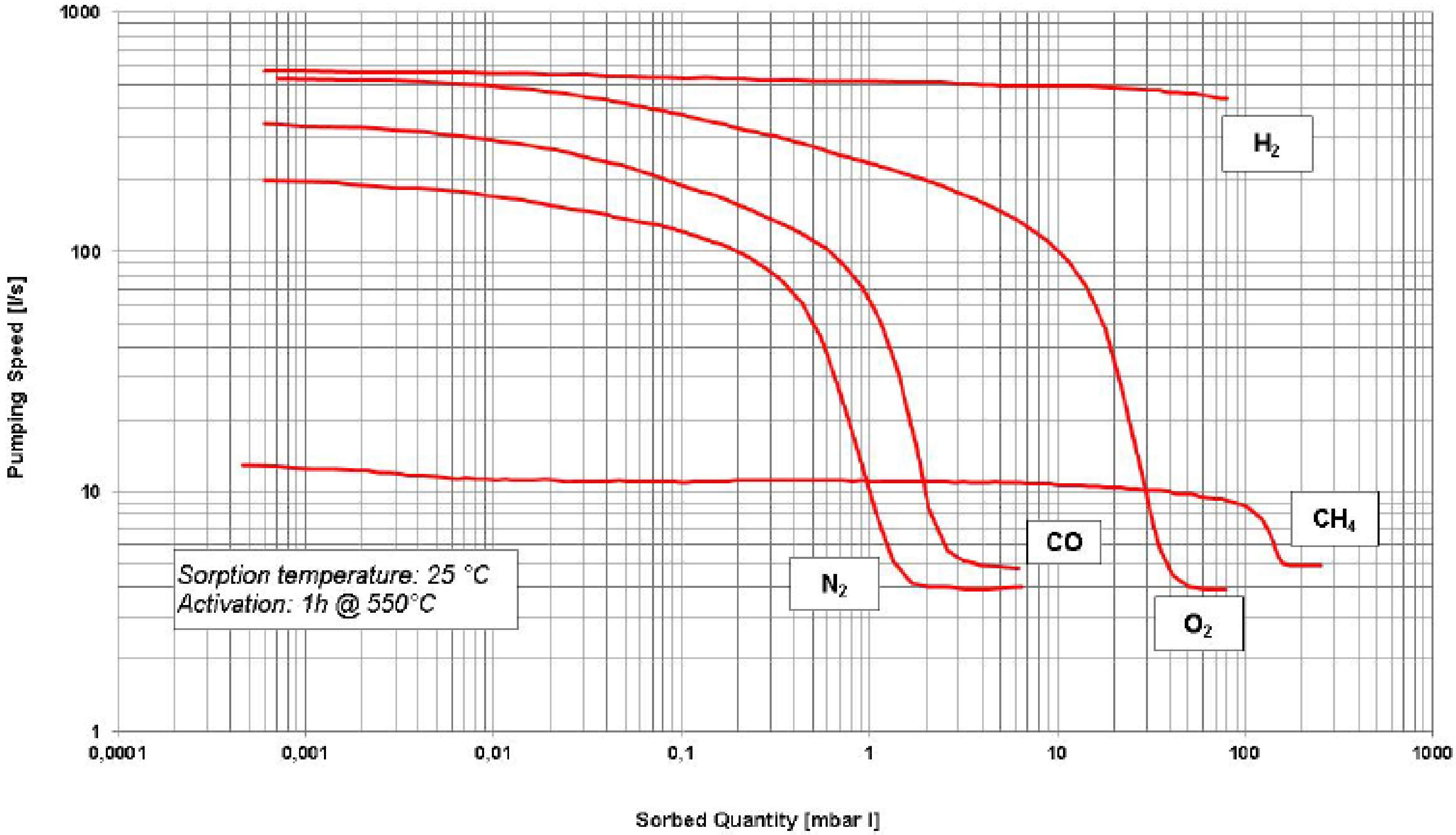


Gamma N100

Gamma N200

Gamma N400

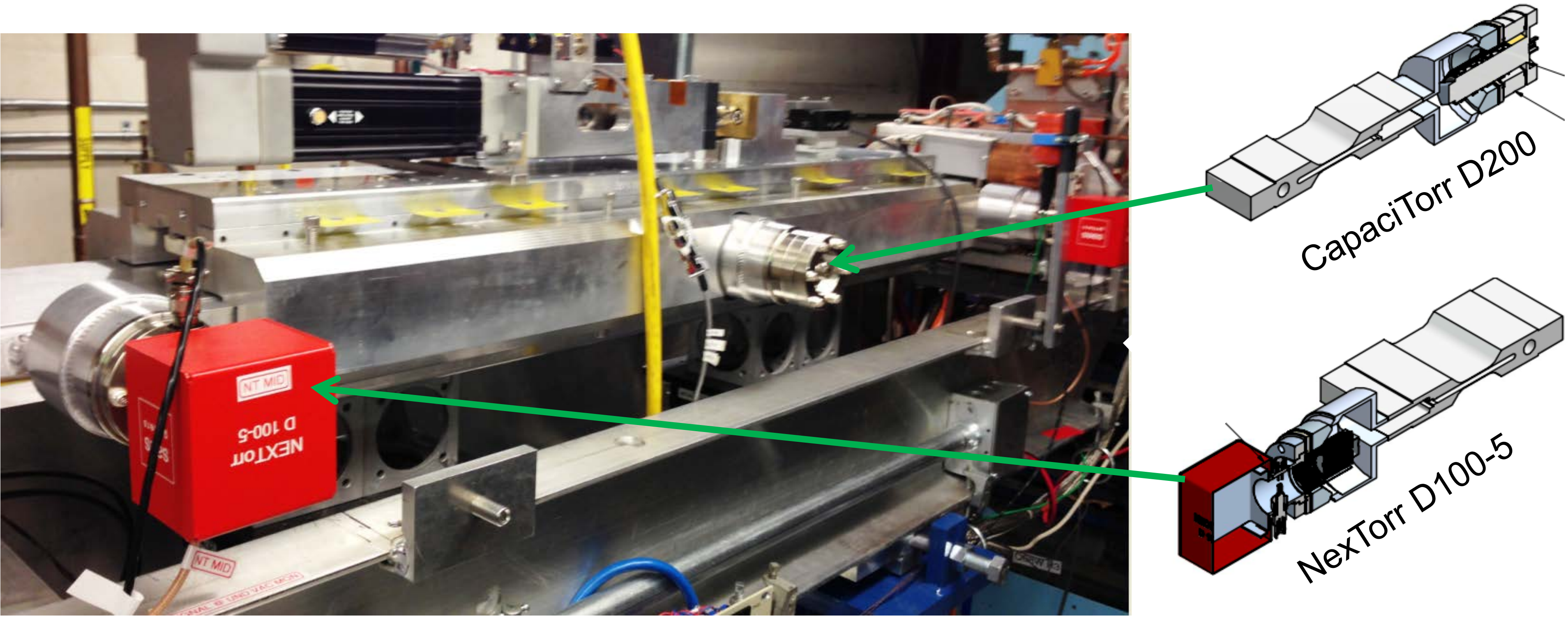
Pumping Performance – NexTorr®



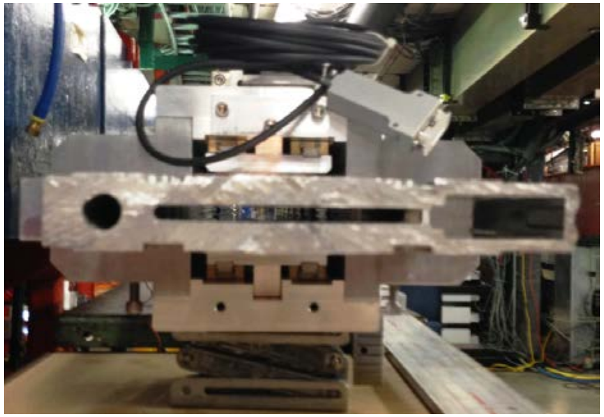
Main Technical Parameters – NexTorr® D500-5

Initial pumping speed (l/s)	Gas	NEG activated	NEG saturated
	O_2	500	4
	H_2	500	6
	CO	340	5
	N_2	200	4
	CH_4	13	5
	Argon[1]	6	6
Sorption capacity (Torr·l)	Gas	Single run capacity [2]	Total capacity [3]
	O_2	17	>1500
	H_2	670	N/A [4]
	CO	1.4	>360
	N_2	0.8	>75
	CH_4	137	50,000 hours at 10^{-6} Torr
NEG section	Getter alloy type		St 172
	Alloy composition		ZrVFe
	Getter mass (g)		68 g
	Getter surface (cm^2)		570
ION section	Voltage applied		DC +5kV
	Number of Penning cells		4
	Standard bake-out temperature		150°C

CapaciTorr and NexTorr Application Examples

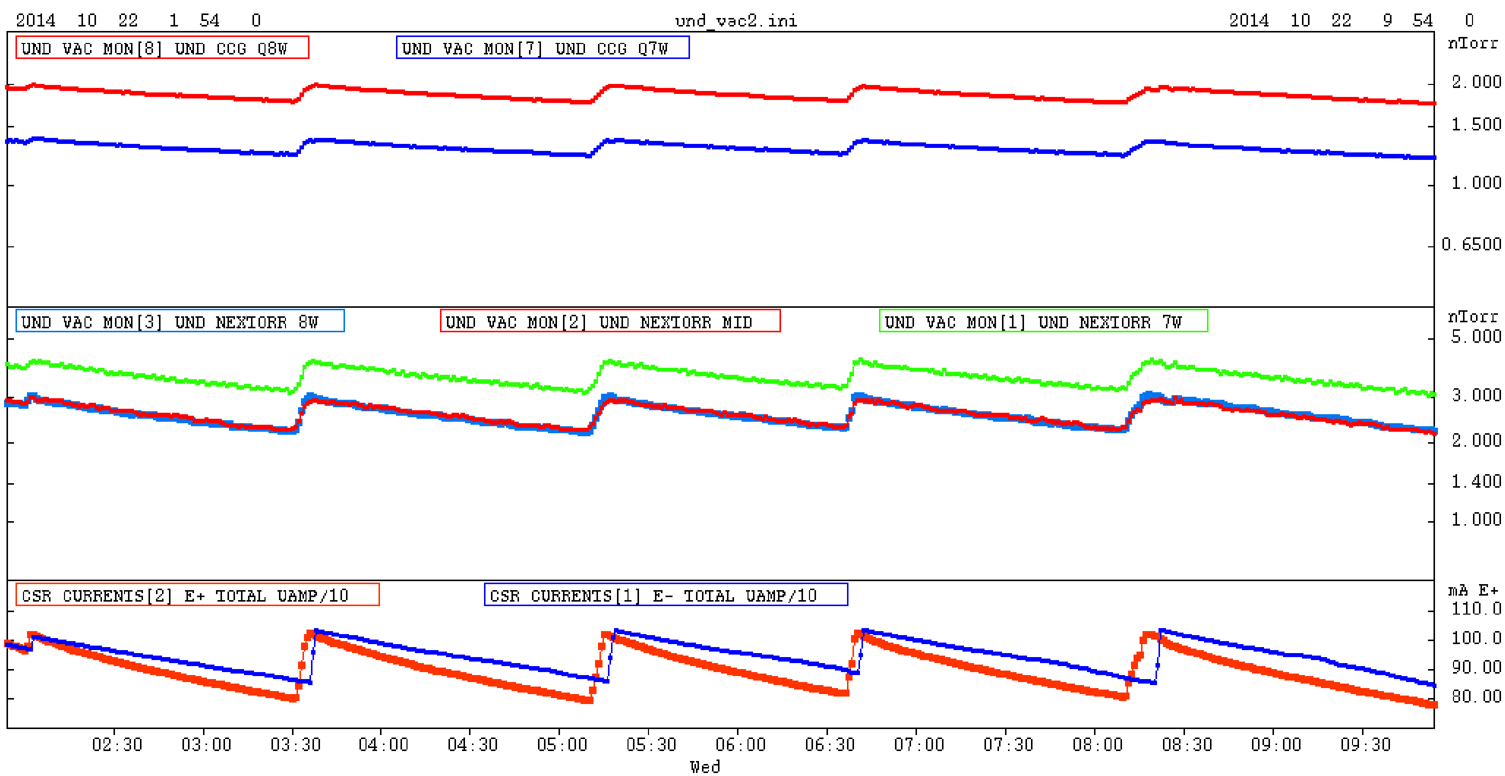


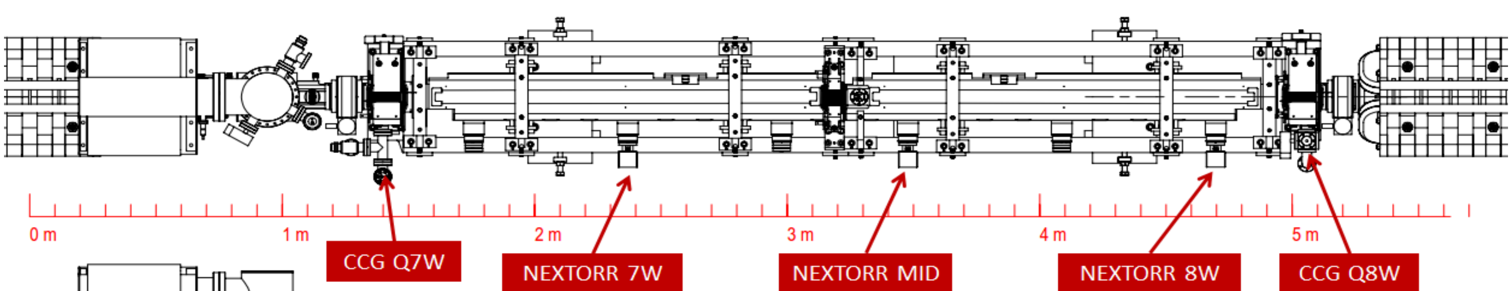
- ❑ *At a recent upgrade project for CESR/CHESS, a 3.5-m long undulator vacuum chamber was designed and installed to accommodate a pair of Cornell Compact Undulator (CCU)*
- ❑ *Three NexTorr D100-5 and three CapaciTorr D200 pumps were used for vacuum pumping, taking full advantage of light weight of the NEGs.*



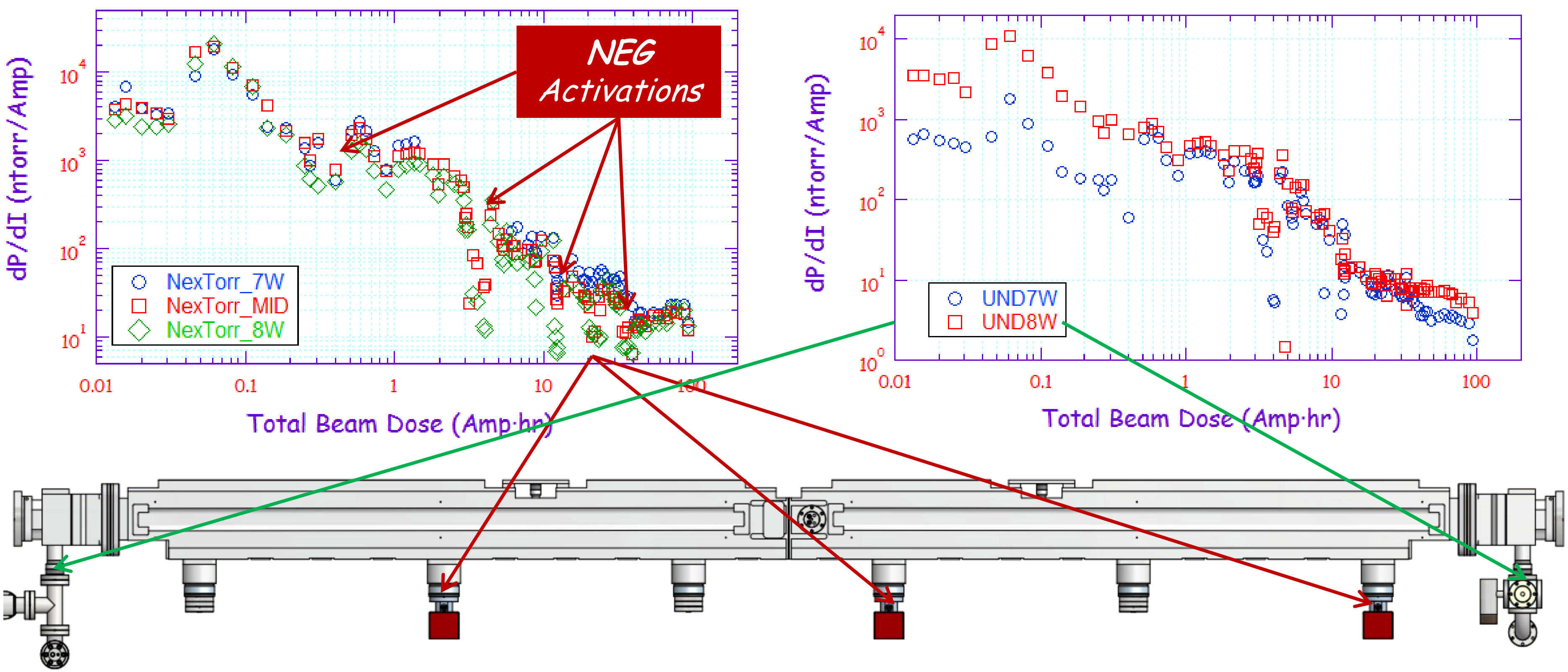
CapaciTorr and NexTorr Performance at CCU – 1

A Snap-shot of Vacuum in a 8-Hour Shift



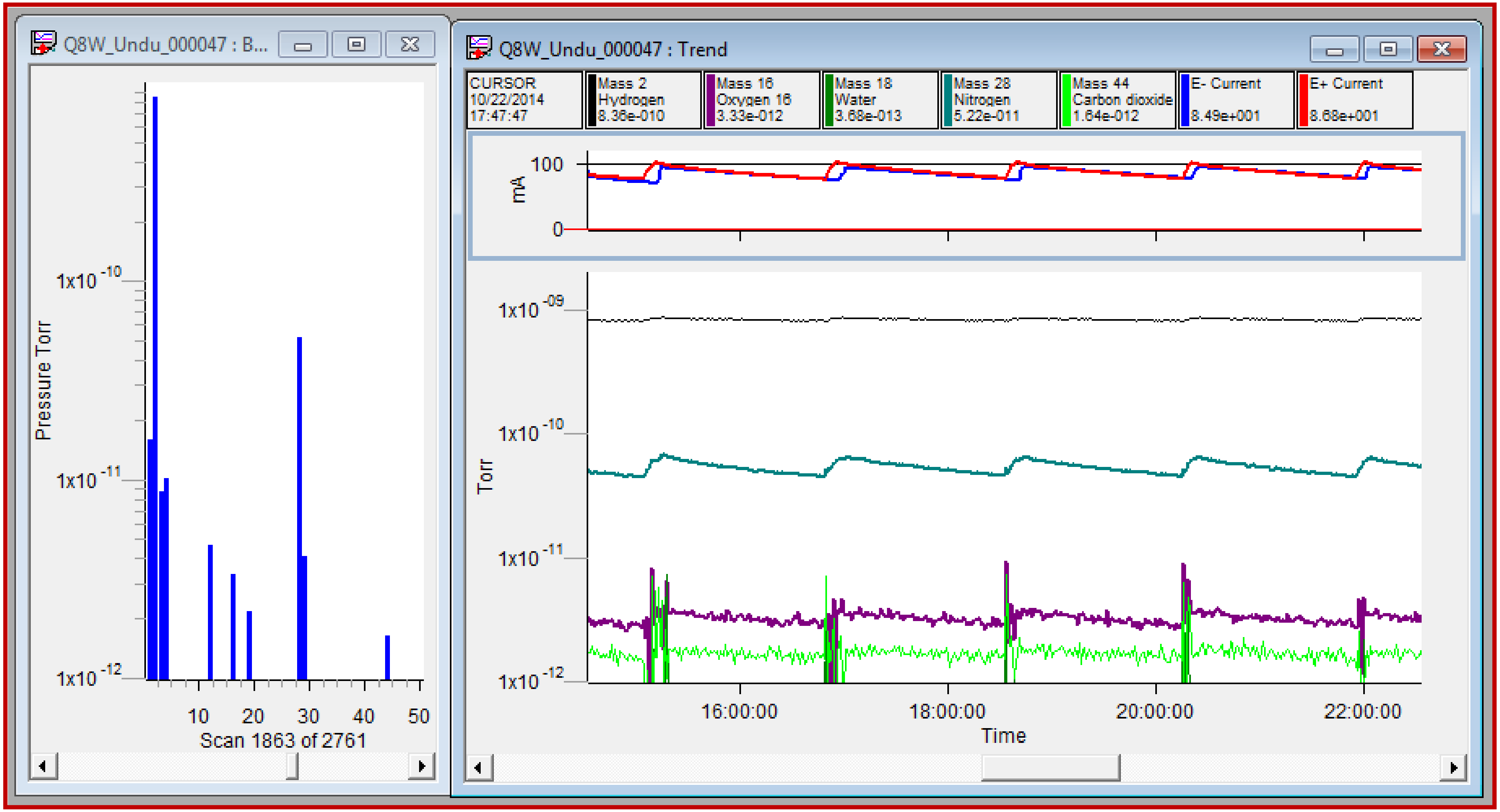


CapaciTorr and NexTorr Performance at CCU – 2



- *The chamber vacuum conditioning are progressing as expected.*
- *The NEGs were re-activated four times during regularly scheduled tunnel access, to keep optimum pumping.*
- *dP/dI values indicating η_{PID} approaches 10^{-6} mol/ph @~100 Amp·hr beam dose.*

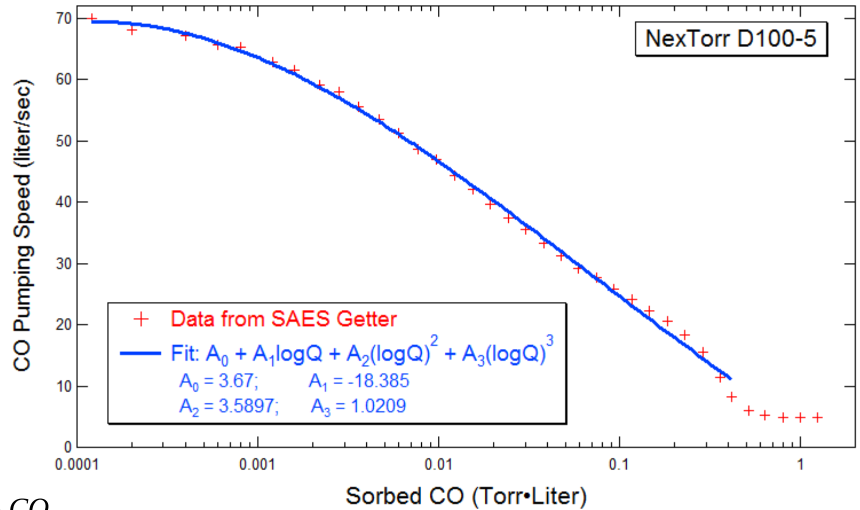
CapaciTorr and NexTorr Performance at CCU – 3



RGA data showed hydrogen being the dominant gas, with trace of other gases (probably produced by RGA filament)

Estimate NEG Pumping 'on-the-Fly' – 1

- In many systems, full vacuum instrumentation is not always possible (lack of space!), so one has to have ways in evaluating NEGs' saturation status.
- For NexTorr pumps, SIP current may be used for evaluating sorbed quantity of a NEG, though gas composition info is needed.



- Estimated sorbed CO-equivalent load Q_t^{CO}:

$$Q_t^{CO} = \sum_i^t \alpha_i^{CO} P_i^{NT_m} \times S_{i-1}^{NT_m} \times \Delta t$$

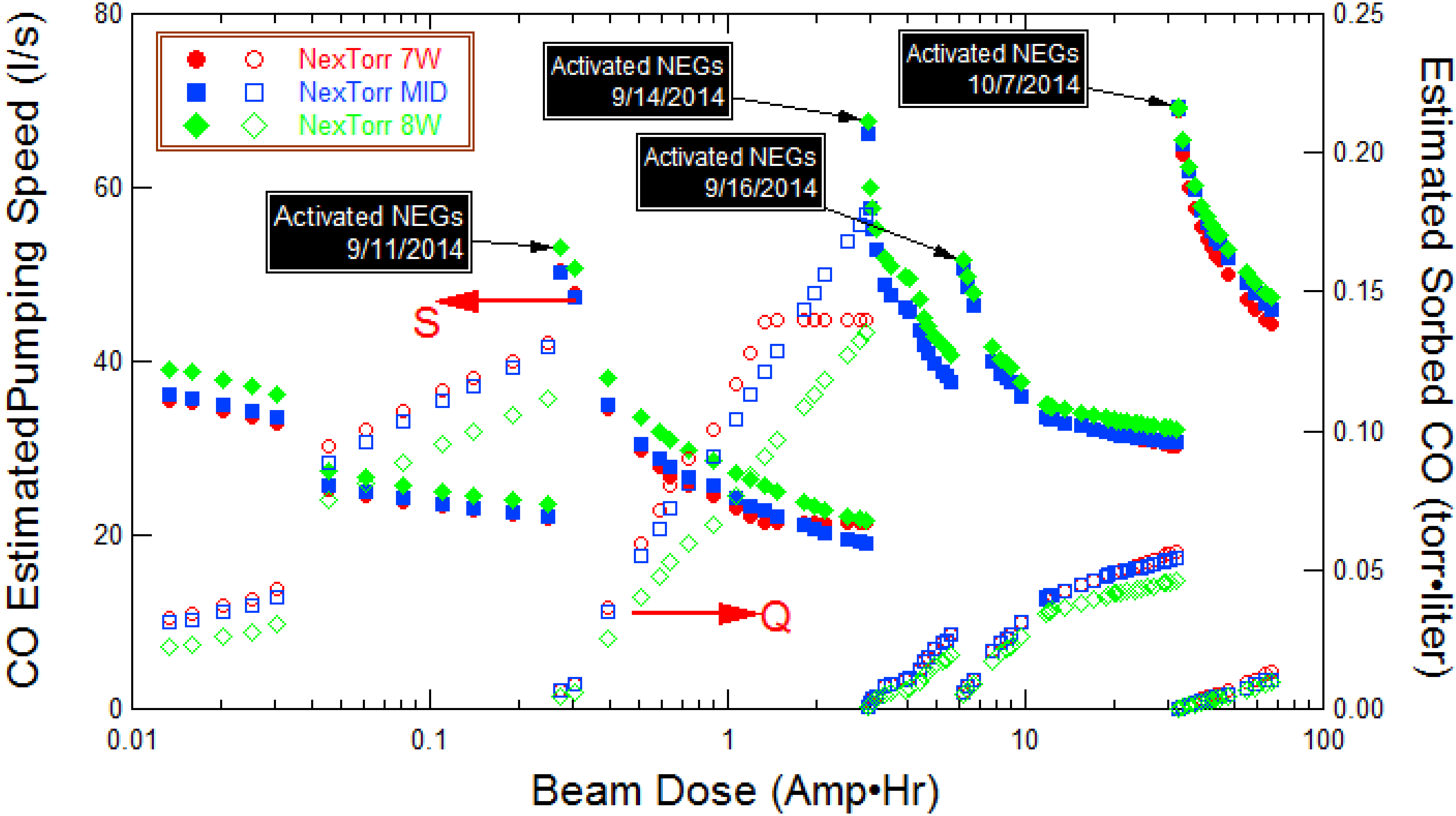
where: $P_i^{NT_m}$ is recorded pressure at t_i from NexTorr m (m=Q7W, MID and Q8W);

α_i^{CO} is estimated CO-equivalent percentage from RGA data;

$S_{i-1}^{NT_m}$ is calculated CO pumping speed using fitted formula above;

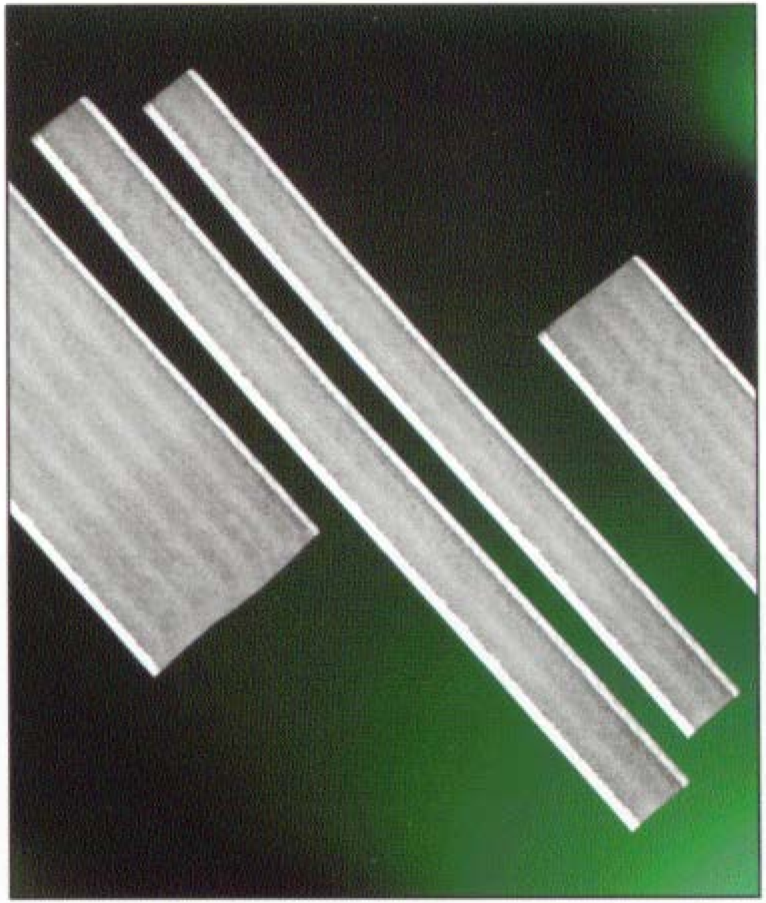
Δt = 60 seconds for data from 1-minute logit files

Estimate NEG Pumping 'on-the-Fly' – 2

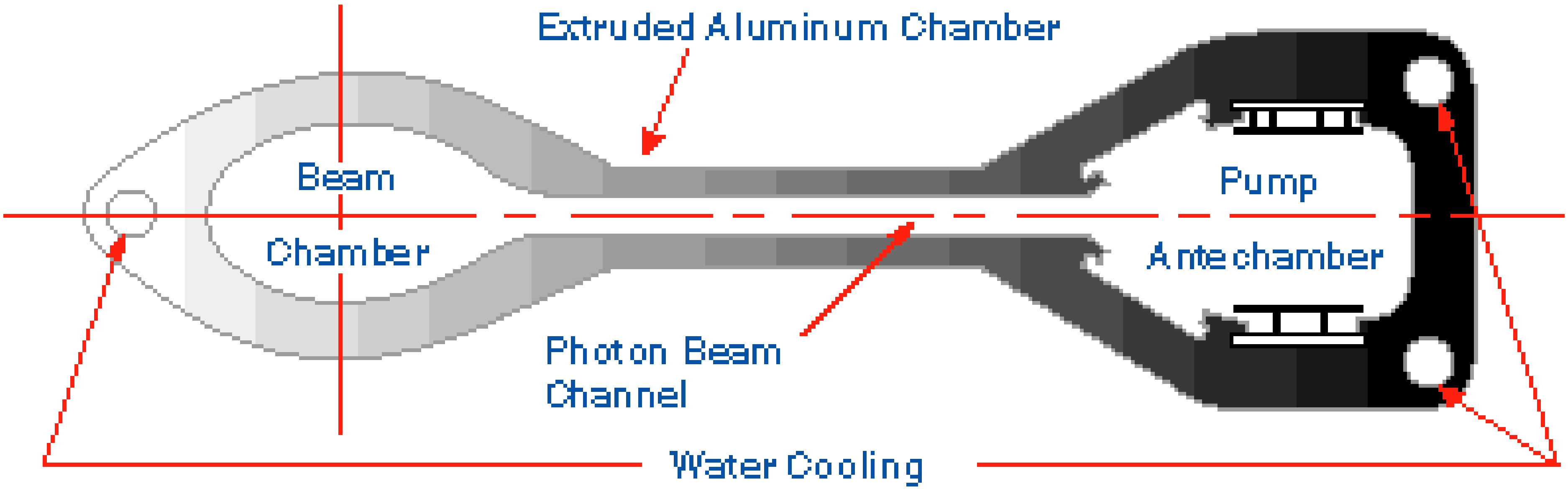


Est. CO equivalent: 100%	75%	50%	25%	15%	10%

Other NEGs forms – Build your own pumps

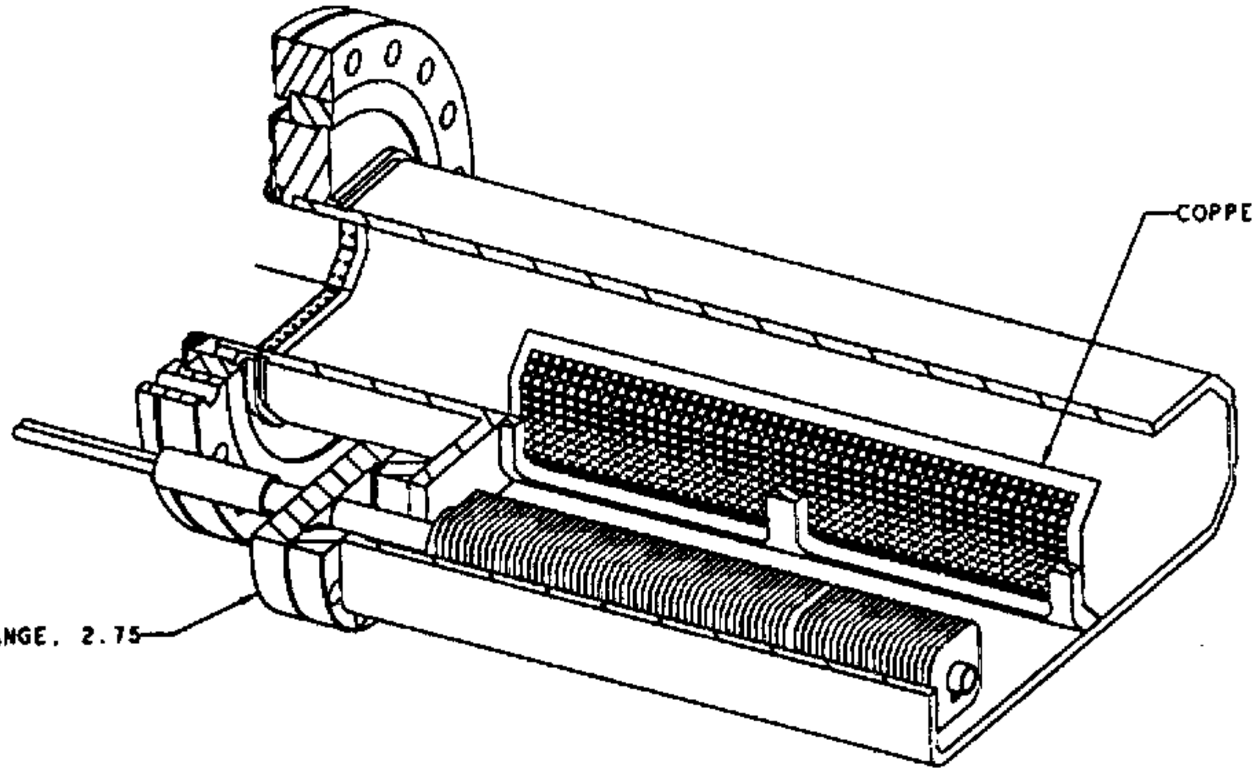


Distributed Pumping with NEG strips



APS Beampipe with NEG strips

LLNL NEG Pump in a PEP-II Vacuum Chamber



Combination Pumping . . . Ion Pumps with TSP or NEG

- Combination pumping produces greater pumping speeds for all gases.
  - TSP and NEG provide high pumping speeds for getterable gases.
  - Ion Pumps provide pumping of argon and light hydrocarbons (usually Noble Diode pumps are chosen).

- Combination pumping can be attained by:
  - Commercial combination pumps
  - Custom built combination pumps
  - Use of multiple types of pumps

- NEGs are used on systems where high constant pump speeds are required or on systems requiring distributed pumping.

- TSPs are used on systems with sudden large gas bursts, localized gas sources and/or frequent venting takes place.

Commercial Combination Pumps . . .
Ion Pumps with TSP or NEG

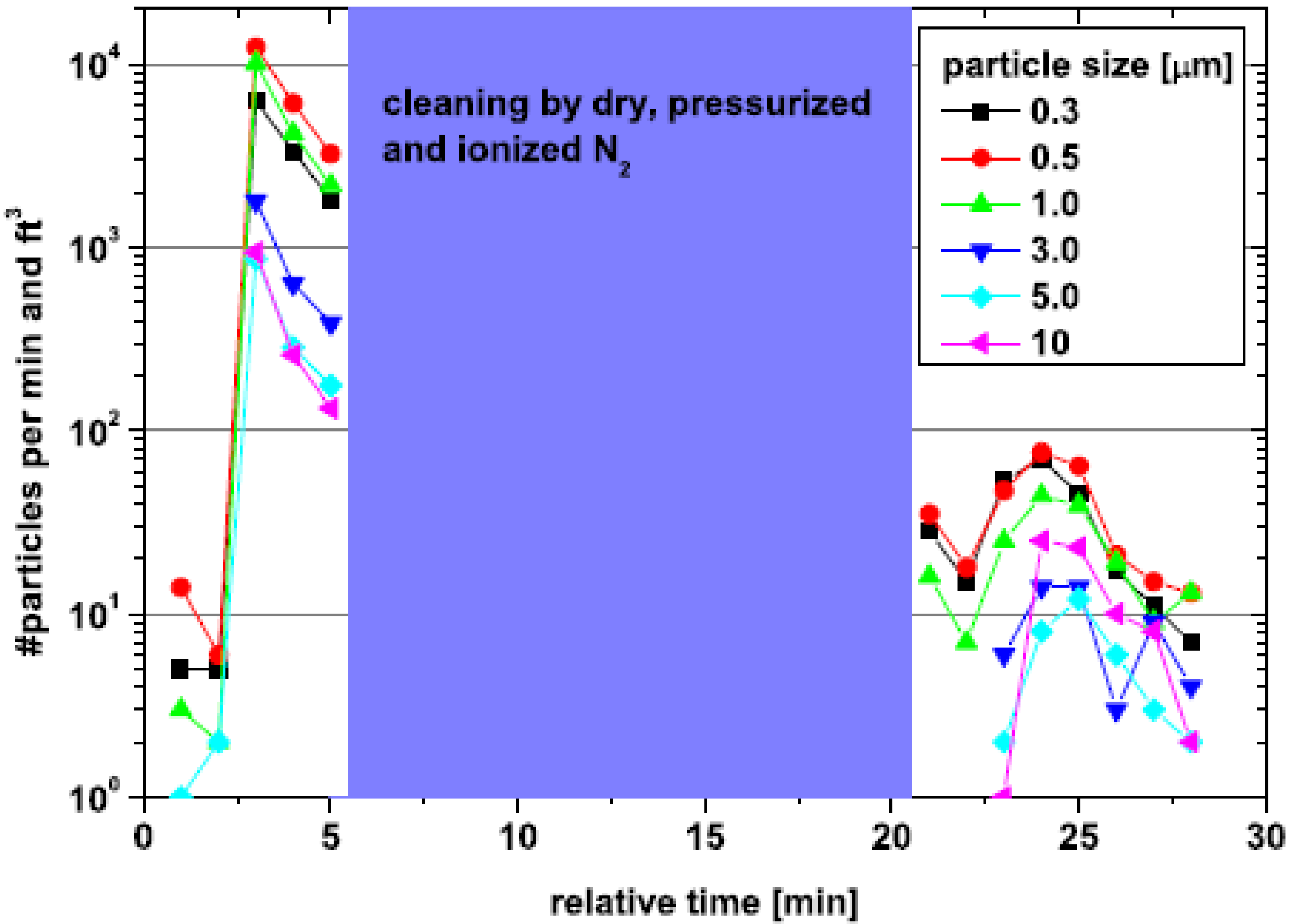
Ion Pump with TSP filaments

Ion Pump with NEG cartrdge

Particle Issues with NEGs and Mitigations

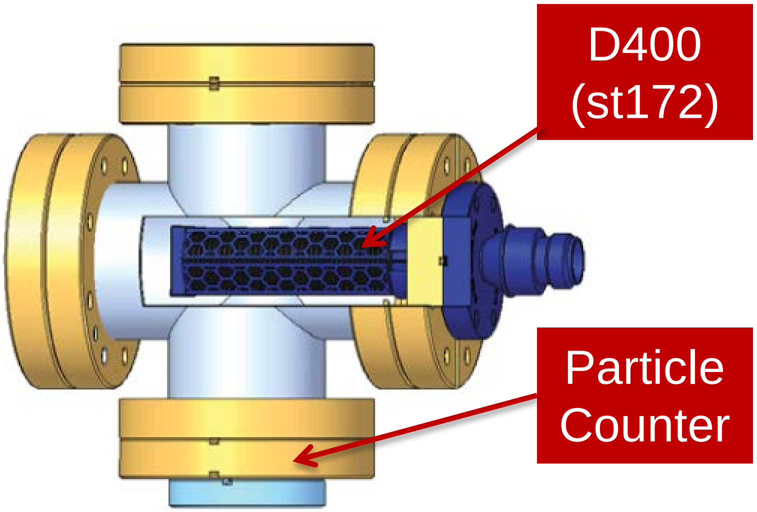
- *Most NEG pumping elements are formed through powder metallurgy, either through cold-press or sintering processes. Thus the NEGs are prone to particulate creation, if not treated.*
- *Particulates creation from NEGs can be a major concern for many UHV systems, such as superconductivity RF cavities, HV DC photon-cathode guns, etc.*
- *Strips with cold-press NEG materials are mechanically less stable than sintered disks/blades. So careful placement consideration should be taken in using these NEG elements.*
- *NEG pumps using sintered materials (such as NexTorr, CapaciTorr) can be cleaned to achieve clean-room compatibility. The proven cleaning methods include N_2-blowing and solvent rinsing (in a Clean-Room condition).*
- *However, cleaned sintered NEG elements may still generate particulates during initial activations. This is currently under further investigations.*

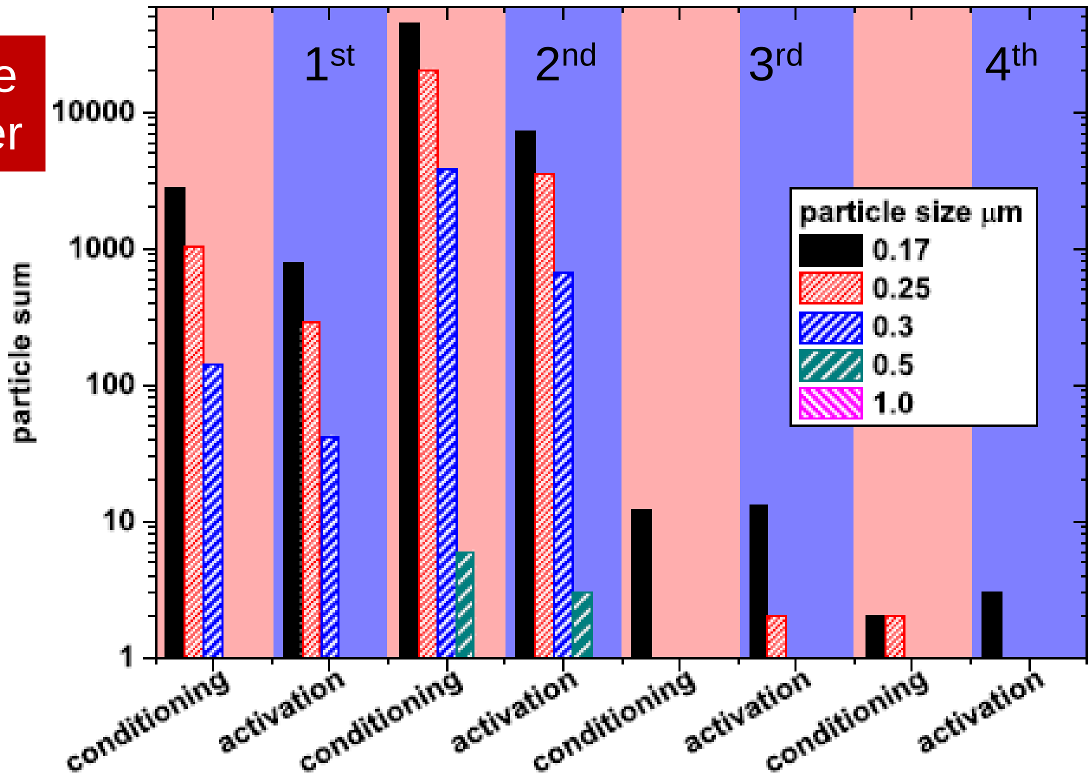
Particles: St172® cartridges



From: S. Lederer, L. Lilje, P. Manini, F. Siviero, E. Maccallini (DESY & SAES)

Particles: St172® cartridges

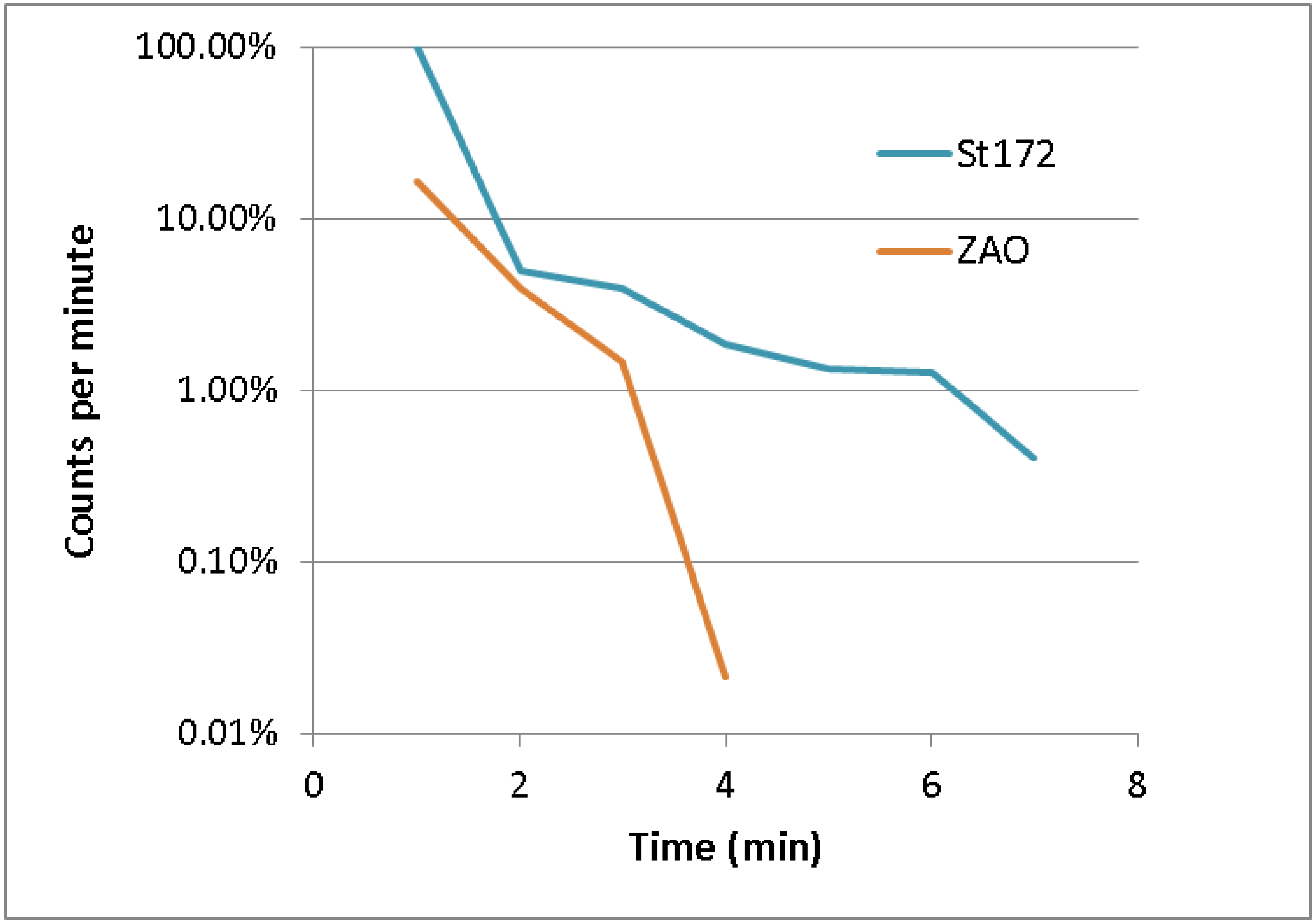




From: *S. Lederer, L. Lilje, P. Manini, F. Siviero, E. Maccallini (DESY & SAES)*

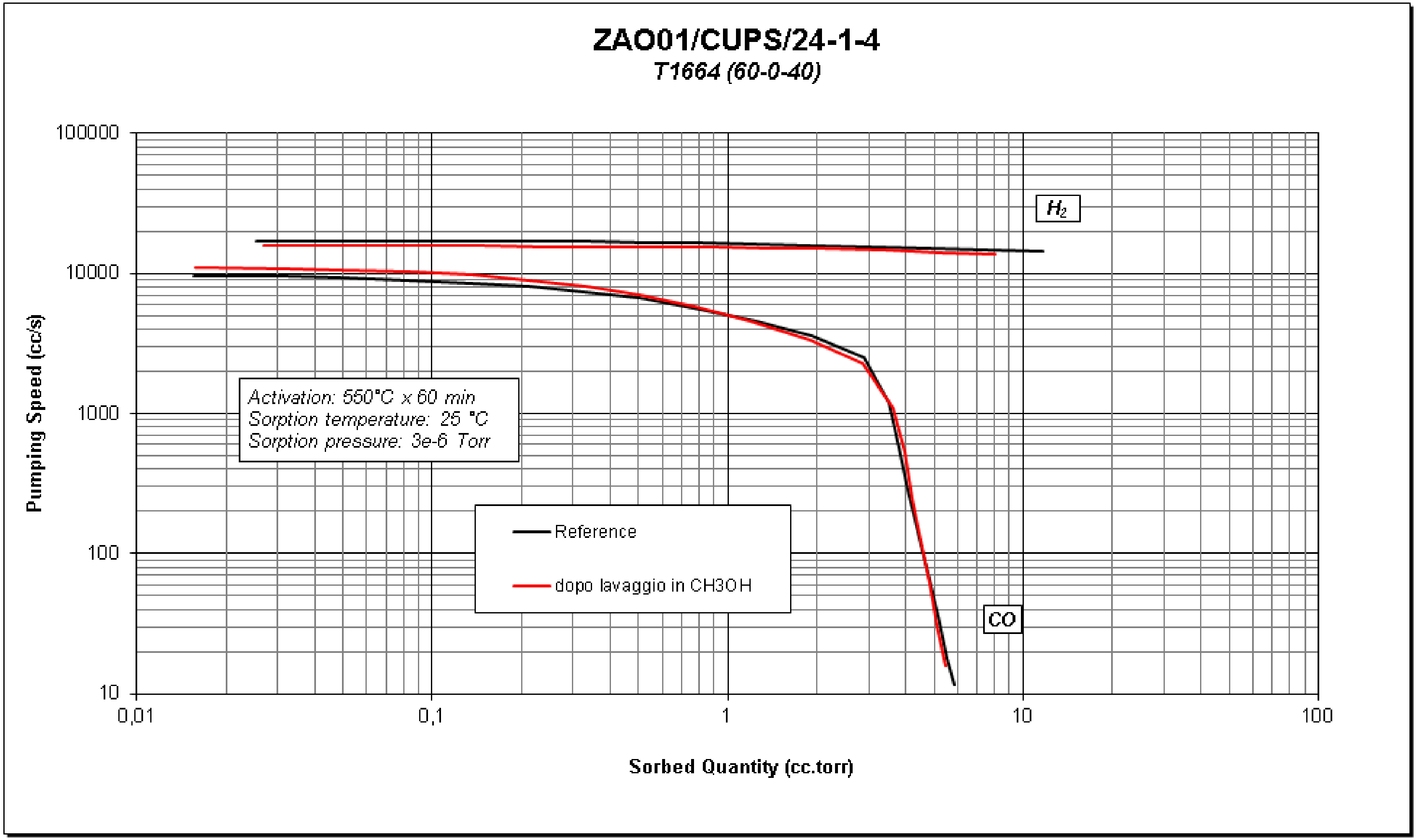
Particles: St172 vs ZAO HV1

Laser particle counter under N_2 flushing



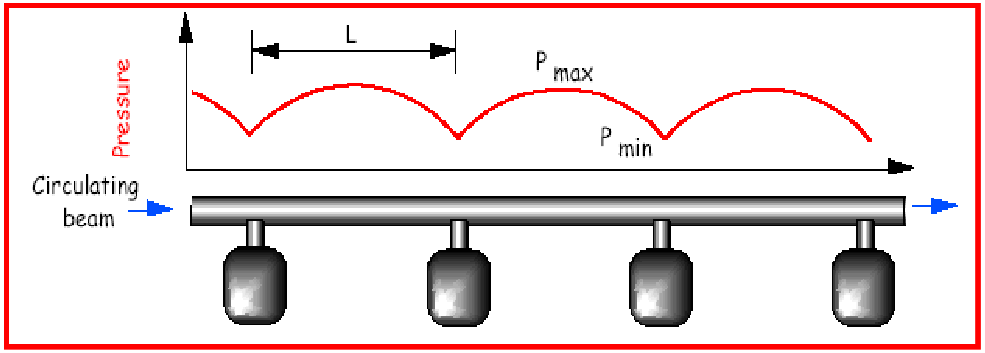
Measurements at INFN Milan

Solvent Cleaning of Sintered NEG



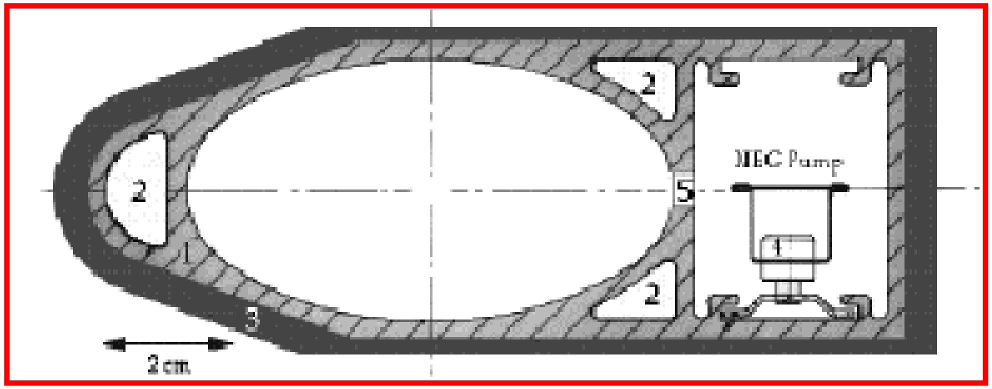
A test by SAES Getters showed no effect on NEG pumping after methanol dipping

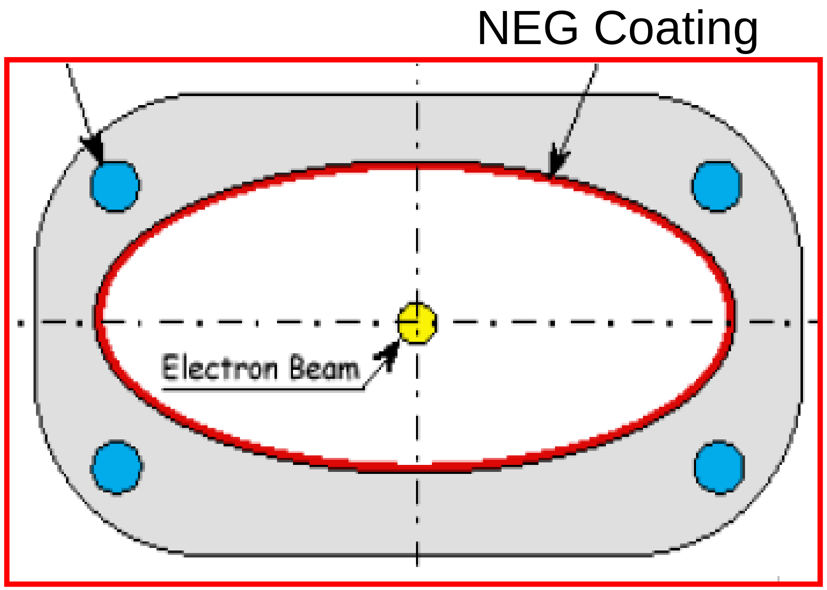
NEG Thin Film – Integrated Pumping



Distributed Pumping

Discrete Pumping

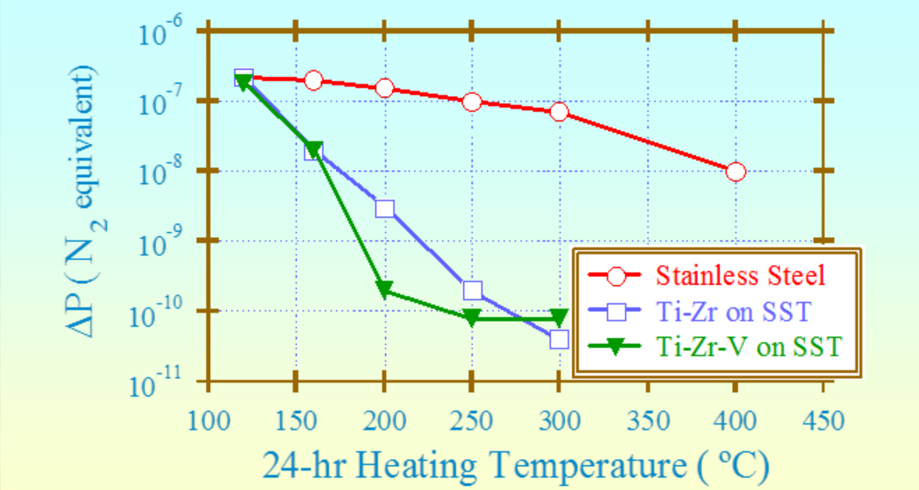




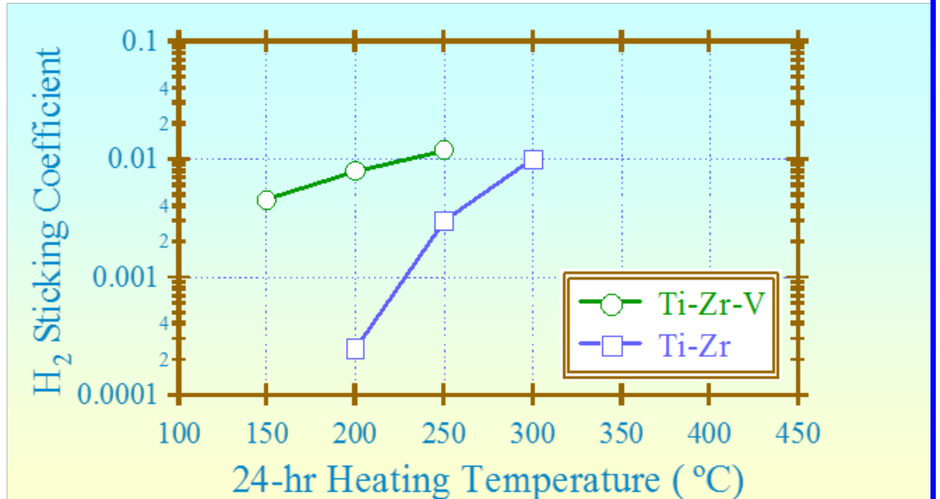
Integrated Pumping

NEG Thin Film – Benefits

- Developed at CERN, by *Bevenuti, et al*



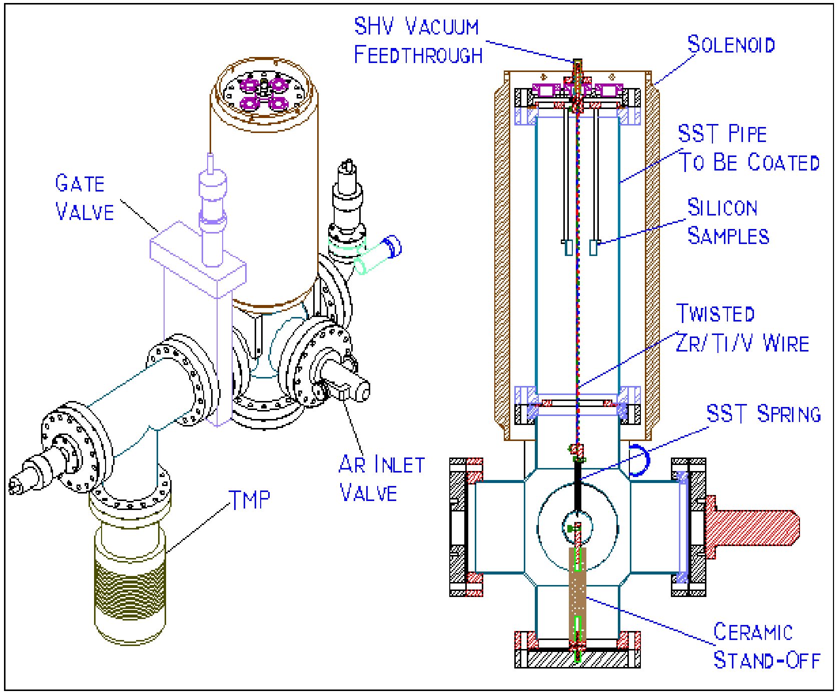
Low Outgassing Rates



LOCAL pumping

Deposition of NEG Thin Films

Typical Sputtering Arrangement – A CLASSE Setup



- Cathode – Twisted wires
- Electric field (ion energy) ~ 600 V
- Magnetic field : 200 ~ 500 Gauss
- Sputtering gas : Ar or Kr P = 2 ~ 20 mtorr

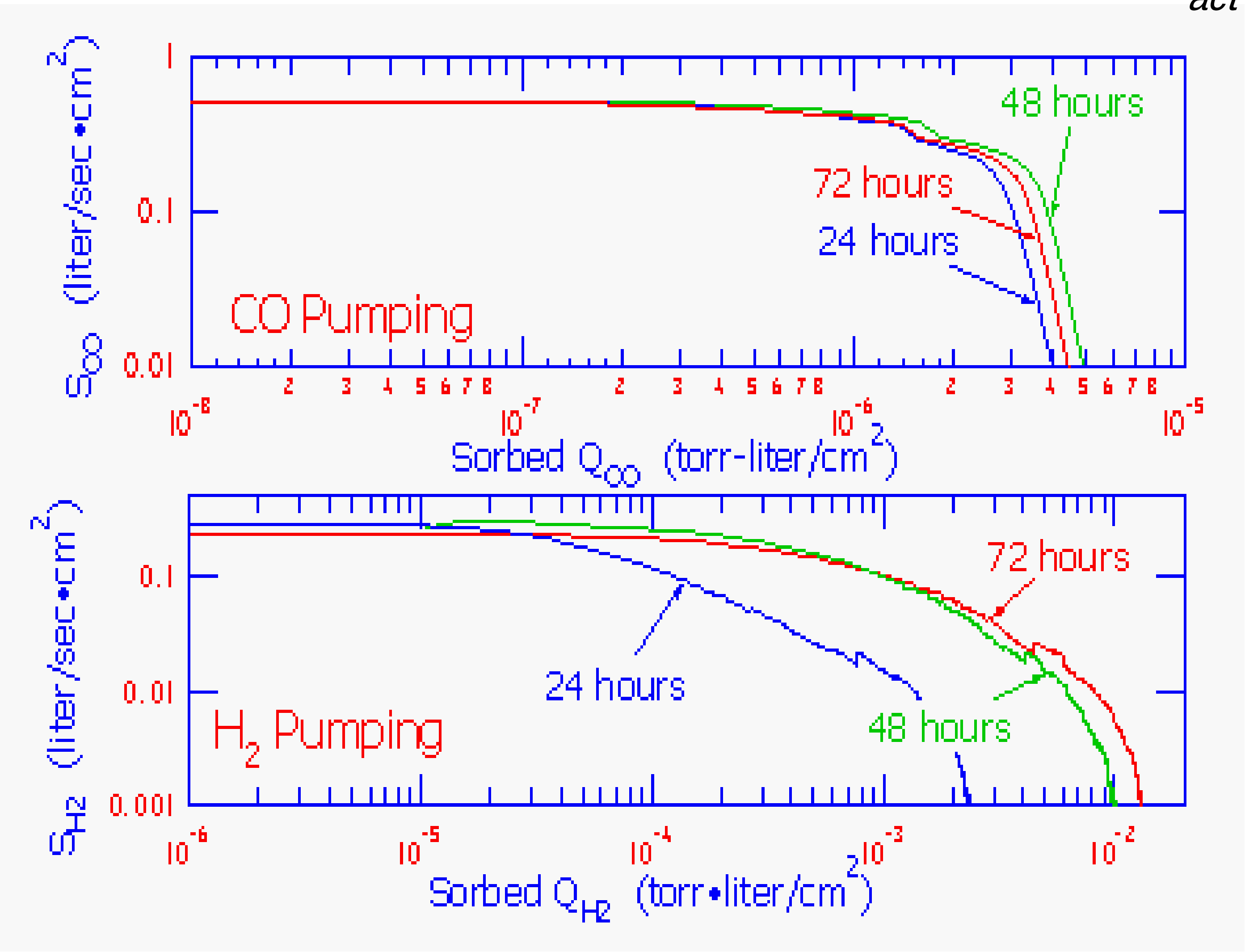
- DC or Magnetron Sputtering arrangement is commonly used.
- Coating surface cleanness is essential for good adhesion
- Sputtering gas purity extremely important

NEG Thin Film Characteristics

- *Most commonly deposited NEG thin films have elementary composition of $Zr_xV_yTi_z$, with x, y, z, close to unity.*
- *Stoichiometric balanced thin film tend to have lower activation temperature, probably due to smaller grain sizes.*
- *Pumping can be achieved at activation temperature as low as 150°C, though typical ~250°C. Thus an in-situ bakeout can activate the NEG coating.*
- *Typical NEG thin film thickness: 2~4 μm.*

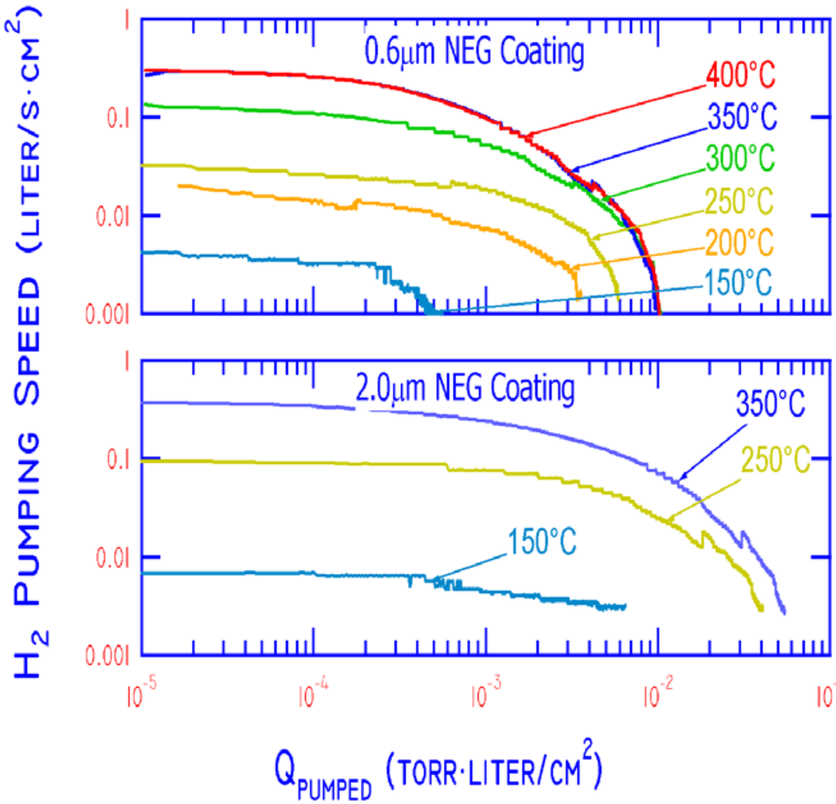
NEG Coating Pumping Performance (1)

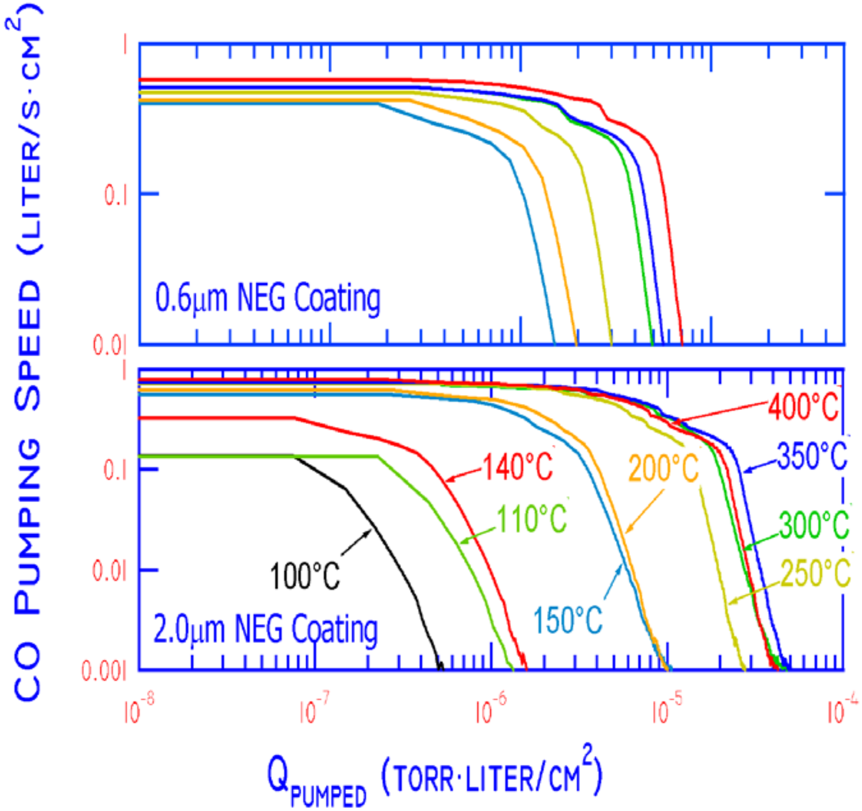
T_{act}=350°C



Pumping Speed vs. Gas-load

Activation Temperature Dependence (48-hr activation)





NEG Film Total Capacity & Aging Effects

- Total pumping capacity of a NEG thin film depends on the film's solubility to oxygen, carbon, nitrogen, etc., and the film thickness

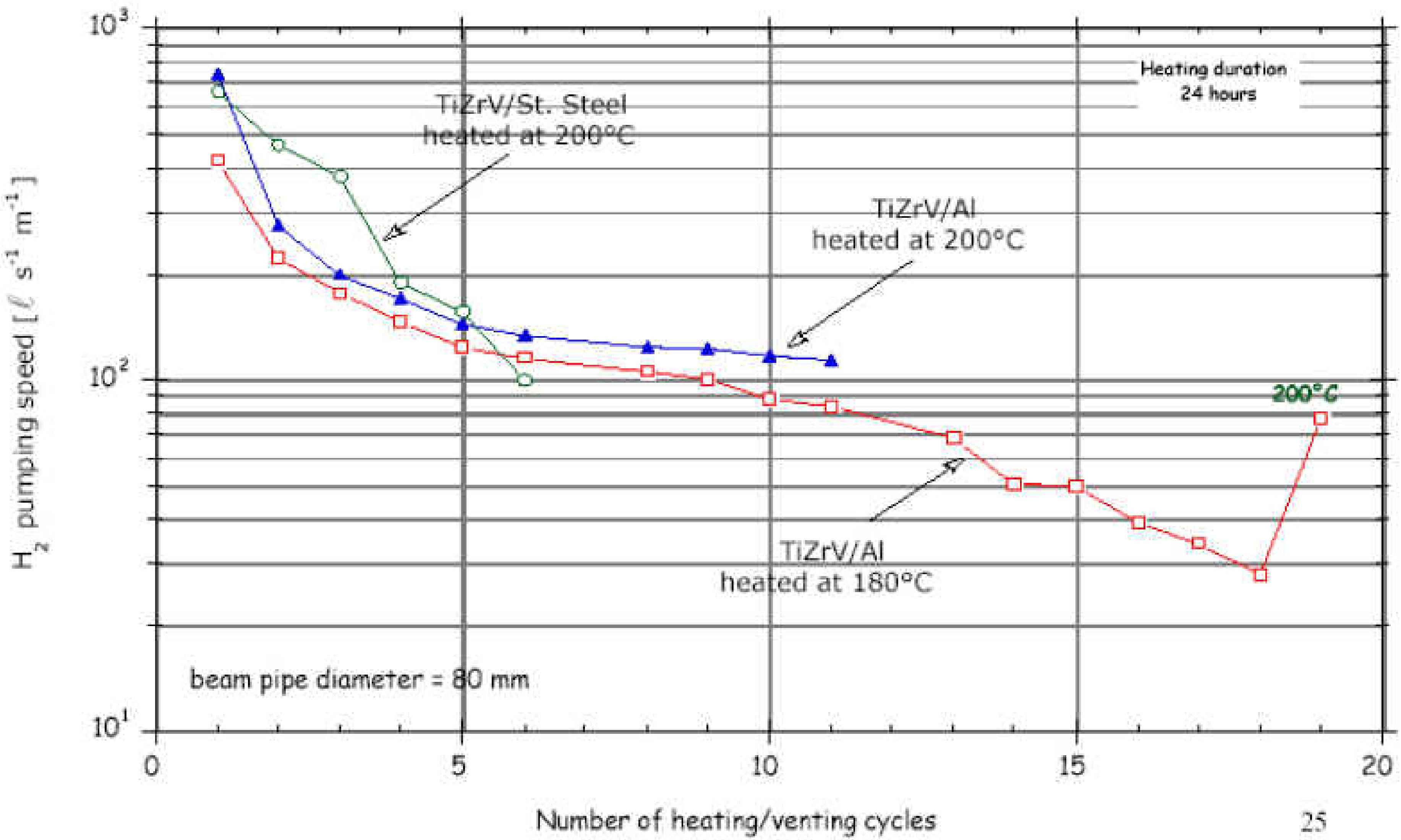
Using solubility of 5%, 1-nm saturated surface oxide layer
Estimated saturation/venting cycles for 1 μm NEG film > **50**

- Gradual aging is a deterioration of the thin film performance due to accumulation of oxygen in the film

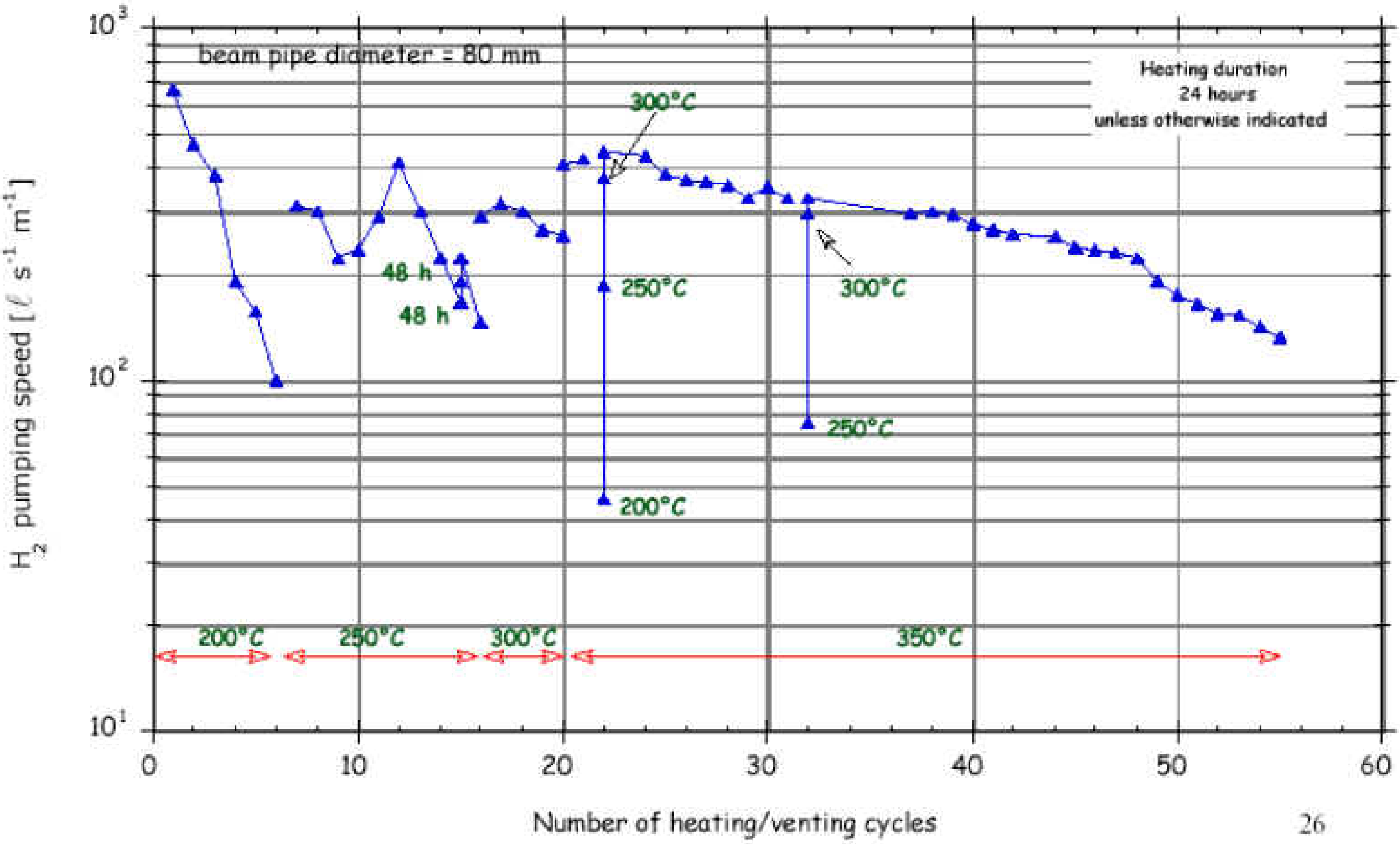
→ Reduction of pumping speed and capacity

→ Increase of activation temperature

NEG Film Aging Effect



NEG Film Aging – More

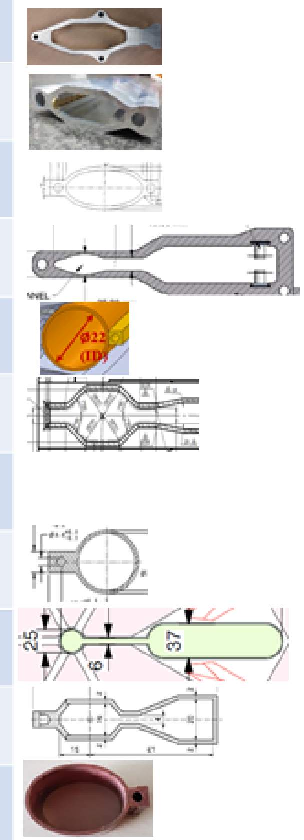


Successful Applications of NEG Coatings

- NEG coating is an idea solution for long narrow-gapped undulator vacuum chambers
- All LHC warm beampipes were NEG coated.
- *ESRF* has had a very successful experience with the NEG-coated undulator chambers.
- RHIC coated ~600m of warm beampipes to suppress e-Cloud and associated abnormal pressure rises, which resulted in significant increase in heavy ion beam performances.
- Other new 3rd generation SR light sources, such as ***SOLEIL*** and ***DIAMOND***, also used the NEG coatings for the undulator chambers.
- A *NEG Coating Workshop* (*45th IUVSTA Workshop*) was held at ***Catania Italy***, in April 2006.

Comparison of SR facilities in attendance @ 80th IUVSTA

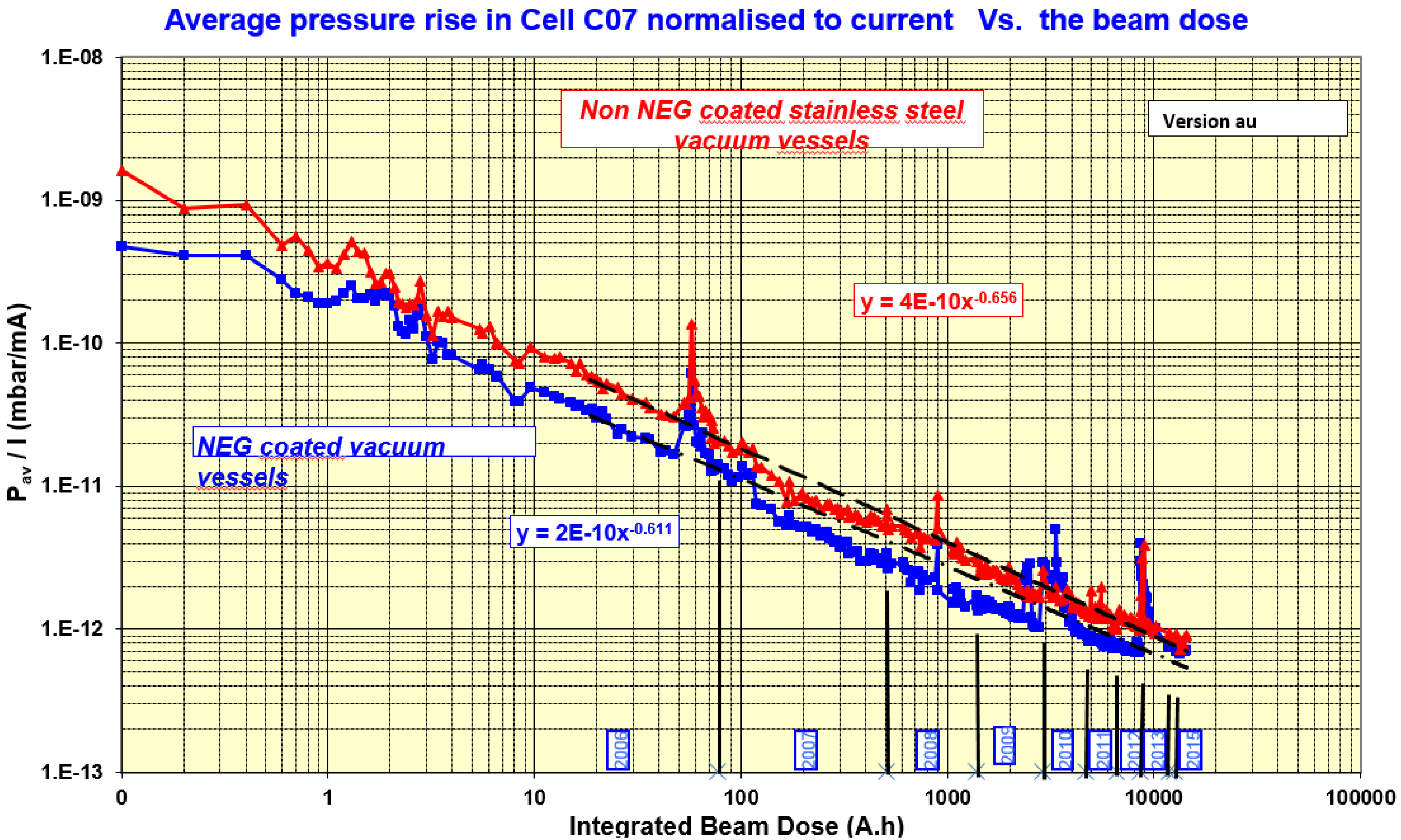
Machine	Country	Status	Lattice	Energy (GeV)	Current (mA)	Circum (m)	Chamber ID (mm)	NEG coat
SOLEIL	France	Active (2006)	DBA	2.75	400	354	25 x 70	56%
PLS-II	S. Korea	Active (2012)	DBA	3	400	281	N/A	0%
TPS	Taiwan	Active (2016)	DBA	3	500	518	38 x 88	0%
NSLS-II	USA	Commissioning	DBA	3	500	792	25 x 76	0%
MAX-IV	Sweden	Commissioning	7BA	3	500	528	22	100%
EBS	France	In Design (2020)	7BA	6	200	844	20	0%
HEPS	China	In Design (2024)	7BA	6	200	1296	22	>80%
APS-U	USA	In Design (2025)	7BA	6	200	1104	22	20%
KEK-LS	Japan	Proposed	8BA	3	500	570	25	>50%
Spring-8 U	Japan	Proposed	5BA	6	100	1436	16 x 30	0%
Diamond-II	UK	Proposed	6BA	3	300	562	18 x 27	0%
ALS-U	USA	Proposed	DLSR	2	500	197	N/A	>20%



Courtesy of Jason Carter of APS

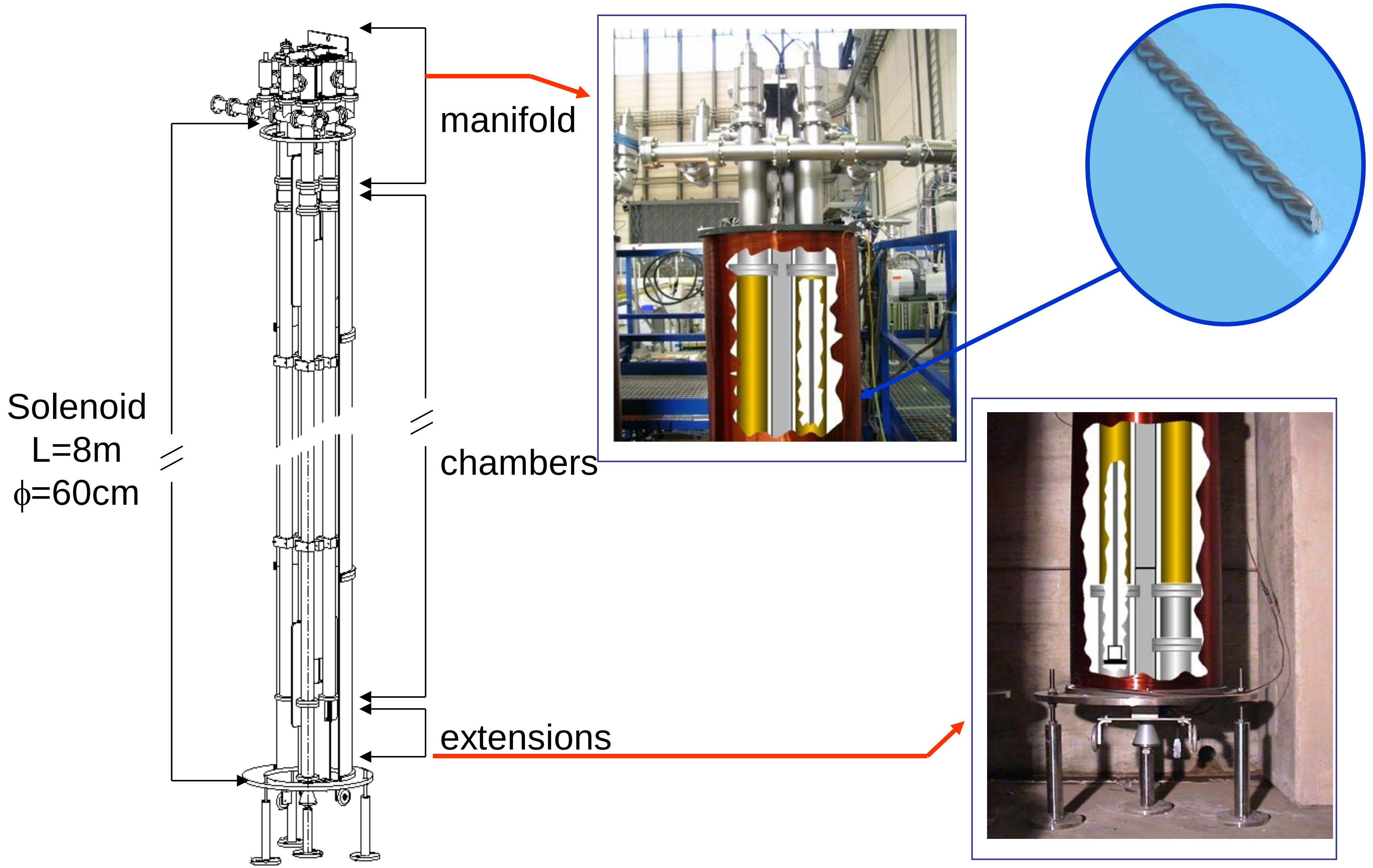
10 year experience of operation with NEG coating at the SOLEIL synchrotron light source

Christian HERBEAUX , N. BECHU, Vacuum Group



CERN's NEG Coating Facility

CERN's NEG Coating Facility – Details



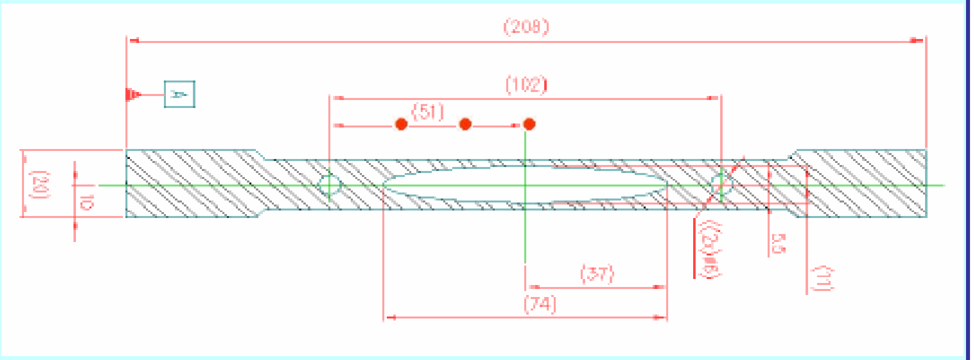
CERN's NEG Coating Production

More than 1300 chambers coated with TiZrV NEG for the LHC.

Standard chambers are 7 m long, 80 mm diameter.

ESRF's NEG Coating Facility

A New NEG Coating Building @ESRF



Extruded Al-Chamber
5-m long, 11-mm Gap

Motorized Air-cool Solenoid (500 G @100Amp)

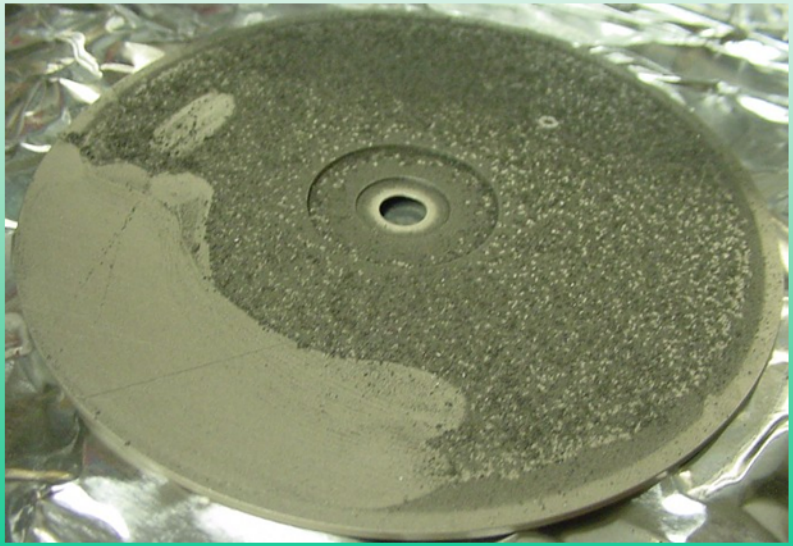
IntegraTorr® – SAES Getters' NEG Coating

- *SAES Getters is licensed by CERN to provide commercial NEG coating services.*
- *All components to be coated by SAES are cleaned by CERN facility, to ensure good thin film adhesiveness.*
- *Known projects used this services: RHIC, CesrTA, etc.*

One of the SAES sputtering systems for NEG coating, capable to coat up to 6.5 meter long chambers with a 2m height coil.

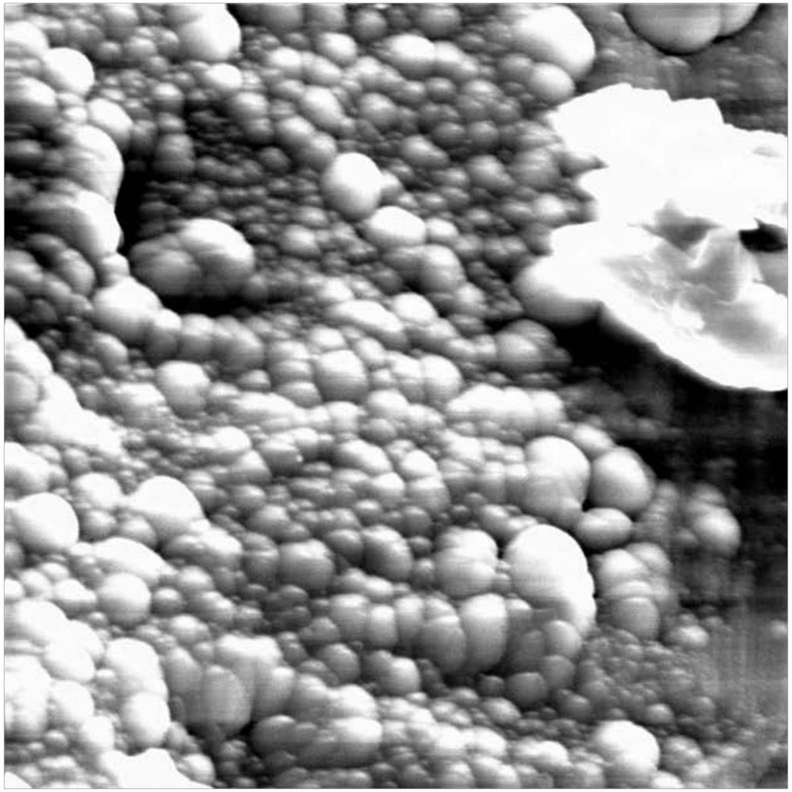
Word of Caution

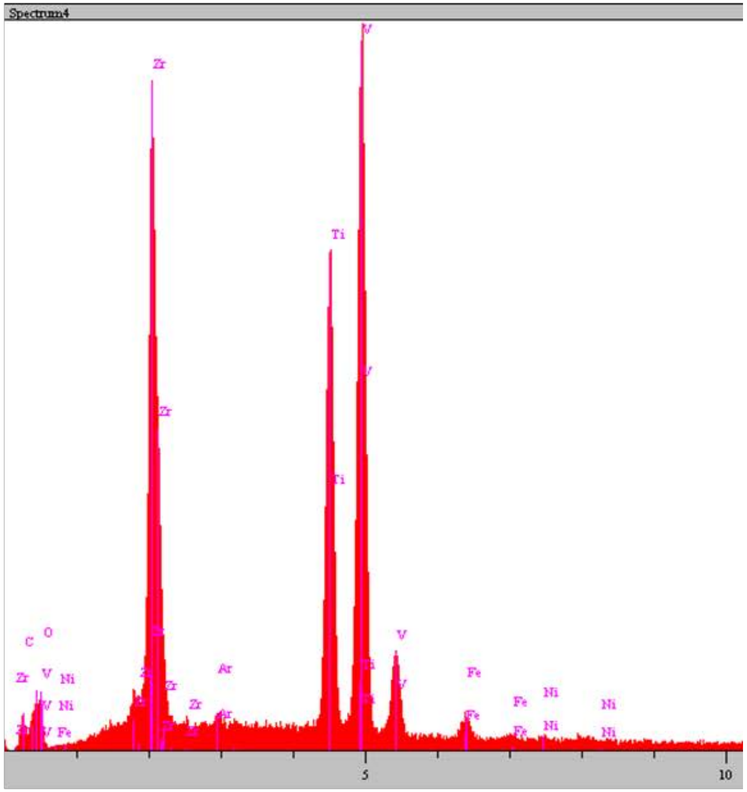
Powder substance were found on the orifice disk, as well as on the coated surface, after extensive pumping tests



- *The original coating had excellent bonding, by visual inspection and/or via 'tape testing'*
- *Believe the coating was damaged by excessive H_2 sorption. More investigation planned*

Powder Confirmed to Be NEG





Powder SEM Image

Powder EDX Spectrum

NEGs or TiSPs

- Both TiSPs and NEGs are great in deal with hydrogen gas load, the main gas in an UHV system
- If space available, TiSPs are the first choice
  - → Much lower cost
  - → More operational friendly
  - → 'Un-limited' capacity
- However, space is always tight in accelerators, NEGs are more favorable
  - → They are more expensive, but similar to the ion pumps
  - → NEGs are usually user-ready, little design involved
  - → Capacity vs. dynamic gas-load needs to be evaluated.
- Some practical questions regarding NEGs
  - → How to reduce hydrogen from NEGs ?
  - → Should the NEGs be thoroughly de-hydrogen before installation ?
    Or is that possible ?
  - → What's sources of hydrogen in the commercial NEG module/cartridge
    (in the NEG materials, or in the heating elements) ?
  - → What's the best way to passivate NEGs for air exposure ?