LEP2 synchrotron-radiation issues

J.M. Jimenez

Main Topics

- **Introduction**
- **Vacuum requirements**
- **Vacuum engineering considerations**
- **What was learnt?**
- **Closing Remarks**

Introduction
Accelerator vacuum requirements

- **LEP particle beams were travelling under vacuum to reduce beam-gas interaction which was responsible for:**
  - Machine performance limitations
    - reduction of beam lifetime (nuclear scattering),
    - machine luminosity (multiple coulomb scattering),
    - intensity limitation by pressure instabilities (ionization) and
  - ☞ heavy gases were the most dangerous because of their higher ionisation cross-sections ☞ Argon from welds…
- **Beam-gas scattering frequently induced background to the Detectors**
  - Non-captured particles which interact with the detectors
  - Nuclear cascade generated by the lost particles upstream the detectors.
- **Beam-gas scattering was responsible for the increase of the radiations**
  - High dose rates lead to material activation (personnel safety issues), premature degradation of tunnel infrastructures like cables and electronics
  - Higher probability of single events (induced by neutrons) which destroyed the electronics in the tunnel

Introduction
Accelerator vacuum requirements [cont.]

- **Vacuum system obeyed to severe additional constraints which had to be considered at the design stage since retrofitting mitigation solutions is often impossible or very expensive**

  – Minimise beam impedance and HOM generation

  – Optimise beam aperture in particular in the magnets

  – Intercept the huge SR power deposited in the vacuum beampipes

  – Specific shielding against radiation to protect magnet coils and tunnel infrastructures

Vacuum requirements
Beam Lifetime Considerations

- **Beam-gas scattering dominated by bremsstrahlung on the nuclei of gas molecules. Therefore, depends on:**
  - Partial pressure
  - Weight M of the gas species
  - Radiation length [g/cm^2]

Typical composition of photon-stimulated desorption: 75% H_2, 24% CO/CO_2, 1% CH_4

- ☞ Ar is 67 times more harmful than hydrogen (H_2)
- ☞ CO_2, CO and N_2 are about 30 times worst compared to hydrogen (H_2)
- ☞ CH_4 is 10 times worst

☞ **Gas density requirements are more stringent in colliders than in Linacs**

- ☞ Bake out was the baseline

Vacuum requirements
Vacuum Cleaning

- **Vacuum Cleaning**
  - Characterize the reduction of the desorption yields (η) of a surface resulting from the bombardment of the surface by electrons, photons, ions.

☞ η = Number of gas molecules desorbed from the surface/bulk by a primary electron, photon, ion.

- **Accelerator vacuum system cannot be designed for nominal performances on "day 1", LEP relied on:**
  - Vacuum cleaning
    - Reduction of the desorption yields (η) by photon, e- and ions bombardments

☞ **Necessitate accepting a shorter beam lifetime or reduced beam current during initial phase, about 500 h for LEP**
  - Could be significantly decreased by using NEG coatings (see end of the talk)

Vacuum engineering considerations
SR Issues

- **Power deposition**
  - 50% of the radiation power hitting the vacuum chamber was absorbed in the aluminum chamber
  - Remainder 50% (high-energy part of the spectrum) escaped into the tunnel and created severe problems:
    - Degradation of organic material and electronics due to high dose rates
    - Formation of ozone and nitric acid leading to severe corrosion problems in particular for aluminum materials

- **Lead Shielding**
  - Lead shielding of 3 to 8 mm soldered directly on the vacuum chamber were used at LEP

- **Heat load extraction**
  - Evacuation of SR induced heat load on vacuum pipe wall and on lead shielding was a critical issue ☞ water circulation was used
    - Critical and required heavy maintenance

- **Material fatigue**
  - The induced thermal stress was studied for LEP ☞ had an impact on the material choice

Vacuum engineering considerations
Materials

- **Extruded aluminum beam pipes were used since:**
  - Cheap and easy to extrude complex shapes
  - High thermal conductivity ☞ optimum for SR cooling issues

☞ **But was a limitation for:**
  - Bake out temperature ☞ pressurised hot water limited to 150°C
  - Reliability of vacuum interconnection based on aluminum flanges is a concern at high temperature (>150°C)
  - Corrosion problems
  - Larger thickness for the beampipe wall since bake out was required

- **Stainless steel**
  - Was more difficult and costly to get machined and shaped
  - Has poor heat conductivity

☞ **But has higher resistance to corrosion and more reliable vacuum connections**

Vacuum engineering considerations
Pumping Scheme

- **Pumping scheme based on:**
  - Mobile turbomolecular pumping stations for roughing
  - UHV was ensured by NEG strips heated by current circulations (40 A)
    - ☞ Activation of the strips only possible during long technical stops

  …combined with ion pumps
    - ☞ Pumping of noble gasses and methane

  - Use of superconducting RF structures and magnets implied Cold/Warm transitions
    - Needed special attention in particular for NEG strips

What was learnt?
Injection areas & Arc to LSS transitions

- **Higher SR power resulted in local pressure and temperature rise**
  - Local pressure bumps
  - Local lead melting ☞ not enough power evacuation capacity
  - Heating of the vacuum flanges to very high temperature (400-700°C) and transition pieces (aperture change) which resulted in failures on:
    - Transitions pieces by fatigue of the material
    - Flanges, each time beam was lost or dumped ☞ too fast cool down!
      - Problem enhanced in presence of steel material (vacuum components and flanges)

☞ **Localised in the double bending dipoles at the injection in LEP ring**

☞ **AT the transition from the arc vacuum beampipes in dipole magnets and the long straight sections**

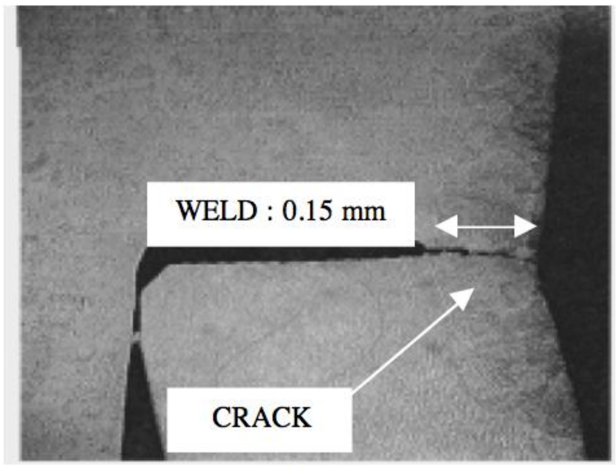
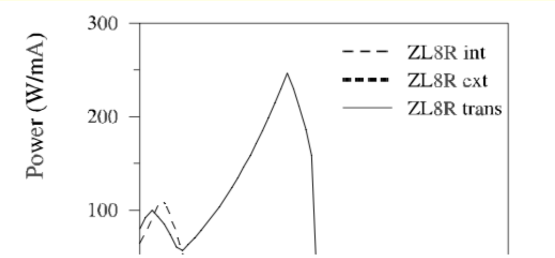


Figure 1
Leak at a stainless steel transition in HC 632

- **Other observations**
  - ☞ HOM escaping from the 2 GHz cavities were burning the RF fingers upstream/downstream the cavity
    ☞ cycle heating up to 750 °C!

What was learnt?
Long straight sections

- **Any unexpected SR heat power deposited in the LSS was creating a vacuum issue since most of the LSS vacuum system was made out of stainless steel**
  - Higher power deposition in components and flanges
- **Problems were observed:**
  - Downstream the wigglers of IR7, in particular when they were used during the ramp in energy with the collimation settings changed during the ramp (more opened)
    - Several leaks despite the consolidation of the cooldown
- **SR generated by the Q0 of the Detectors**
  - Tiny high power irradiation creating a temperature transient of up to 350°C for few seconds!
- **RF fingers heated and melted when they were in direct view of the SR generated by the quadrupoles of the LSS or of the Experimental areas**
  - Several consolidation required



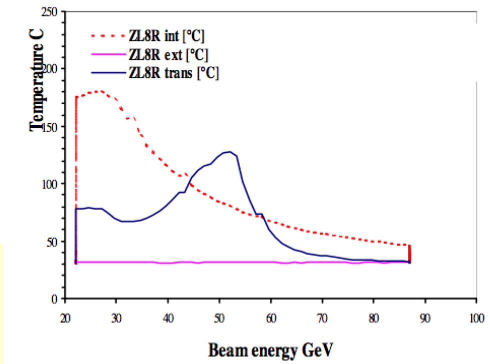


Figure 1:Temperatures measured on the interior and

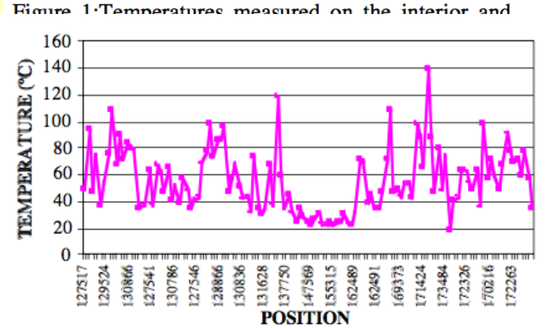


Figure 3
Temperature distribution around IP1

Closing Remarks
Aspects to be addressed in details

- **Vacuum engineering issues**
  - HOM and Impedance implications
    - Use the engineering design of the SR facilities instead of simple LEP design!
      - Cost increase!
  - Bake-out of vacuum system ☞ use NEG coatings instead of strips
    - Activation of NEG coatings and compatibility with Al chambers approach…
  - Heat loads induced by synchrotron radiation
    - More shielding issues due to existing infrastructures ☞ more lead thickness (weight / cost)
      - Heat load evacuation to avoid lead melting
      - Water cooling and compatibility with NEG coating activations
    - Bellows and flanges shall be optimised: HOM and transparency to SR
    - Unexpected SR heat loads generated by orbit displacements resulting from:
      - Adjustments of quadrupoles and wiggler magnets
      - Collimator settings during the ramp in energy

    ☞ Were degrading LEP performances by inducing leaks
  - Corrosion issues

Closing Remarks
Aspects to be addressed in details [cont.]

- **Experimental areas**
  - – SR induced pressure rise
  - ☞ Heat load evacuation if using photon absorbers

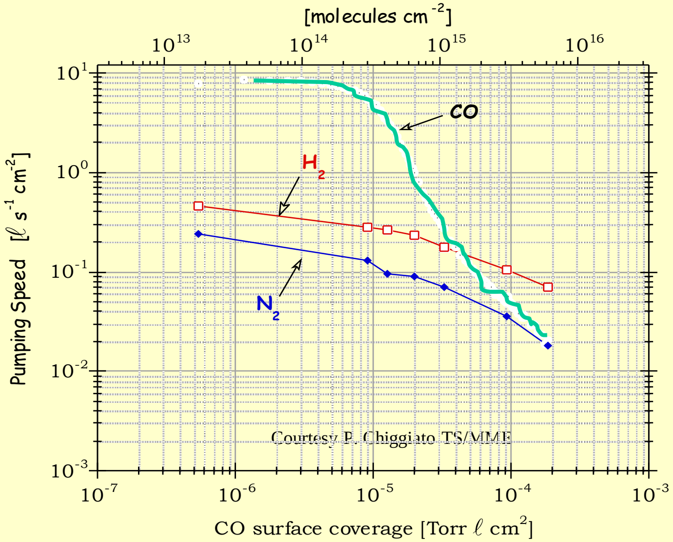
- **LEP required long maintenance and consolidations periods**
  - – Impact on the LHC siting below shall not be neglected

  - ☞ Safety aspects for Helium release

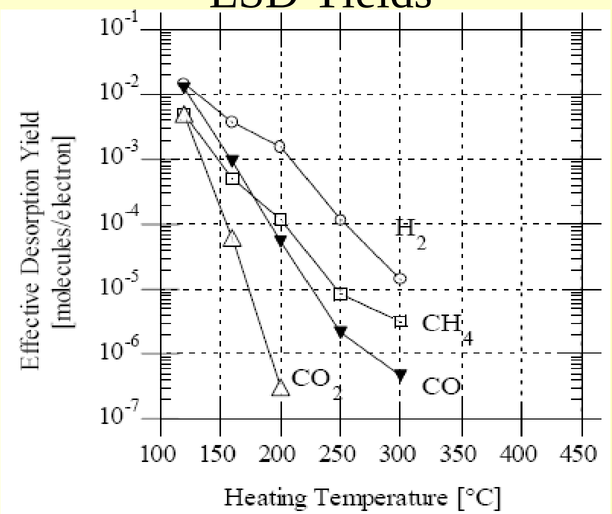
Closing Remarks

NEG coatings: THE baseline…

Pumping Speed



ESD Yields



•C. Benvenuti *et al.* J.Vac.Sci.Technol A 16(1) 1998

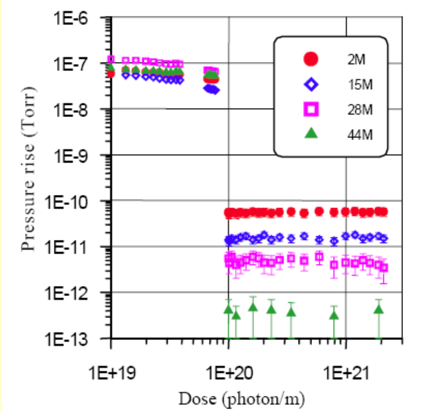


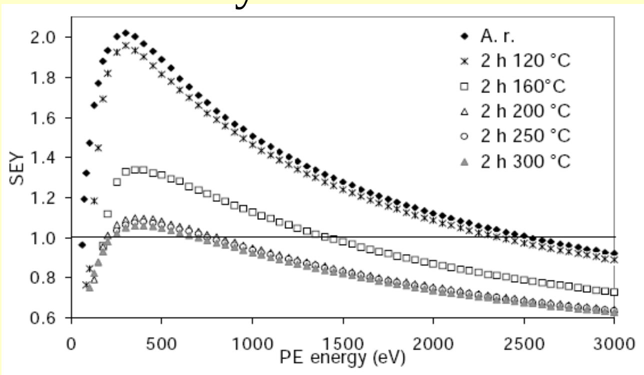
Figure 2: Pressure rise measured in the centre of the TiZrV coated test chamber before activation ($<1\cdot10^{20}$ photons/m) and after activation ($>1\cdot10^{20}$ photons/m).

PSD Yields

Table 2: Summary of results from the activated test chamber

Gas	Sticking probability	Photodesorption yield (molecules/photon)
H_2	~0.007	$\sim1.5\cdot10^{-5}$
CH_4	0	$2\cdot10^{-7}$
CO (28)	0.5	$<1\cdot10^{-5}$
C_xH_y(28)	0	$<3\cdot10^{-8}$
CO_2	0.5	$<2\cdot10^{-6}$

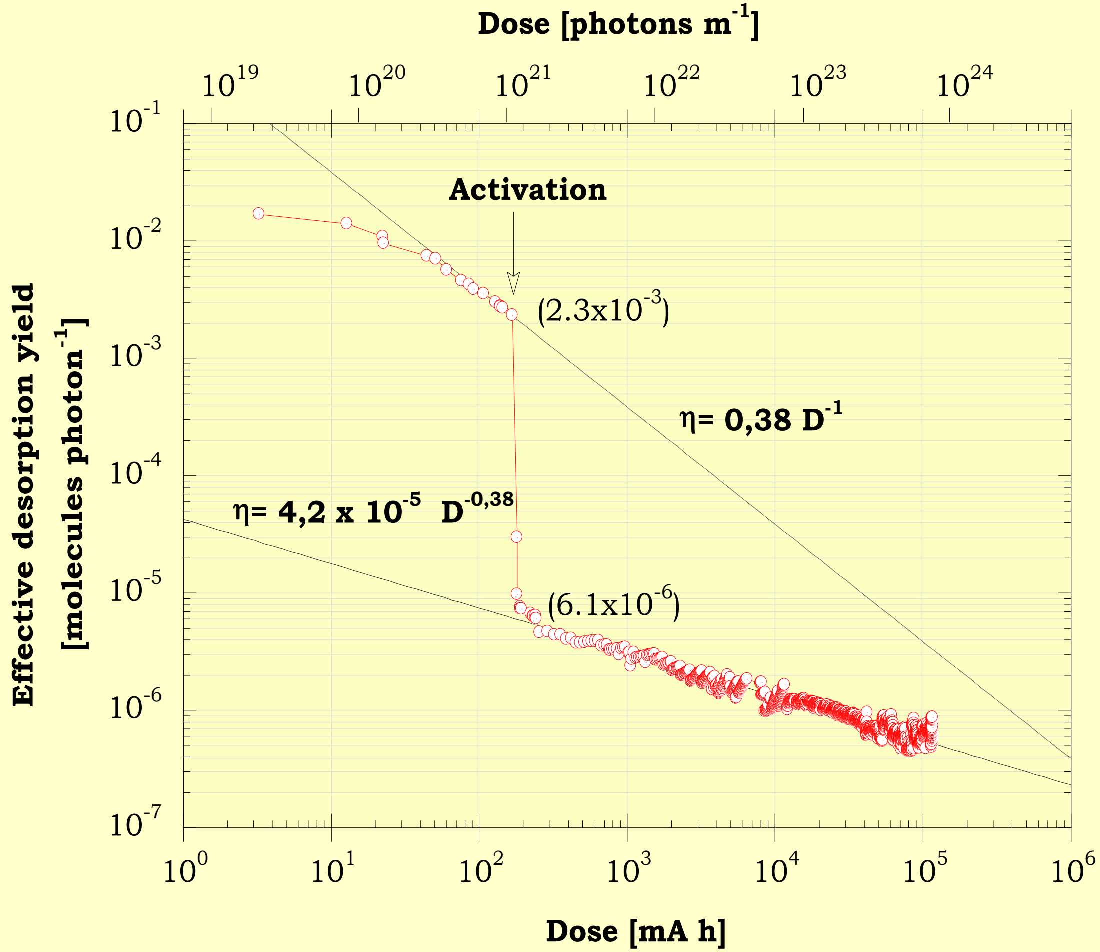
Secondary Electron Yield



C. Scheuerlein *et al.* Appl.Surf.Sci 172(2001)

…being successfully used in SR facilities

Closing Remarks
NEG coatings: THE baseline… [cont.]



CH_4 desorption yield reduced by a factor of at least 200 after activation, no Kr degassing detected

PSD at ESRF

Some evidences exist that a large part of the remaining desorption after activation could be due to a small fraction of the photons flux striking outside the chamber

Courtesy of P. Chiggiato

References

- *The pressure and gas composition evolution during the operation of the LEP accelerator at 100 GeV* **by Billy, J C ; Bojon, J P ; Henrist, Bernard ; Hilleret, N. (CERN) ; Jiménez, J M ; Laugier, I ; Strubin, Pierre M ; Vacuum 60 (2001) 183-9**
- *Operation of the LEP vacuum system above 100 GeV : observations and expectations* **by Billy, J C ; Bojon, J P ; Hilleret, Noël (CERN) ; Jiménez, M ; Laugier, I ; Strubin, P.; 10th Workshop on LEP-SPS Performance, Chamonix, France, 17 - 21 Jan 2000, pp.222-225**
- *The LEP Vacuum System : A Summary of 10 Years of Successful Operation* **by Billy, J C ; Bojon, J P ; Gröbner, Oswald ; Hilleret, Noël (CERN) ; Jiménez, M ; Laugier, I ; Strubin, P ; 7th European Particle Accelerator Conference, Vienna, Austria, 26 - 30 Jun 2000, pp.e-proc. 2286**
- *Synchrotron Radiation Power from Insertion Quadrupoles onto LEP Equipment* **by Butterworth, A ; Cavallari, Giorgio ; Jiménez, M ; Von Holtey, G ; CERN-SL-98-058-EA. - 1998. - 9 p.**
- *Experience with the LEP vacuum system at energies above 90 GeV and future expectations* **by Billy, J C ; Bojon, J P ; Hilleret, Noël (CERN) ; Jiménez, M ; Laugier, I ; CERN-LHC-98-004-VAC.- Geneva : CERN, 1998 - 4 p. 6th European Particle Accelerator Conference, Stockholm, Sweden, 22 - 26 Jun 1998, pp.314-316.**
- *Synchrotron Radiation Effects at LEP* **by Bailey, R ; Balhan, B ; Bovet, Claude ; Goddard, B ; Hilleret, Noël (CERN) ; Jiménez, J M ; Jung, R ; Placidi, Massimo ; Tavlet, Marc (CERN) ; Von Holtey, G ; CERN-SL-98-046-OP.- Geneva : CERN, 1998 - 3 p. 6th European Particle Accelerator Conference, Stockholm, Sweden, 22 - 26 Jun 1998, pp.385-387**