The use of NEG pumps and coatings in large vacuum systems: experience and limitations

F. Mazzolini
Elettra - Sincrotrone Trieste S.C.p.A., Trieste, Italy

Abstract
Today Non Evaporable Getter (NEG) materials are commonly used for vacuum production in large vacuum systems, in particular in particle accelerators. Recently, a new technology based on NEG sputtering techniques was successfully developed by CERN and utilized at various synchrotron light sources and ion collider facilities. The aim was to improve the vacuum performance in some conductance limited vacuum systems in order to minimize the gas bremsstrahlung emission and to reduce the impact of the electron-cloud instability discovered in some machines. The most recent results obtained are presented.

1 Introduction

In the last thirty years Non Evaporable Getters (NEGs) have been successfully used for Ultra High Vacuum (UHV) applications. However, the adoption of NEGs in a vacuum system requires an *in situ* bake-out. Moreover, NEGs are not suitable for pumping every gas (e.g. noble gases, methane) and for vacuum systems routinely open to air.

The need for a distributed pumping system in large particle accelerators and storage rings has been met by the adoption of linear Sputter-Ion Pumps (SIPs) or long NEG strips integrated in the vacuum vessels. But the presence of SIP magnetic fields close to the particle orbit may not be acceptable. In addition, the design of the chambers has to be modified with the integration of the longitudinal antechamber for these pumps. A new solution involves the use of traditional 'localized' pumps and a thin film coating of NEG material directly on the vacuum chamber walls [1], [2].

By doing this, three aims are achieved: a distributed pumping system, the reduction of the coated chamber degassing [3], and the simplification of the vacuum vessel design. The NEG coating proves to be very suitable in reducing both the static and dynamic pressure inside the narrow and long vacuum chambers of the insertion devices of a synchrotron radiation storage ring, where the photon-induced degassing is strong [4], [5]. NEGs activated at a lower temperature (180–200ºC for Ti-Zr-V getters) can be used on materials like aluminium and copper [6]. Therefore the conditioning time of extruded aluminium chambers, and the bremsstrahlung radiation caused by outgassing, can be significantly reduced by means of NEG coating [4].

2 NEG pumps

NEG pumps were originally developed and industrialized by CERN and SAES Getters Company. Originally they were produced in strip form, in order to be installed in some of the LEP accelerator vacuum chambers at CERN. In this case, the NEG powder is 'pressed' and stuck on a thin metallic strip. A good choice is Constantan that can act both as support and heater. It should be electrically insulated from the vacuum chamber and it should conduct an adequate current, so electrical feedthroughs are required. Its typical installation is in a longitudinal antechamber connected to a straight, narrow and long vacuum chamber.

The metallic strip can be folded many times in order to obtain a more compact pumping unit, having the same active surface. They are commonly referred to as wafer modules. Both types are illustrated in Fig. 1.

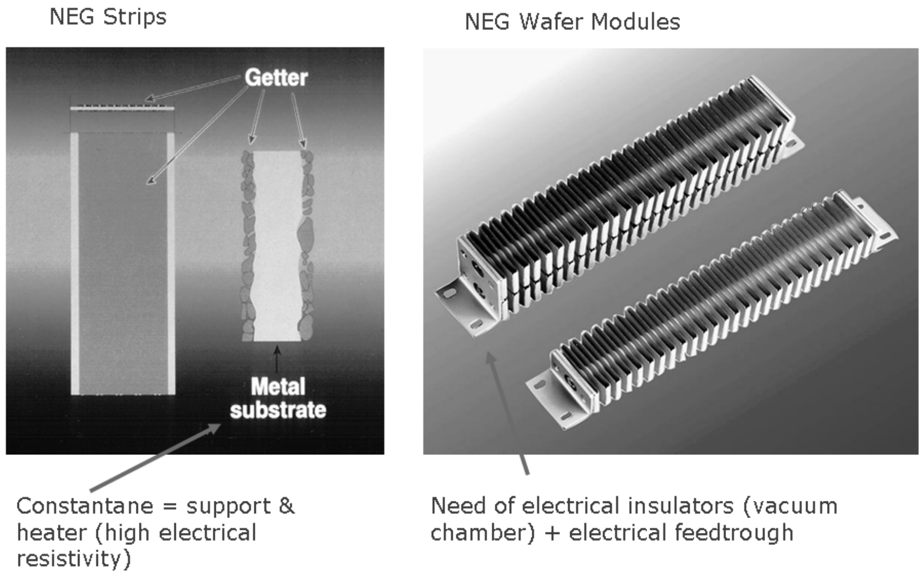

Fig. 1: NEG strip and wafer module

A third type of NEG pump is the NEG cartridge pump. It is based on a wafer module, bent in a cylindrical shape and installed on a Conflat flange. Heaters and a temperature gauge, together with their feedthroughs, are also installed on the same flange, as shown in Fig. 2.

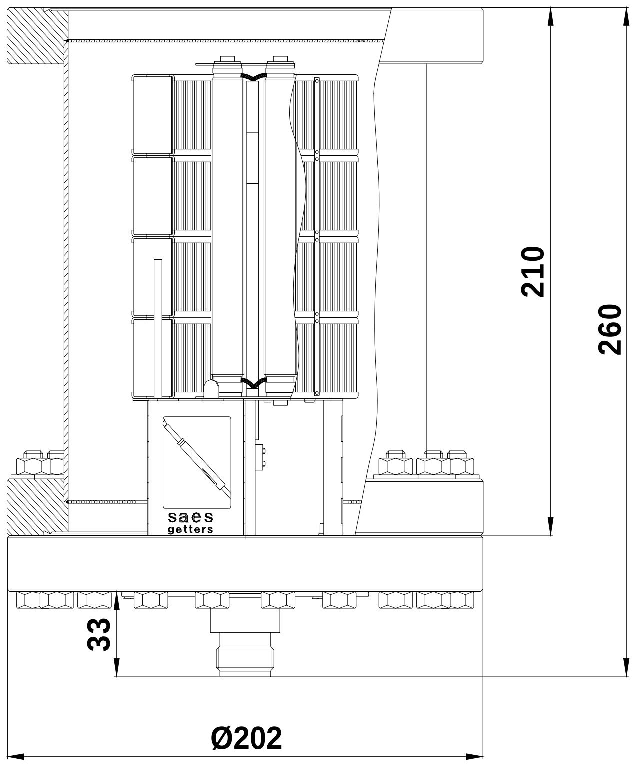

Fig. 2: NEG cartridge pump (SAES GP500)

Usually NEG pumps can be easily integrated in a vacuum system. In particular the cartridge version can be simply added to an already existing vacuum system, because of its quite compact size and light weight. Their main limitation is the activation procedure that implies a heating process up to 350–400°C (in the case of SAES St 707 alloy) and the relatively high initial cost.

Their use offers many advantages:

– a high pumping speed for all active gases (especially for hydrogen);

– a high capacity, that means a very long life. As an example, NEG cartridges installed in the front-ends at Elettra have never been changed after their initial installation more than 12 years ago;

– a very clean vacuum can be obtained, because of the virtual lack of oil, grease and similar contaminants. Theoretically, NEG powder detachment from the cartridge is always possible, but it is not evident in common use;

– their operation is totally vibration-free;

– after the initial activation, their operation does not require any cabling, controller and power consumption;

– the possibility to be operated in the presence of a high magnetic field;

– a reversible behaviour with respect to hydrogen pumping, if required;

– their inability to pump noble gases is essential during a leak test procedure: it can also be conveniently utilized for noble gas purification.

The activation procedure of a NEG pump installed in a vacuum system hosting other vacuum equipment implies many different steps. An example concerning a typical vacuum system of a particle accelerator (that includes ion pumps, NEG pumps, vacuum gauges, residual gas analyser, vacuum valves, etc.) is provided:

– pump the vacuum system down (e.g. by means of a turbomolecular pump connected to the vacuum chamber through a vacuum valve)

– bake the vacuum system; for example at 150°C for 24 hours

– cool the system down to 100°C and hold this temperature

– ‘degas’ all the ion pumps (switch them on–off 3–4 times, until the pressure decreases)

– switch all the pressure gauges off

– activate all the installed NEG pumps at 430°C for 1 hour, as shown in Fig. 3.

– ‘degas’ all the filaments (RGAs, etc.)

– switch all the ion pumps and all the pressure gauges on

– cool the vacuum system down to room temperature

– close the valves connecting the turbomolecular pumps and switch the turbomolecular pump off.

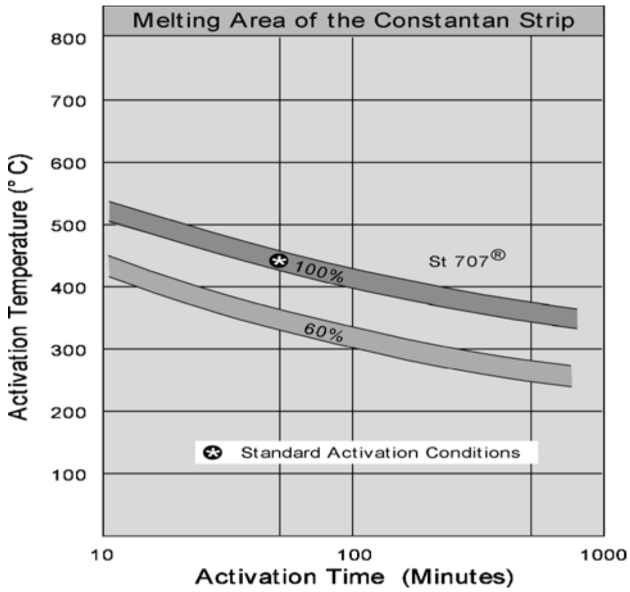

Fig. 3: NEG activation: time vs. temperature for SAES GP series (St707 alloy)

The previous example should be modified according to the complexity of a specific vacuum system, but in principle is always applicable [7].

The two main limitations of the NEG activation procedure for a given vacuum system are the large amount of gas initially released, which must be evacuated by means of appropriate auxiliary pumping units, and the high temperature required for the activation.

3 Towards the NEG coating

Owing to their specific geometry, the vacuum systems of particle accelerators typically require a distributed vacuum pumping. Actually, the vacuum chambers are usually very long, with a reduced cross-section. This is due to the fact that, for technical and economic reasons, the poles of magnets steering the particle beam should be as close as possible to the beam itself, limiting the transverse dimensions of the pipe. In this case, vacuum performance is significantly limited by the poor vacuum conductance of the chamber. Therefore, a practical way to optimize the pressure profile is to distribute the pumping. This can be obtained by replacing big pumps with more, smaller pumps, and reducing the relative distance between them (Fig. 4, distance *L*).

In some specific cases this is not possible because of the lack of space needed to add additional flanges for the added pumps and because of the already existing components (magnets, diagnostic, ancillary subsystems, etc.) that greatly reduce the available space around the vacuum vessel for subsequent new installations.

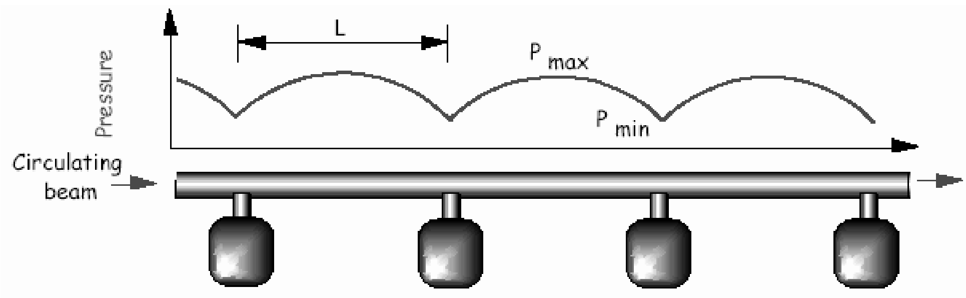

Fig. 4: Pressure profile (discrete pumping)

Another common way to obtain a distributed pumping requires the use of a so-called antechamber, parallel to the main one and connected to it by means of a longitudinal slot. A typical cross-section is represented in Fig. 5. This is a compromise that allows the magnetic pole to stay close to the beam while increasing the cross-section and, consequently, the vacuum conductance of the pipe. But the ‘chamber plus antechamber’ design, besides the increase of the vacuum conductance, offers the further advantage of facilitating the installation of additional pumps inside the antechamber: linear sputter ion pumps or NEG strips. The first solution is more complex to realize, expensive, and not optimized like a commercially available sputter ion pump. The second offers the advantage of merging the benefits of NEGs with properties of other vacuum pumps. For example, in particle accelerators ultra high vacuum is typically maintained by means of sputter ion pumps because they guarantee an air-tight, closed system even in the case of electrical power failure, they are clean, vibration-free, UHV compatible.

Drawbacks of these solutions are the increase in the dimensions of vacuum vessels; the increase in their complexity; their production cost; the increase in the inner surface and in the consequent thermal outgassing; the difficulty of maintenance in a working particle accelerator.

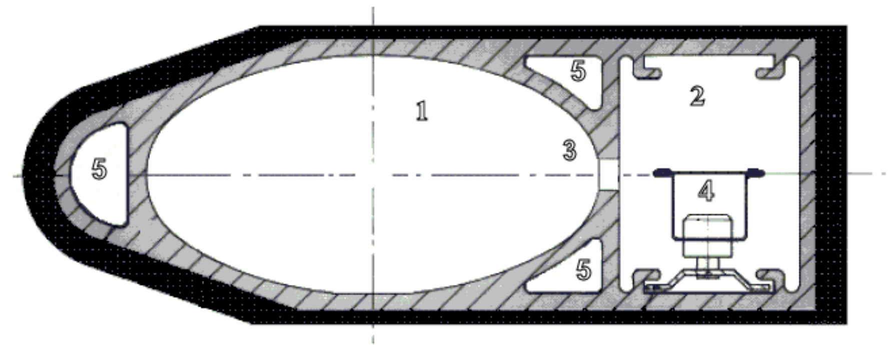

Fig. 5: Cross-section of the LEP dipole vacuum chamber: 1) chamber, 2) antechamber, 3) slot, 4) NEG strip and its support, 5) cooling channels

Almost fifteen years ago, a new NEG technology was developed at CERN. It was based on the deposition of a thin film of NEG material directly on the inner surface of the vacuum vessel by means of sputtering techniques and on the discovery of the new NEG alloy (TiZrV), with a remarkably low activation temperature: 180–200°C instead of 400–450°C of the previous generation of NEG (SAES St707).

The TiZrV coating has the same properties in pumping gases as a traditional NEG material, but it does not require an additional space to be installed. It is also characterized by a very low desorption, both thermal and photon-induced [3]. Moreover it does not require a dedicated heating system, but it can be ‘passively’ activated during the normal UHV bake-out procedure, owing to its relatively low activation temperature.

This gave the opportunity to develop new types of vacuum chambers, especially suitable for particle accelerators: it was possible to obtain a narrow pipe with a very low, flat pressure profile. Figure 6 shows a qualitative comparison between a pipe pumped by means of two pumps placed at both ends (top curve), the same pipe with two additional pumps in between (middle curve) and by two pumps at both ends and a NEG coating (bottom curve).

The first application of the NEG coating technology to a vacuum vessel installed in a working particle accelerator as a permanent component was the realization of an insertion device vacuum chamber for the European Synchrotron Radiation Facility (ESRF) in 2000 [8], followed by a similar chamber installed at Elettra, the Italian Synchrotron Light Source, at the beginning of 2002 [9].

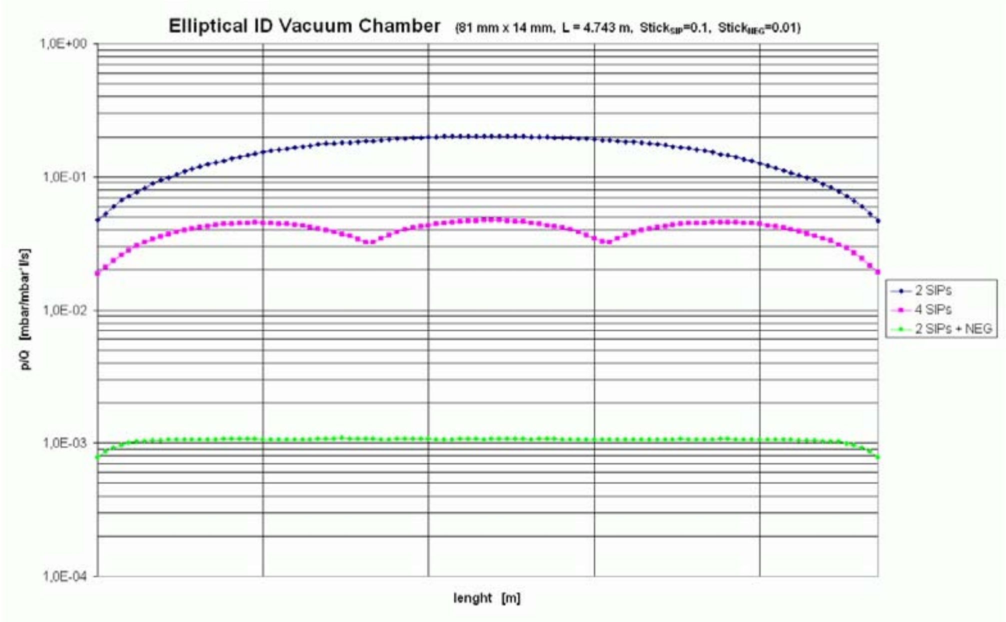

Fig. 6: Pressure profile comparison (see text)

4 Six years' experience in working particle accelerators

It was immediately possible to observe a reduction of the conditioning time of the new chamber and a decrease of the gas bremsstrahlung emission, a clear indication of a very good vacuum performance [10].

In a particle accelerator, the measurement of the gas bremsstrahlung provides indirect information about the total pressure inside the vacuum chamber. Figure 7 shows the fast bremsstrahlung reduction obtained after the installation of a new NEG-coated vacuum chamber at Elettra. It clearly shows the recovery of the original bremsstrahlung level after less then 10 Ah [11].

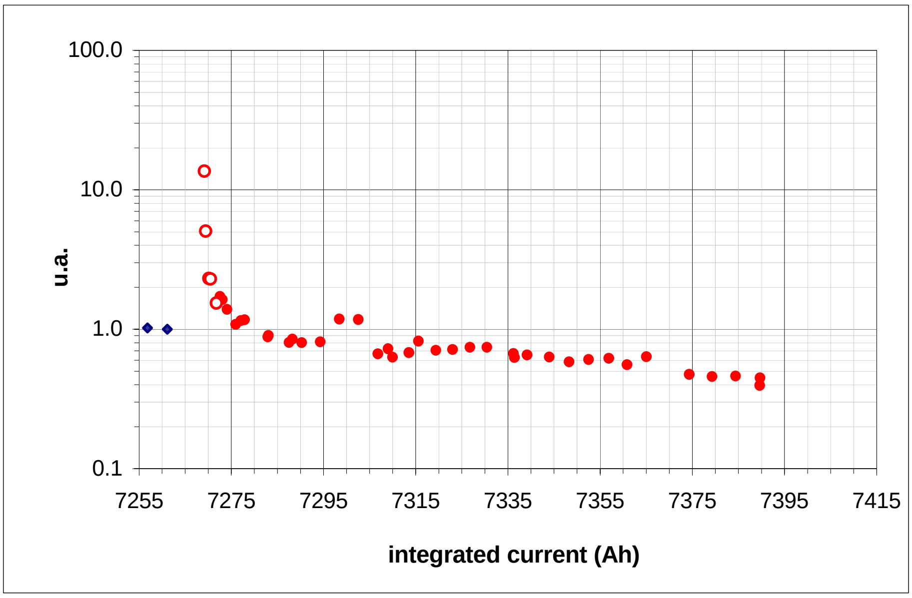

Fig. 7: Gas bremsstrahlung reduction during the commissioning of a NEG-coated vacuum chamber installed at Elettra (K. Casarin, Health Physics Group, Elettra)

"The machine division of the ESRF, in conjunction with Elettra and Soleil, has carried out throughout several years a rather detailed study of the effect of NEG-coated chambers, both made of SS and Al, as far as the resistive-wall impedance budget is concerned, especially on its effect on the single-bunch threshold. The rather poor resistivity of Ti, Zr and V should enhance the imaginary part of the resistive wall impedance, affecting the single-bunch threshold: coating thicknesses have been reduced, from 1μm to 0.5μm (nominal)." [12]. This decrease of thickness did not reduce the vacuum performance, as predicted by P. Chiggiato [13].

In these six years it has also been demonstrated that ageing (the maximum number of venting and reactivations that a NEG coating can safely withstand without noticeable reductions of this vacuum performance) is sufficiently high for normal operations: at least 30 times, but probably more.

In addition, in ion colliders "the most promising remedies to e-cloud seems to use thin film coatings: TiZrV NEG will also bring linear pumping upon activation" [14].

5 Conclusion

While NEG materials have been widely used in vacuum technology since their discovery thirty years ago and their properties have been thoroughly investigated, TiZrV NEG coating techniques and their applications are relatively new. However, there is a huge increase in the adoption of this technology, especially in particle accelerators. In synchrotron light sources an improved vacuum performance, a reduction of commissioning time, and a suitably long lifetime of coatings have been demonstrated over the last six years in different laboratories. Moreover the pressure rise due to the negative impact of electron-cloud instability in ion colliders has been reduced by means of NEG coatings.

Acknowledgements

I wish to thank all the colleagues who enthusiastically shared their experience gained from the use of NEG technology in their Laboratories. In particular I wish to express my gratitude to C. Benvenuti (CERN, Switzerland), who made the NEG coating technology possible, P. Chiggiato (CERN, Switzerland) and R. Kersevan (ESRF, France) who installed a NEG-coated chamber in a working machine for the first time, collecting and sharing the results of their pioneering measurements, J. Setina (IMT, Slovenia) who helped me in organizing the 41st IUVSTA Workshop partially dedicated to the use of NEG coating in particle accelerators, O. Malishev (Astec, UK) and P. Manini (SAES Getters, Italy), who organized the 45th IUVSTA Workshop specifically devoted to the use of NEGs in particle accelerators and vacuum systems.

References

[1] C. Benvenuti, Non-evaporable getters: from pumping strips to thin film coatings, Proceedings of EPAC 1998, Stockholm, June 1998.

[2] C. Benvenuti *et al.*, A novel route to extreme vacua: the non-evaporable getters thin film coatings, Vacuum **53** (1999) 219–225.

[3] C. Benvenuti, P. Chiggiato, F. Cicoria and V. Ruzinov, Decreasing surface outgassing by thin film getter coatings, Vacuum **50** (1998) 57–65.

[4] R. Kersevan, Vacuum system of the ESRF: operational experience and status report, Vacuum **60** (2001) 95–99.

[5] P. Chiggiato and R. Kersevan, Synchrotron radiation-induced desorption from NEG-coated vacuum chambers, Vacuum **60** (2001) 67–72.

[6] C. Benvenuti *et al.*, Vacuum properties of TiZrV non-evaporable getter films, Vacuum **60** (2001) 57–65.

[7] A. Rossi, 45th IUVSTA Workshop on NEG coatings for Particle Accelerators and Vacuum Systems, http://www.aiv.it/neg_documenti/session_7/Adriana_Rossi.pdf .

[8] R. Kersevan, Performance of a narrow-gap, NEG-coated, extruded aluminium vacuum chamber at ESRF, http://accelconf.web.cern.ch/accelconf/e00/PAPERS/THP5B11.pdf .

[9] F. Mazzolini *et al.*, Performance of the insertion device NEG-coated aluminium vacuum chamber at Elettra, Synchrotron Radiation News, Vol. 15, No. 3, May/June 2002.

[10] F. Mazzolini *et al.*, Performance of insertion device vacuum chambers at Elettra, http://accelconf.web.cern.ch/AccelConf/e02/PAPERS/WEPDO026.pdf .

[11] F. Mazzolini, 45th IUVSTA Workshop on NEG Coatings for Particle Accelerators and Vacuum Systems, http://www.aiv.it/neg_documenti/session_5/Fabio_Mazzolini.pdf .

[12] R. Kersevan, 45th IUVSTA Workshop on NEG Coatings for Particle Accelerators and Vacuum Systems, http://www.aiv.it/neg_documenti/session_1/Roberto_kersevan.ppt .

[13] P. Chiggiato, 41st IUVSTA Workshop on Vacuum System Design for Particle Accelerators: A Multidisciplinary Approach, http://www.imt.si/iuvsta/index.html .

[14] F. Le Pimpec, 45th IUVSTA Workshop on NEG Coatings for Particle Accelerators and Vacuum Systems, http://www.aiv.it/neg_documenti/session_4/Frederic_Le_Pimpec.pdf .

Bibliography

For theory, principles and history behind NEGs and NEG coatings see C.Benvenuti's lecture (these proceedings).

For applications of NEGs and NEG coatings to particle accelerators and large vacuum systems, see the: *45th IUVSTA Workshop on NEG Coatings for Particle Accelerators and Vacuum Systems* documents.

In April 2006 the Accelerator Science and Technology Centre (CCLRC Daresbury Laboratory, UK) and the Italian Vacuum Association (AIV), under the sponsorship of the International Union for Vacuum Science Technique and Applications (IUVSTA), organized the 45th IUVSTA Workshop on NEG Coatings for Particle Accelerators and Vacuum Systems. The aim of this workshop was to promote an exchange of information among researchers investigating NEG properties, people involved in the design of vacuum chambers and components, as well as UHV pump manufacturers.

The workshop was organized in seven sessions:

Session 1. NEG coating technology

Session 2. Underlying physics, properties, preparation technology, and future directions.

Session 3. Laboratory measurements: methodologies and experimental results.

Session 4. Electronic properties, surface chemistry, film morphology, film mechanical properties.

Session 5. Experience of NEG-coated vessels installed in working machines.

Session 6. Electron, photon and ion stimulated desorption from NEG films.

Session 7. Use of NEG coating in future projects and further areas of research.

Contributions presented at this workshop, summary, and final report can be found at the following link:
http://www.aiv.it/ita/scuole/neg_aiv.asp

Additional contributions on the use of NEG coatings from the *41st IUVSTA Workshop on Vacuum System Design for Particle Accelerators: A Multidisciplinary Approach* can be found at the following link:
http://www.imt.si/iuvsta/index.html