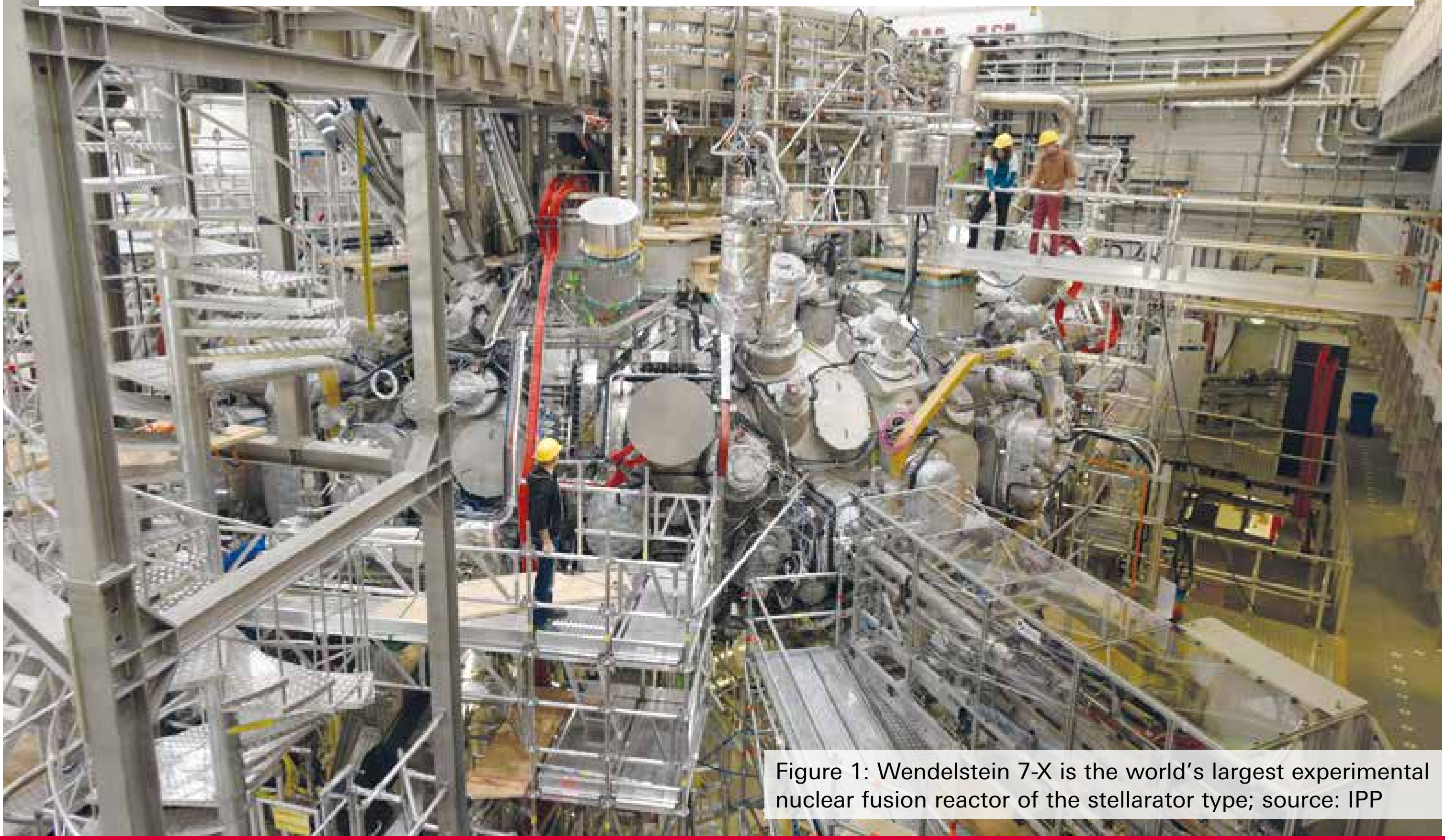


Figure 1: Wendelstein 7-X is the world's largest experimental nuclear fusion reactor of the stellarator type; source: IPP

VACUUM SOLUTIONS FOR WENDELSTEIN 7-X

Pfeiffer Vacuum interviews Dr. Heinz Grote, Head of the Vacuum Group at the Max Planck Institute for Plasma Physics (IPP)

The world´s largest experimental fusion reactor of the stellarator type, "Wendelstein 7-X", has been in operation at the Max Planck Institute for Plasma Physics (IPP) in Greifswald, Germany, since December 2015. This reactor is used to carry out experiments in which a hydrogen plasma is created that is suitable for the continuous operation of a nuclear fusion power station. In the long-term, the energy generated by nuclear fusion is supposed to be used as an alternative, clean way of producing electricity. Wendelstein 7-X helps to investigate the extent to which the stellarator principle can be used as a power plant. After completion of the first operating phase at the end of March 2016, the reactor is now being upgraded and prepared for the second series of experiments. Vacuum technology is a fundamental component of the reactor: the experiments can only be carried out under ultra-high vacuum conditions. Pfeiffer Vacuum has been working with the IPP's scientists in Greifswald for many years in close cooperation on the design, implementation and operation of the reactor´s vacuum system.

In August 2016, the Pfeiffer Vacuum project team and Dr. Ulrich von Hülsen, member of the Pfeiffer Vacuum GmbH management, paid a visit to the experimental fusion reactor in Greifswald. During this visit, the team inquired about the progress of the first operating phase, the use of Pfeiffer Vacuum products and the demands of the second phase.

An interview with Dr. Heinz Grote

Dr. Grote, Wendelstein 7-X has been in operation since December 2015. The first phase of the experiment was very successful. Could you please tell us what has been achieved since the experimental fusion reactor was commissioned?

In the first operating phase, which ended on March 10, 2016, we generated around 2,200 plasma discharges – from helium gas at first, and then, starting in February 2016, from hydrogen. Initially, the focus was on technical discharges to clean the plasma vessel or to check the interactions of all the machine systems – superconducting magnets, cooling system, microwave heating, diagnostic systems, vacuum systems and machine controls. Even at this early stage, however, a large proportion of the plasma discharges were used for physical investigations, such as estimating the confinement properties of the magnetic field that has been specially optimized for Wendelstein 7-X, the thermal load distribution at so-called limiters and the influence of external shim coils.

At the outset, the discharge times achieved for the hydrogen plasmas were a half second, but at the end we were already achieving times of six seconds. The plasmas with the highest temperatures were achieved with 4 MW microwave heating power for the duration of one second. With medium-range plasma densities, we were able to measure temperatures of 100 million degrees Celsius for the plasma electrons and 10 million degrees for the ions.

Figure 2: Dr. Heinz Grote explains the Wendelstein 7-X experimental nuclear fusion reactor to Dr. Ulrich von Hülsen, a member of Pfeiffer Vacuum GmbH management, and the Pfeiffer Vacuum project team.

What significance do the results of this first experimental phase have for the Wendelstein project and for the planned use of the energy to be generated by nuclear fusion for electricity production?

The experiments concerning magnetic field configuration were important for the modifications currently made to the Wendelstein 7-X plasma vessel. By the summer of 2017, around 6,000 differently shaped carbon tiles, for the protection of the vessel walls, and the so-called divertor are to be installed, with an accuracy of less than a millimeter, so that longer plasma discharges at higher capacities can be investigated in the next operating phase. There are two concepts for the confinement of plasma using magnetic fields: the tokamak and the stellarator. The Wendelstein 7-X is a stellarator and supposed to demonstrate the key advantage of stellarators – continuous operation under the kind of plasma conditions required in power stations. It should also demonstrate that its plasma confinement is now on a par with that of a tokamak. The knowledge gained from the Wendelstein 7-X will contribute to a better understanding of the physical basis of plasma for fusion power plants.

The Wendelstein 7-X, and therefore also the experiments, could not work without vacuum technology. Please explain to us why vacuum is necessary.

The core of the Wendelstein 7-X is a superconducting magnetic coil system that makes magnetic confinement of the high-temperature plasma – the actual subject of the experiment – possible. These magnetic coils are operated at temperatures close to absolute zero (around -269 °C) with liquid helium. The most important vacuum system, therefore, is responsible for maintaining the lowest possible level of thermal conduction in the cryostat. The pressure must be kept below $1 \cdot 10^{-5}$ mbar. The greatest challenge here is the size of

Figure 3: Dr. Ulrich von Hülsen with Dr. Heinz Grote, Head of the Vacuum Group at the IPP.

the degassing surface of 20 insulation layers – around 100,000 m^2. With five turbopumps and the corresponding backing pump systems, we achieve $1 \cdot 10^{-4}$ mbar at room temperature. After cooling, the cold surfaces then act as a large cryo pump and help to reduce the total pressure down to $3 \cdot 10^{-7}$ mbar.

The plasma is then generated in a UHV vessel within the cryostat with a base pressure of around $1 \cdot 10^{-8}$ mbar by introducing a small amount of hydrogen, deuterium or helium. The pressure increases at the same time in the area of several 10^{-5} mbar. The amount of gas produced is 50 – 100 mbar · l/s and this must be dealt with by a pump system specially designed for the purpose. This consists of 30 turbopumps and 10 adapted backing pump systems.

In addition to these two main vacuum systems, several vacuum generation systems are needed for the spaces inside double sealing systems, for the gas supply during the experiment, for the high-frequency heating systems, the neutral particle heating system, various plasma diagnostic processes and for the cooling system used for the generation and transport of liquid helium.

Which Pfeiffer Vacuum products do you use in your system? What made you choose the solutions offered by Pfeiffer Vacuum?

For the main vacuum systems, we decided on the HiPace 2300 C and UC turbopump from Pfeiffer Vacuum. In our system, the turbopumps work in close proximity to a strong, alternating magnetic field that changes within milliseconds. For this reason, solutions using actively magnetically levitated rotors were not an option. The disc rotor of the HiPace 2300, with its two widely spaced bearings, provides the most mechanically stable configuration when subjected to changing forces. With the permanent magnetic bearing on the high vacuum side it ensures lubricant-free operation at this location. The pumping speed values for light gases were also a deciding factor.

Five HiCube Eco pumping stations are used to generate the insulation vacuum at the power supply lines for the superconducting coils.

In some cases, pressure measurements also have to be taken in the vicinity of stray magnetic fields. This is why we use a combination of RPT 100/RPT 200 Piezo/Pirani vacuum gauges and IKR 070 Penning gauges with TPG 300 from Pfeiffer Vacuum at every measurement point – 65 in total – within the high vacuum, since these devices have been shown to offer the necessary resistance to these stray fields. They can also be easily integrated into our control concept.

For the residual gas analysis in the cryostat and the plasma vessel, we use Pfeiffer Vacuum SPM 220 sputter monitors, which can also operate at high pressure ranges.

Furthermore, Trinos Vakuum-Systeme was commissioned to manufacture most of the tailor-made pipework and connection components for the UHV, HV and fore-vacuum systems. Many of the diagnostic systems have special dip tubes for inserting their apparatus directly into the plasma vessel via sampling pipes, which are two meters long in some cases.

How would you assess your cooperation with Pfeiffer Vacuum?

Our cooperation with the field staff has always been very professional, from the very first inquiry through to bid preparation and project execution. Particularly in the case of the vacuum chambers, where we often had to make special requests or changes at a later date due to changes in the external constraints arising from our very limited installation space, we also had direct contact partners in Göttingen where the connection components were manufactured.

Unlike your other customers, perhaps, we consider the pumps and measurement systems currently in operation to be a part of our experiment. When specific questions arise, therefore, we are particularly pleased to be able to speak directly to staff in your development departments, who are always willing to listen.

Service work requested to address problems that arose during commissioning of the individual systems or during normal operation was always carried out quickly and our staff were often able to learn from it.

You are now preparing for the second experimental phase and equipping the Wendelstein 7-X accordingly. What adaptations are being made to the system?

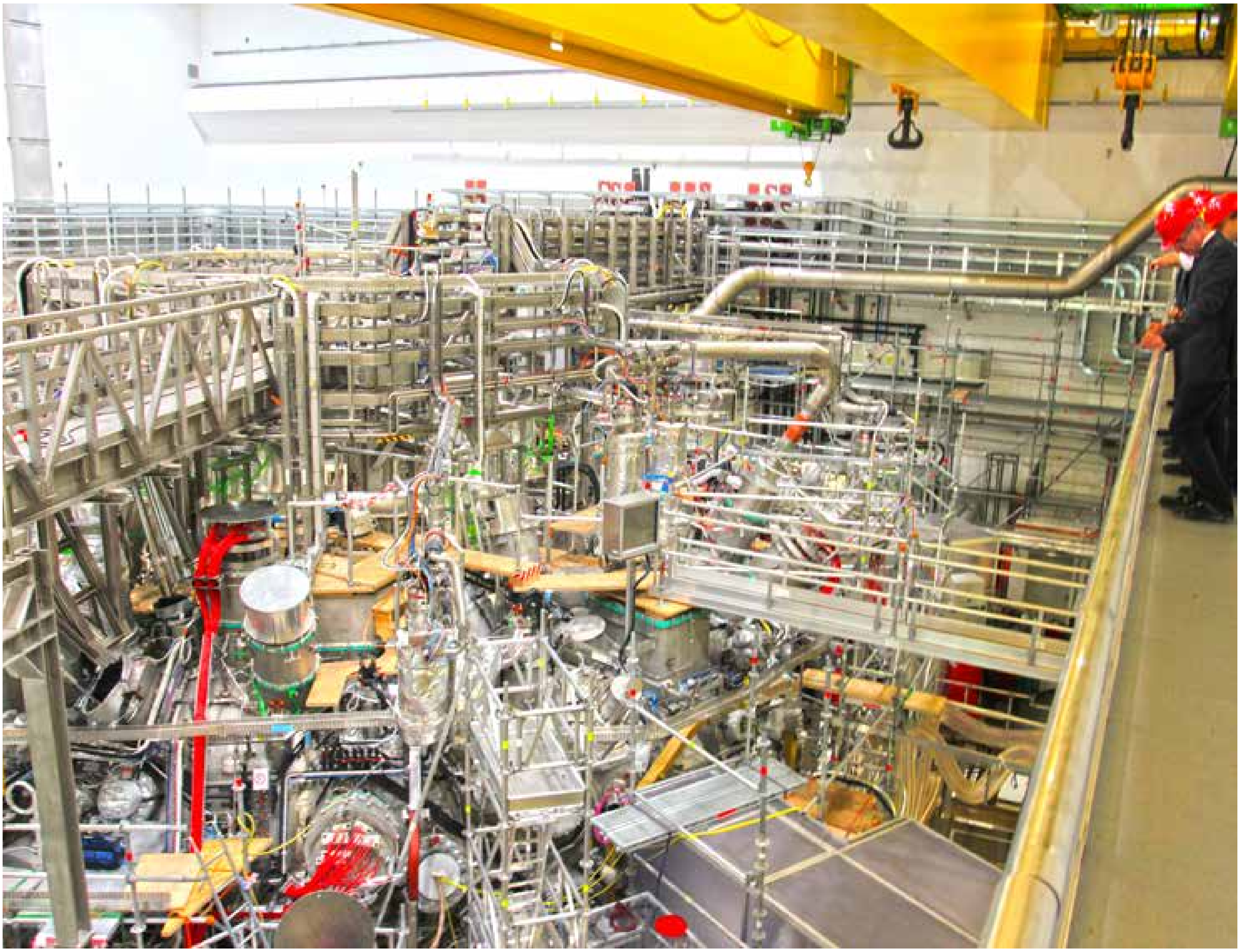
First of all, the cladding of the interior wall of the plasma vessel is completed and special components (divertors) installed so that higher power and particle fluxes can be taken up. This leads to an increase in the heat output of the plasma and in the discharge time. The gas supply and the vacuum system for the plasma vessel are also equipped for operation with diborane. This gas is needed for conditioning the interior wall of the plasma vessel, whereby boron is deposited on the wall in a glow discharge. This subsequently reduces the oxygen content in the experiment plasmas. Adjustments to the vacuum system controls, with particular emphasis on safety improvements, will be absolutely essential, since diborane is combustible and toxic and must therefore not be allowed to escape into the surrounding area. Also, some of the diagnostic systems already in operation are overhauled and others reinstalled.

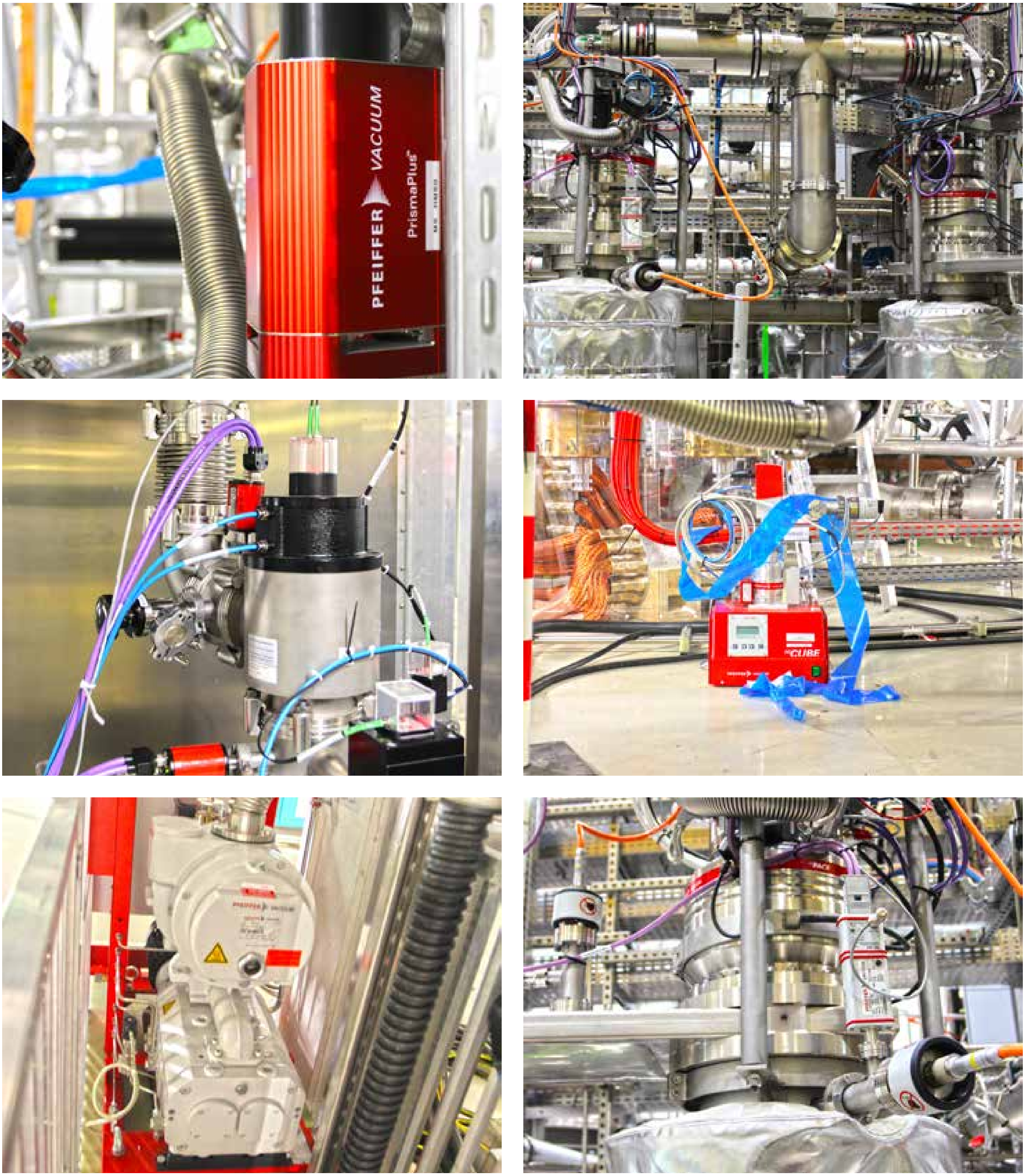
Which Pfeiffer Vacuum products are of interest for the second experimental phase of Wendelstein 7-X?

We are currently in the process of ordering a new HPA 200 mass spectrometer from Pfeiffer Vacuum, for the previously mentioned operation with diborane.

Thank you very much for the interview!
Further information on Wendelstein 7-X and the Pfeiffer Vacuum solutions used can be found on our website in our application report entitled "Producing energy the way the sun does".

https://www.pfeiffer-vacuum.com/application-reports/





Turbopumps, pumping stations, mass spectrometers and analyzers from Pfeiffer Vacuum used in Wendelstein 7-X

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