Perhapsatron with a Future

Nuclear fusion could safeguard the energy supply of the future. The shining example is our Sun, which obtains its energy from the fusion of light atomic nuclei. Fundamental findings for the development of this new energy source originate from the **Max Planck Institute for Plasma Physics (IPP)** in Garching, which celebrates its 50th anniversary this year.

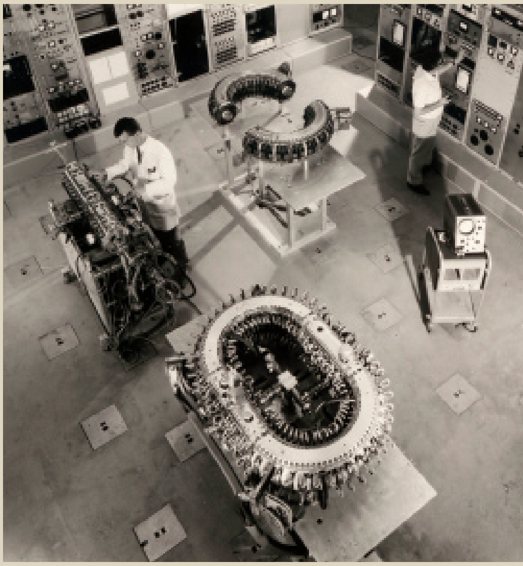
TEXT **ELKE MAIER**

Everything started with the mythical figure of Prometheus: Zeus, father of the gods, had taken fire away from mankind. In order to return it to them, Prometheus held the stalk of a plant into the sky and ignited it with the sparks flying off of the carriage of the sun god, Helios. The thought of capturing solar fire has fascinated mankind ever since. Researchers worldwide, including the staff of the Max Planck Institute for Plasma Physics (IPP) in Garching and Greifswald, are now working on igniting the solar fire on Earth itself, and making it available for energy generation. The challenges of this undertaking are much greater than the pioneers of fusion research anticipated a few decades ago.

In the late 1940s, scientists began investigating how energy could be obtained from nuclear fusion. Back in 1929, physicists Fritz G. Houtermans and Robert d' Escourt Atkinson suggested that solar fire originated from the fusion of light atomic nuclei. Ten years later, Hans Bethe and Carl Friedrich von Weizsäcker described the reaction cycle during which hydrogen nuclei fuse to helium at around 15 million degrees Celsius in the Sun's interior. This created the theoretical foundation for fusion research.

In order to initiate nuclear fusion under terrestrial conditions, the researchers would have to succeed in confining and thermally insulating an extremely thin, ionized gas – a plasma – comprising the hydrogen isotopes deuterium and tritium, and heating it to temperatures of more than 100 million degrees. Only at these temperatures is the speed of the particles so high that two positively charged atomic nuclei overcome their mutual repulsion and fuse with each other. If this succeeds, the energy yield is huge: 1 gram of fuel could provide the same amount of energy as the burning of 11 tons of coal.

But how can such hot plasma be kept under lock and key? In a container, the fuel would immediately cool when it comes into contact with the wall material, and the fusion would come to a standstill. American astronomer Lyman Spitzer from Princeton University came up with the key idea in 1951. He proposed capturing the plasma in a magnetic cage. The magnetic fields would keep the electrically charged particles floating without physical contact.

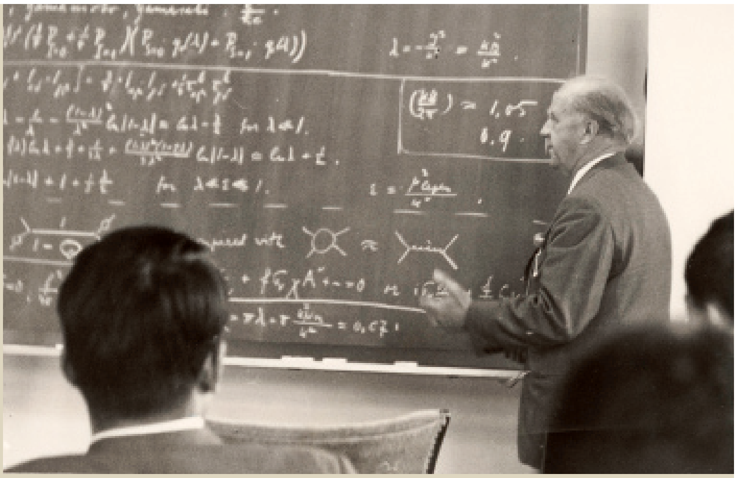


Wendelstein 1a, the IPP's first stellarator (front), went into operation in 1960, the year the institute was founded. In the background: the *Wendelstein 1b* (right) and *Wendelstein 4* (left) stellarators.

Photo: IPP

The enthusiasm was great at first – especially since the supply of the components for the fuel was almost limitless. Deuterium is present in the oceans, and tritium can be produced from lithium, which is found in rocks. In 1955, experts thought that mankind's energy problems would be solved once and for all in 20 years. In Los Alamos, where British scientist James Tuck called his planned experiment the *Perhapsatron*, the scientists' reaction was more subdued. Tuck wasn't completely on the wrong track with the name, as it soon emerged that the fleeting plasma was hard to harness. A large number of instabilities interfered with the magnetic confinement and caused the charged particles to escape. In the late 1950s, the scientists resigned themselves to the fact that the road to fusion would probably take longer than they hoped.

At that time, Germany also had plans to expand fusion research. At the Max Planck Institute for Physics in Göttingen, the key fields included general plasma physics and nuclear fusion. Werner Heisenberg, the then Director of the institute, championed the expansion of the "work in the field of thermonuclear



Visionary of fusion research: Werner Heisenberg at a symposium in Feldafing in July 1965.

reactions." His application for research funds, which he submitted to the German Federal Ministry for Nuclear Issues in 1956, was successful. This positive response was followed by the physical expansion of the institute in Göttingen. On June 28, 1960, the IPP was founded in Garching, on the outskirts of Munich, initially as the Institute for Plasma Physics GmbH, and was converted to the Max Planck Institute for Plasma Physics in 1971. The associates were Werner Heisenberg and the Max Planck Society. The IPP signed an Association Agreement with the European Atomic Energy Community (EURATOM) as early as 1961, and it has been part of the European fusion research program ever since. In the early years, researchers had no idea which approaches would lead them to their goal. The Garching-based scientists therefore conducted their research on a broad front to test various methods of confining the plasma. Plasma physicists all over the world also tried out many ideas for harnessing the fleeting mixture of particles – and rejected most of them.

Süddeutsche Zeitung from November 22, 1955

> »Ultimately, one will start to (...) utilize the greatest energy source that nature can provide, which can be found in the interior of the Sun and most stars, for the peaceful development of Earth (...) In terms of daring, this problem is set to surpass anything developed thus far.«

Two types of systems survived the selection process: the stellarator, whose principle harks back to the efforts of Lyman Spitzer, creates the magnetic field confinement solely by means of external coils; the tokamak, on the other hand, which was invented by Russian physicists Igor E. Tamm and Andrei D. Sakharov, also had a current flowing in the plasma that heated the fuel at the same time. Since this plasma current is generated in pulses by a transformer, tokamaks can operate only in pulsed mode, while stellarators are suitable for continuous operation.

However, the experimental progress achieved with both types of devices remained unsatisfactory in the 1960s. Above all, the physicists were concerned about the particle losses, which were far too high. Toward the end of the decade, the scientists seemed to have reached a dead end – until, in 1968, news arrived from Russia: researchers reported that, with their T3 tokamak, they had achieved values for the plasma temperature, density and confinement time that exceeded all results obtained thus far. Scientists in other countries were initially skeptical. Therefore, in early 1969, a British team traveled to Moscow for the sole purpose of checking the information provided by their Russian colleagues. They took along five tons of physics equipment for their new type of laser measurements. When the measurements not only confirmed the reports, but even bettered some of the reported findings, tokamak euphoria erupted in the scientific world.

Scientists in Germany couldn't ignore the new developments. In 1973, the first tokamak *Pulsator* went into operation at the IPP; at the same time, the scientists continued to experiment with their stellarators. And they were also working on another bold idea: they wanted to use the *Asterix* high-energy laser to bombard tiny, frozen deuterium-tritium pellets in free-fall with focused laser beams. The energetic light flashes would compress the pellets to an extreme degree within one billionth of a second and bring them to ignition temperature, detonating them as "mini-hydrogen bombs" and thus releasing energy.

In 1974, however, the decision was made to focus the work at the IPP exclusively on the magnetic confinement of plasmas, and to halt the research into laser fusion that had been started in 1967. On January 1, 1975, the laser fusion was spun off into a project group from which the new Max Planck Institute of Quantum Optics evolved in 1981.

In 1980, the IPP achieved a world premiere when it successfully used the *Wendelstein 7-A* stellarator to confine hot plasma without additional plasma current; up to that point, this had succeeded only with cold plasmas. "Garching shows stellarators may be good after all," was the headline that followed in the journal Physics Today. And this although the reaction vessel and the helical solonoids of *Wendelstein 7-A* had been manufactured in the institute's workshop as a short-term interim solution – which then remained for almost a decade, gaining no small degree of fame.

The researchers were able to score their next big success in 1982: the *ASDEX* tokamak provided the proof that the heat insulation could be doubled by using a special magnetic field arrangement (called a divertor). The physicists thus achieved a plasma state with particularly good heat insulation, the so-called H-mode. Fusion systems around the world have been working with a divertor ever since.

Today, the IPP is the only institute that investigates the tokamak and stellarator in comparison. The *Wendelstein 7-X* stellarator is currently being built at the Greifswald branch institute, which was established in 1993, while the researchers in Garching are experimenting with the *ASDEX Upgrade* tokamak. The results are incorporated into *JET*, the European joint venture in Culham, in the UK, and in the international test reactor *ITER*, which has been under construction in Cadarache/southern France since 2007. If everything goes according to plan, the first power plant could go online in the middle of this century – thus igniting the fire of Prometheus on Earth once again.

Photo: IPP