W7-AS has been successfully operated in the high-confinement mode (H-mode), a region of improved thermal insulation [Wagner F., *Europhys. News* **17** (1986) 48] which is the most relevant tokamak confinement regime. This is the first time that the H-mode has been achieved outside the tokamak family. The W7-AS device at Garching has also demonstrated ultra-high density operation and the possibility of utilizing the natural islands residing at the edge of the plasma to divert the fluxes crossing the last closed flux surface.

W7-X

The W7-X stellarator is an experimental device (Fig. 1). It will not only deliver many new results important to successful continuation of the stellarator line but has also to demonstrate that its optimization based on theoretical concepts is indeed feasible (optimization — see insert — became possible with the introduction of modern computers). Work carried out so far has demonstrated that the various goals of the optimization process, which occasionally conflict, can be met in a single device. Experimental flexibility is incorporated so that stability aspects of the optimized magnetic architecture such as shear (spatial variations of the field-line pitch) and magnetic well (the minimum of magnetic field at the plasma centre) can be changed. Exhausting of plasma impurities can be studied and modified by operating with a series of edge islands or with a more ergodic edge configuration for the so-called divertor used to define the structure of the magnetic field surfaces at the edge of the plasma. Moreover, resonating field lines can be placed in the core of the plasma to simulate, if necessary, the effect of sawteeth-like variations of the core parameters on impurities, or at its edge to simulate a divertor configuration comprising a single island.

It will also be interesting to explore the effect of optimized drift orbits on the mechanisms leading to turbulent transport. The characteristics of trapped particles in turbulent transport can be changed by operating at various ratios of the minimum to the maximum field strengths (mirror ratio). It is important to note that the resonance of trapped particles is avoided in W7-X because diamagnetic fluid flow and trapped particle poloidal precession are of opposite sign.

The availability of 10 MW of steady-state electron cyclotron resonance heating (ECRH) will allow the study of plasmas under reactor-relevant, long mean-free path conditions, and 20 MW pulsed neutral beam injection will permit a systematic investigation of MHD stability and the β-limit. The ECRH current drive can be used to provide a toroidal current of 50-100 kA, which will add further experimental flexibility for investigating MHD and confinement issues while allowing stellarator physics to be linked to the tokamak world.

Fig. 2 — Bird's eye view of the city of Greifswald on the Baltic Sea. Greifswald is a university town where plasma physics is well established in the physics faculty of Ernst Moritz Arndt University. The Institute of Low-Temperature Plasma Physics of the former east German Academy of Sciences is also located in Greifswald, and the site of a disused nuclear plant at Lubmin some 20 kilometres from Greifswald has been proposed for the ITER reactor.

Status of the W7-X Project

W7-X was approved by the IPP in 1990 and received restricted Phase I approval by EURATOM review panels in 1991. One crucial question remained unanswered at that time, namely how W7-X would fit into the European fusion strategy. It was answered in the frame of a detailed assessment of the European fusion programme for 1994-1998, where W7-X is proposed as the major new project to be started in this period. The project has meanwhile received full Phase I approval and the Phase II process, the final step in the European assessment procedure, has begun. Members of the European Associations have been invited to join the IPP in the pioneering enterprise to realise the W7-X.

If this final step is passed successfully the first plasma can be expected in 2002. W7-X will, however, not be built at the IPP, Garching, the site of present German stellarator research where the optimization idea was born. It will most likely be located in Greifswald (Fig. 2) following another optimization process which has to do with the research structure in Germany after reunification. The national financial support (55%) is being provided under the condition that W7-X is treated by the German fusion community as a contribution to the development of research structures in the eastern part of Germany.

The IPP has been charged with the task of founding an extension at Greifswald and operating the institute within the framework of the Max-Planck Gesellschaft, which has already given its approval. As "W" stands for Wendelstein, a prominent mountain in the Bavarian Alps, the device would then become a symbol that fusion is indeed capable of moving mountains.

ANOMALOUS TRANSPORT

European Task Force Formed

The ubiquitous anomalous transport processes observed in magnetically confined plasmas have defied a convincing explanation. The US Transport Task Force (TTF) inaugurated in 1989 has been a very successful in harnessing US resources to develop understanding. Working groups comprising experimentalists, diagnostic experts, theoreticians, and modellers from participating institutes concentrate on specific topics, such as the physics of the transition from the low-confinement mode (L-mode) to the high-confinement mode (H-mode). The groups then report at the TTF annual meeting. This focussed and collaborative mode of working has already clarified many facts, although many questions remain unanswered — indeed new ones have arisen!

There is also considerable activity within the European Fusion programme addressing transport issues. The question of enhanced co-operation between the various European groups involved has naturally arisen; formal links between Europe and the US are another possibility.

A discussion, led by Friedrich Wagner (Institute for Plasma Physics – IPP, Garching) and attended by Ben Carreras, head of the US TTF, at a workshop organized by Jan Weiland in Göteborg last June considered the possibility of a European TTF. While there was general support for the idea it was recognized that the situation in Europe was very different: a simple replica of the US organization was inappropriate. Nevertheless, stronger collaboration between existing programmes would enhance European work. A number of topics, mainly those being treated by existing collaborations, were suggested and individuals offered to take the lead in building on these collaborations and focusing their efforts to clarify important issues. The readiness of the theorists to join these "topical groups" was particularly encouraging. Interactions with the US TTF would involve information exchange rather than active participation in joint working groups.

Additional meetings and costs would be avoided and existing conferences and workshops should be used to develop collaborations within the topical groups and with members of the US TTF. However, it was envisaged that significant progress would be reported at successors to the Göteborg meeting, namely the annual meetings of the US TTF and a new, biannual joint meeting in Europe (the first will be held in 1996, possibly in Vienna). The IPP Jülich, IPP Garching and Chalmers University have volunteered to organize several European-US workshops.

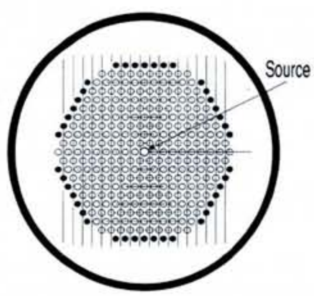
Jack Connor (Culham) agreed to co-ordinate the European TTF and maintain contacts with the US TTF, with help from Francesco Romanelli (Frascati), Jan Weiland (Chalmers University) and Friedrich Wagner. They would coordinate workshops, disseminate information, organize the biannual European meeting and, jointly with the European topic coordinators, propose European contributions to the US meetings. J.W. Connor and B. Carreras belong to the Confinement and Transport ITER Expert Groups so the results of TTF activity can be fed into the ITER framework to avoid duplication.

The support of laboratory Directors in Europe is being sought. As it is hoped that the initiative will harness the undoubted strength of the European Fusion Programme to solve the grand challenge of understanding the cause of anomalous transport in magnetic confinement devices, F. Wagner reported the outcome of the Göteborg discussion to the European Programme Committee last September. General approval was given and terms of references suggested. The European collaboration must take full account of the ITER physics and Expert Group activity to avoid duplication; appropriate dissemination of knowledge must occur; working structures must incorporate all EURATOM Fusion Associations as well as JET; additional travel costs must be kept low, the organizational overhead minimized and activity concentrated at the working level.

The Topic Coordinators are: edge turbulence (Hidalgo, Madrid), core transport and turbulence (Romanelli, Frascati), physics of short timescales in transport (Cordey, JET), perturbative transport (Jacchia, Milan), and stellarator-tokamak comparisons (Stroth, Garching).

J.W. Connor, *Culham Laboratory*

Elegant Demonstration Successful



The sub-critical reactor assembly used for demonstrating the energy amplifier comprises 270 Al-clad bars of natural uranium immersed in demineralised water with a neutron spallation source at the centre. The assembly is normally used in Madrid for teaching purposes.

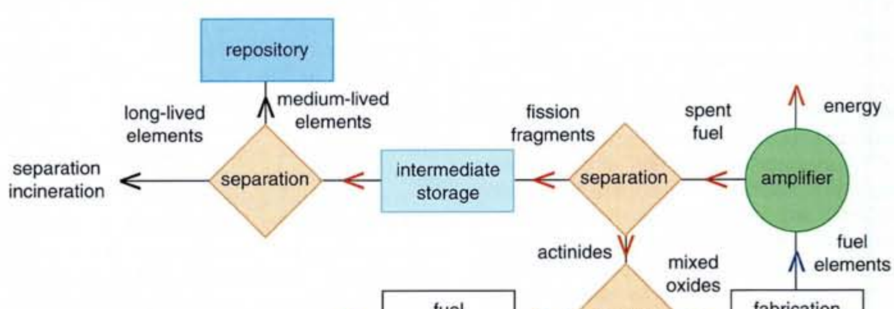
It is just over a year since C. Rubbia, CERN's former Director-General, made headlines by proposing an energy amplifier — a nuclear reactor based on an accelerator-driven sub-critical assembly with thorium as the breeder fuel. Neutrons produced by spallation multiply *via* fission reactions in a fuel-moderator medium to give an overall energy gain. The main advantages, apart from sub-critical operation, lie in: the use of thorium (inexhaustible on the human scale; little plutonium production so reduced risk of nuclear proliferation); the production of much less transuranic actinide waste than conventional nuclear reactors; mainly existing technologies unlike other hybrid systems for energy production.

His group found resources to check calculations experimentally using well-established but nonetheless elegant techniques. The results were presented in detail by Professor Rubbia at CERN in early December. A spallation target, placed at the centre of a sub-critical assembly comprising 3.6 tonnes of natural uranium encased in aluminium tubes and immersed in water, was irradiated by a low-intensity proton beam produced by CERN's Proton Synchrotron beam over a two-week period. Observed temperature increases of the order of a mere 0.01 °C (since the device only generated 1 W to minimise radioactive waste production) correlated with measurements of fission fragments. Assumed cross-sections and approximate analytical solutions were verified and the estimated energy gain of 30 agreed with the results of a Monte-Carlo simulation.

On the analysis side, the window of opportunity for the amplifier approach is narrowing as the group rediscovers various technological, environmental and commercial restraints. A practical system delivering 10^8 to 10^9 W would operate in a different regime where transmutations modify significantly the evolution of cascades (thus allowing the required breeding of a Th fuel with a long burn-up period). Studies have been extended from the original graphite and water-cooled systems based on thermal and epithermal neutrons to systems involving fast neutrons with lead coolant. This allows a higher gain which is not flux limited, thus avoiding the need for several accelerators. But it also means that one is now discussing larger (1 GW), more exotic reactors working closer to criticality. Fuel regeneration has also become more complicated: established processes to separate out long-lived actinides need improving, and economic considerations suggest storing short-lived fission products while concentrating processing on the long-lived, high-mobility varieties.

On the accelerator side, the experiment demonstrated that there is no point in going beyond about 1 GeV proton energies. The analysis so far indicates that useful systems may also involve fairly modest currents (≈ 10 mA, roughly an order-of-magnitude less than for the high-intensity linac-based fission schemes being proposed for various applications of transmutation — see *EN*, August 1995, p. 135). So some existing cyclotron designs may be suitable, notably isochronous ring cyclotrons with C-separated magnets of the type operating at the Paul Scherrer Institute. Overall, the economics of the fast-neutron option appear favourable, but a detailed analysis is needed.

Professor Rubbia aims is to remain an experimentalist at heart by seeking support for a pilot facility involving a larger reactor assembly, fuelled this time with thorium, to once again verify calculations (a proposal along these lines is expected shortly).



A possible fuel cycle for the energy amplifier. Fuel reprocessing is limited by the efficiency of separating out the actinide fission products. For cost-effectiveness, medium-lived fission products may be stored, with costly processing reserved for long-lived elements.