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HOTLINE

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New Stellarator Project Underway

An Interview with Hutch Neilson

On April 1, the National Compact Stellarator Experiment (NCSX) was officially granted Project status by the U.S. Department of Energy. A successful Conceptual Design Review of NCSX was held in May, 2002. A Preliminary Design Review, which will examine engineering design, as well as cost and schedule issues, is planned for this fall. Contracts have been awarded for the fabrication of prototype components to begin in June. The new machine will be built at C-Site, with first plasma scheduled for June of 2007. Recently, ***Hotline*** *staff interviewed NCSX Project Head Hutch Neilson to learn about this exciting new venture.*

How did you first become interested in stellarators?

I became interested in stellarators in the early 1980's when I was at Oak Ridge National Laboratory (ORNL). We built a stellarator called the Advanced Toroidal Facility (ATF). I was responsible for preparing the ancillary systems, the power supplies, diagnostics, plasma heating systems, and so on, and pulling everything together to achieve the first plasma milestone.

Hutch Neilson

What interested me about stellarator physics was the three-dimensional structure of the magnetic field and the plasma shape. The cross-sectional shape of a 3-D plasma depends on where the torus is sliced, while the cross-sectional shape of a tokamak, a 2-D torus, is always the same. Consequently, stellarator physicists have three degrees of freedom to tailor the plasma shape for good performance. There are only two degrees of freedom in a tokamak.

I had worked on tokamak magnetic diagnostic data analysis. I became fascinated with the idea that stellarator coils could generate a spiraling magnetic field without the plasma current needed in a tokamak. I began trying to understand high pressure stellarator equilibria and how to infer their properties from magnetic data. It was a much more difficult task than I expected, and I didn't get very far. Today there is a national team, led by some of our best researchers, working on the 3-D magnetic data analysis problem. So I don't feel so bad about my lack of progress working on it part-time back in the 1980's.

Can you reflect on how it feels to return to a concept on which PPPL was founded?

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Lyman Spitzer believed that we would make a lot of progress in plasma physics and performance with tokamaks, but that the stellarator would make the better reactor because it is more straightforward to make it run steady-state. I think it is fitting that the Laboratory, after making historic advances with tokamaks, has turned to the task of expanding our understanding of toroidal configurations to find the best solution for magnetic fusion reactors. For instance, just as we are using the National Spherical Torus Experiment (NSTX) to push into new physics regimes, we will use NCSX to understand how to use 3-D fields and plasma shaping to optimize performance. We are encouraging and supporting other institutions that are tackling different aspects of this difficult challenge. It is a challenge that is worthy of PPPL's talents. This is what attracted me to join the Laboratory staff in the mid-1990's. But more importantly, I believe Professor Spitzer would approve and be proud of us for taking on these important problems.

What are the advantages of a stellarator compared to other magnetic confinement configurations?

The basic conditions for good magnetic confinement are a toroidal geometry and a magnetic field that twists around helically on magnetic surfaces. A stellarator can create those conditions with coils alone. It doesn't require a plasma current. That means it is easy to make a stellarator steady-state. Also, stellarator plasmas typically don't disrupt. These advantages result from the three-dimensional nature of the stellarator. Its coils and vacuum vessel have more complex shapes than those of tokamaks and STs, and this carries a cost. However, it also carries enormous opportunity for improved performance. As I noted earlier, a stellarator gives designers three degrees of freedom to tailor the plasma shape for good performance. We now have good enough physics models and computer power to do this, and this is how modern stellarators, such as NCSX, are designed. With these experiments, we can test physics solutions that will lead to practical reactors. We can study 3-D physics effects that are important for all magnetic configurations, but should be much easier to see in a configuration that is itself 3-D. A goal of our research is to quantify both the benefits and the costs, giving the designers the information they need to optimize future devices.

Where are the major existing stellarators located?

Japan and Germany both have long histories of stellarator research and are the leaders in the field. Japan has a TFTR-scale superconducting stellarator, the Large Helical Device (LHD). The Germans are building a large superconducting stellarator, the Wendelstein 7-X, the next step in their stellarator line. This follows the recent closure of their W7-AS stellarator experiment in Garching after a successful run of almost 15 years. The W7-X is being built in Greifswald in the former East Germany. Spain, Australia, and the United States also have operating stellarators. Our new stellarators, the NCSX here and the Quasi Poloidal Stellarator (QPS) to be built at the Oak Ridge National Laboratory (ORNL), will not be among the world's largest, but they will develop physics ideas that will lead to more compact stellarator power plant designs. The U.S. compact stellarator designs have much lower aspect ratios than previous stellarators. They are closer to tokamaks in that respect. Moreover, they have strong physics ties to tokamaks, so they can take advantage of, and build on, all the progress we have made with tokamaks — nothing is thrown away.

How did the idea of a compact stellarator evolve? Will NCSX be the first compact stellarator in the world?

The seminal ideas originated with theorists, many of them at PPPL, who in the early 1980's explained how the confinement properties of a stellarator depended on the details of the magnetic-field structure. By incorporating that understanding into computer codes, we have been able to design stellarator configurations to meet physics specifications. Those designs can then be built and tested to validate the physics models. The W7-AS and the University of Wisconsin's Helically Symmetric Experiment (HSX) are the first examples of this new approach. It is a dramatic departure from the cut-and-try approach to experiment design that we used to take. It came about because both our physics understanding and our design capabilities matured to the point where we can target the characteristics we want in our designs. That allows us to design better experiments that are more precisely targeted to the questions we want answered, to take larger steps, and consequently to make faster progress.

The compact stellarator strategy actually combines several ideas. One is magnetic quasi-symmetry, which means that even though the plasma shape is three-dimensional, the magnetic field has a symmetry direction, just as a tokamak or an ST does. HSX is now testing this idea on a small scale, and it is working very well. As a quasi-axisymmetric stellarator, the NCSX has a strong physics overlap with the tokamak. In fact, a charged particle following a magnetic field line around in NCSX would think it was in a tokamak. That is, the charged-particle orbit confinement is the same as in a tokamak, so we believe that some of the tokamak's good performance features will carry over to NCSX. Unlike previous stellarator designs, the NCSX was optimized to be both quasi-axisymmetric and stable at finite pressure in a compact configuration. The result is a passively stable configuration that relies on the shape of the coils rather than active feedback and current drive to maintain a high-performance stable plasma. A fusion power reactor based on this approach would have power densities as high as a tokamak, but would operate with a higher overall efficiency, because it would not need to recycle any power to drive current and plasma rotation. It would have more complex coil geometries than a tokamak, but would be a simpler and more reliable system overall.

The QPS experiment proposed by ORNL is a smaller, higher-risk experiment designed to push stellarators to aspect ratios less than 3.0. Auburn University is building a small stellarator, the Compact Toroidal Hybrid (CTH), to explore magnetohydrodynamic (MHD) issues in support of NCSX. As you can see, NCSX is not an isolated experiment but part of a national program that includes theory and multiple experiments to develop the knowledge base needed to assess the attractiveness of the compact stellarator concept and decide on a major next step by 2011 or 2012.

What was the genesis of the National Compact Stellarator Experiment?

In 1996-1997, several working groups were formed at PPPL to come up with new initiatives for the Laboratory. There was one on stellarators looking at quasi-axisymmetric configurations. At the same time, other groups around the country, including the ORNL stellarator group, were also interested in modern optimized stellarators. A national program planning committee drafted a blueprint for a national stellarator proof-of-principle program, with NCSX as its central element, to develop the compact stellarator. In 1998 PPPL and ORNL formed a partnership to propose and carry out the NCSX project by pooling our talents in stellarator physics and engineering. A national advisory committee was formed about the same time and has guided the project ever since. The project has been debated in many forums and passed several major peer reviews, including a physics validation review in 2001 and a conceptual design review in 2002. The fabrication project was approved by DOE last fall and officially started on April 1.

What is the overall timeframe for the design, construction, and operation of NCSX?

This year we are continuing with the design and are starting R&D to determine exactly how the modular coils and vacuum vessel, the most challenging components, will be manufactured. We recently placed contracts with industry to develop the manufacturing processes and build prototypes for the winding forms and the vacuum vessel. We are developing the coil winding methods here at PPPL, and are planning to wind the NCSX coils at PPPL in the former TFTR test cell. Most of the machine subassembly will also be performed at D-Site. Next year we will start building the vacuum vessel and the eighteen modular coils that will be the heart of the machine itself. We will start building the three field-period subassemblies in 2005. Each will consist of six coils and one-third of the vacuum vessel. Final assembly will begin in 2006, with first plasma scheduled for June of 2007. We expect NCSX to operate for about ten years.

What are the roles of other U.S. fusion laboratories in the NCSX program? Which labs are involved? Foreign labs?

ORNL is our partner in the project. They have key leadership roles including responsibility for the design of the stellarator core itself. When the project moves into operation, ORNL will have significant responsibilities for management and research. Other laboratories and universities, including foreign ones, will collaborate with us on NCSX research. Several have already expressed interest. It is too early to know exactly who will do what, but certainly diagnostics, divertors, plasma heating, and theoretical tools will be fruitful areas for collaboration.

Starting next year, we will hold a series of national research forums, like those so successful for NSTX, for open discussions of the NCSX research program with the larger community. The input from these meetings will help determine what tools are needed and will enable our potential collaborators to plan for participation in the program.

A program advisory committee composed of fusion physicists from several U.S. and foreign institutions has served the project very well through the planning and design phases. It includes experts in all branches of plasma physics, both stellarator and non-stellarator people. It will focus on research planning issues when we get closer to operation to help guide the research program.

Tell us about the site preparations that are now underway at PPPL and about the space that will be dedicated to NCSX and its support systems.

NCSX will be located in the former PLT/PBX-M test cells, and the NCSX control room will be constructed in the area

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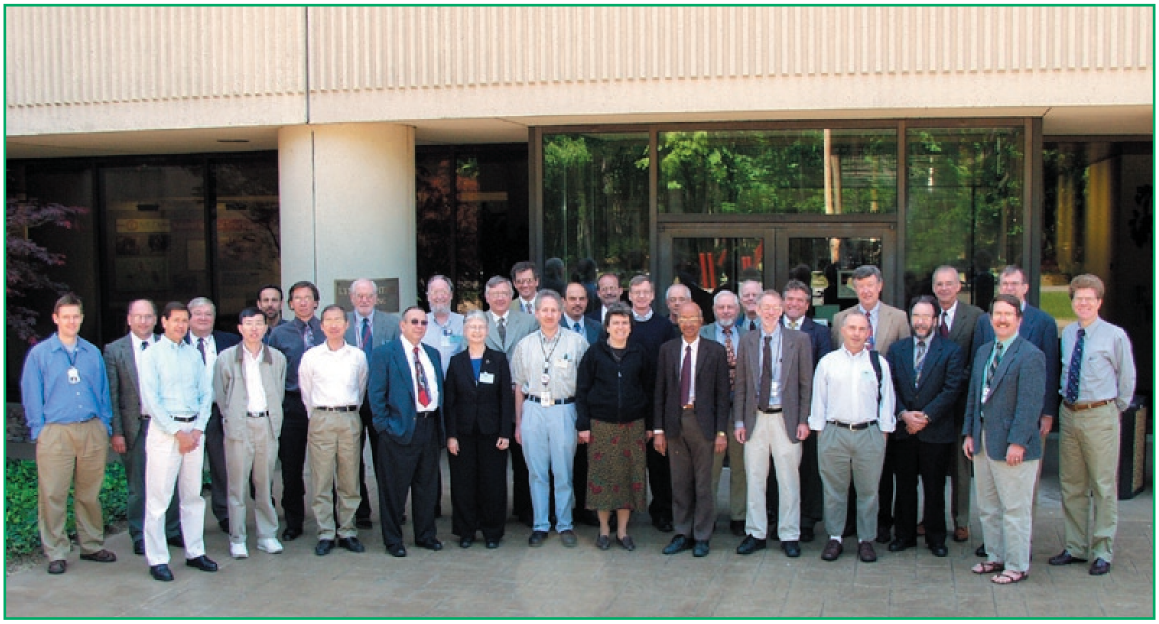

NCSX Conceptual Design Review attendees are, from left, Alex Pletzer, Art Grossman (UCSD), Don Monticello, Phil Heitzenroeder, Guo-Yong Fu, Mike Kalish, Ron Strykowsky, Long-Poe Ku, Gary Oliaro, Ed Lazarus (ORNL), Jim Lyon (ORNL), Martha Redi, Jim Chrzanowski, Hutch Neilson, Jerry Levine, Greg Pitonak (DOE), Brad Nelson (ORNL), Judy Malsbury, Dave Johnson, Neil Pomphrey, Raki Ramakrishnan, Chuck Finfgeld (DOE), Bob Simmons, Allan Reiman, Wayne Reiersen, Harry Mynick, John Schmidt, Rob Goldston, Warren Marton (DOE), Mike Zarnstorff, Rich Hawryluk, and Irving Zatz.

The team members participating in the NCSX project are: *(from PPPL)* Bill Blanchard, Art Brooks, Tom Brown, Fred Dahlgren, Larry Dudek, H. M. Fan, Russ Feder, Eric Fredrickson, Guo-Yong Fu, Charlie Gentile, Geoff Gettelfinger, Rob Goldston, Pamela Hampton, Ron Hatcher, Rich Hawryluk, Phil Heitzenroeder, Stuart Hudson, Dave Johnson, Chang Jun, Mike Kalish, Long-Poe Ku, Henry Kugel, Doug Loesser, Jerry Levine, Frank Malinowski, Judy Malsbury, Dick Majeski, David Mikkelsen, Don Monticello, Lew Morris, Harry Mynick, Hutch Neilson, Gary Oliaro, Erik Perry, Alex Pletzer, Neil Pomphrey, Raki Ramakrishnan, Martha Redi, Wayne Reiersen, Allan Reiman, Joe Rushinski, Paul Rutherford, John Schmidt, Bob Simmons, Tim Stevenson, Brent Stratton, Ron Strykowsky, Hiro Takahashi, Al von Halle, Mike Viola, Mike Williams, Mike Zarnstorff, Irving Zatz; *(from ORNL)* Bob Benson, Lee Berry, Mike Cole, Paul Goranson, Steve Hirshman, Ed Lazarus, Jim Lyon, Stan Milora, Peter Mioduszewski, Brad Nelson, Larry Owen, Don Spong, Dennis Strickler, David Williamson; *(Others)* Allen Boozer (Columbia U.), Alexander Georgiyevskiy (consultant), Art Grossman (UCSD), Dave Hill (LLNL). ●

once occupied by the PLT and PBX-M control rooms. So there will be a significant modernization and upgrade of the C-Site facility, which in the 1960's was the site of the Model-C Stellarator.

Currently, a crew led by Erik Perry is orchestrating the removal and preparation of the PLT/PBX-M areas. The old control rooms have been cleared out. Power supplies have been disconnected from PBX-M, and a decommissioning contractor has purchased PBX-M for scrap. Four of the old PBX-M poloidal field coils will be shipped to our NCSX partner, ORNL, for use on QPS. We expect that the test cell will be cleared by August. In 2006, following their fabrication in the TFTR test cell, NCSX's three field-period subassemblies will be transported to C-Site, and assembly of the stellarator core will begin. ●

— Edited by Anthony DeMeo

Hotline

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