Review of NCSX

NCSX Review Committee

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Committee's task:

- To inform a decision on the future of NCSX, by addressing certain scientific and technical questions about the experiment, its capabilities and its role in the international fusion program
- Complementary to programmatic review by Lehman

Charge from Ray Orbach

1. Critical issues for the US compact stellarator program

a. What unique toroidal fusion science and technology issues can a compact stellarator program address independent of its potential for a reactor concept?

b. What are the advantages and disadvantages of the quasi-symmetric stellarator as a potential fusion system concept? What unique features does the compact stellarator offer in this regard?

c. What scientific and technical issues need to be resolved to evaluate the compact stellarator as a viable concept for a fusion energy system?

Charge, continued

2. Role of NCSX in the international context:

a. What critical, unique contributions does NCSX offer for addressing the issues identified in (1)?

b. Given PPPL's proposed plans for operation of the NSTX and NCSX, what would be the timetable for resolving relevant issues identified in (1) above?

c. What are the technical differences of the current NCSX design compared to other stellarators operating or being built abroad? What is the significance of these differences? Does NCSX fill a critical void in the development of the stellarator concept as a viable fusion energy system?

Charge, continued

3. Options for the US stellarator program

a. If the NCSX program were not continued, what options would exist or would be possible to address the key issues of the quasi-symmetric stellarator in general and the compact stellarator in particular?

b. Assuming NCSX is not available, what program elements would be required to maintain the US as a significant participant in the international stellarator program?

i. Identify potential opportunities for US leadership.
ii. Include more international collaboration as appropriate.

Review schedule

Charge issued on August 9, 2007; FESAC promptly consulted for advice on membership.

Committee not fully populated until September 11, leaving less than five weeks to research, debate and prepare report.

Even with the dedicated effort of Committee members, the tight schedule required focus and judicious interpretation of charge. We attempted a thorough, unhurried discussion of the central questions.

Review procedure

Email reflector, with help from BPO (James DeKock)

Reading list, mostly suggested by NCSX team

Particular help from ARIES team (Farrokh Najmabadi)

--summary document on compact QAS reactor

Lively teleconferences

Week-end meeting at PPPL

--presentations by NCSX team; site tour

--intensive discussions in executive session

--additional sessions to address specific Committee questions

Debate and refinement of (six) drafts

Findings

From here on each sentence is taken, with some compression, from the report.

Critical science and technology issues for the US compact stellarator program

- Stellarator research programs generically address two key issues in fusion energy research: disruption avoidance and steady-state operation. The scientific issues to be addressed include transport, energetic particle confinement, equilibrium, stability and density limits, and particle and power handling. Technology issues to be explored include simpler magnet coils and support structures, metrology, correction coils and divertors.

- The *compact* quasi-axisymmetric stellarator is distinctive in having relatively small aspect ratio; its geometry approaches that of a tokamak. One expects a compact stellarator to provide particular insights into tokamak physics; and similarly one expects existing knowledge of tokamak behavior to benefit compact stellarator research. The Committee finds these potential mutual rewards to be plausible and significant.

Critical fusion issues: advantages, disadvantages and unique features

- Stellarators offer the important advantages of steady-state operation with relatively soft and forgiving stability limits–advantages that might become especially important as the international fusion program begins to study the DEMO device to follow ITER. Quasi-symmetry provides one means for improving predicted neoclassical transport.

- The key disadvantage of the stellarator is the complexity and cost of its field coils, whose precise design and alignment are essential for acceptable confinement. Furthermore present coil designs complicate external access to the plasma and to the plasma blanket, for maintenance or other purposes, in a stellarator reactor.

- An ARIES study indicates somewhat smaller construction and operation costs for a compact stellarator, compared to a stellarator with large aspect ratio. At the same time it is recognized that there remain many unanswered questions about compact stellarator reactor performance.

Critical fusion issues: evaluation as viable fusion system

Many issues, detailed in the body of the report, will need to be addressed in the design of a stellarator for fusion energy production. Three issues of particular note for compact stellarators as a fusion concept are

- determination of the size scaling of confinement
- the required tolerances for coil construction
- the magnitude of plasma current below which disruptions due to plasma instabilities are avoided.

Role of NCSX in the international context: critical, unique contributions

- NCSX is designed using a compact, quasi-axisymmetric configuration that is unique in the world stellarator program. The Committee finds that, assuming successful construction and testing phases, the NCSX device is likely to perform at a level sufficient to address its scientific and technical missions. Therefore the Committee expects the NCSX program to have a profound impact on stellarator research worldwide.
- By virtue of both QAS and compactness, NCSX offers a similarity to tokamak science that is unmatched by any other stellarator device. This similarity should allow NCSX to illuminate a number of issues concerning the effects of symmetry-breaking on confinement.
- Comparative studies of the three major lines in the international stellarator program – LHD , W7-X , and NCSX – will inform a decision on which system has the highest reactor potential, thus influencing decisions on the continuation of the fusion program toward the DEMO reactor.

Role of NCSX in the international context: significance of timetable

- NCSX plans to achieve its first plasma in 2012 and then to alternate its operation with that of NSTX. Thus the key initial experimental results for NCSX would be obtained in FY2013 and FY2015. The Committee is concerned about the practical realism of this plan; we find in particular that the resolution of key experimental issues is likely to require five years of actual operation.

- One technical requirement that the Committee considers likely to affect the timeliness of physics results is the quality of the magnetic flux surfaces in three-dimensional geometry. The NCSX team has developed appropriate strategies for constructing and maintaining flux surface quality. While finding these strategies to be well thought out, the Committee recommends that attention to construction details that may affect flux-surface quality, and the study of their effects and methods to counteract them, remain top priorities for the project.

Role of NCSX in the international context: significance of differences

- NCSX will be unique in the world stellarator research program, because of both its quasi-axisymmetry and its compactness. The W7-X device uses a distinct configuration optimization, has a large aspect ratio, and moreover is designed to minimize plasma currents. The LHD device achieves reduced orbital excursions by means other than quasi-symmetry; it has a intermediate aspect ratio. Both W7-X and LHD employ super-conducting magnets.

- The Committee finds that the comparison of these three devices will be extremely useful in understanding the physics optimization of advanced stellarator configurations.

Options for the US stellarator program

- The present US stellarator research program includes other devices that could address at various levels a subset of the central physics and technology issues of stellarator fusion research. However no present or planned US program could provide the breadth of scientific and technical information that is expected to come from NCSX. NCSX is the only PoP scale device in the US repertoire that addresses quasi-symmetry, and the only such device capable of examining the key issues in an integrated context. Therefore, if NCSX were abandoned, the US would have to significantly reduce its ambitions in stellarator research, or begin constructing a new PoP stellarator experiment.

- The Committee finds it important that the U. S. have a significant stellarator presence as part of its magnetic fusion energy research program. The Committee notes that at present about 75% of the US stellarator effort is focused on the construction of NCSX, so the loss of NCSX would change the basic character of the US program.

Options for the US stellarator program

- The HSX at the UW-Madison allows fundamental tests of quasi-symmetry and can span a range of symmetry-breaking geometries. The CTH device at Auburn is used to study passive disruption avoidance. Both of these relatively small experiments provide valuable scientific information, and both could be upgraded. However neither could provide the integrated research program of a PoP device like NCSX.

- The proposed QPS device at ORNL is a low-aspect ratio stellarator with quasi-poloidal symmetry. QPS could therefore extend the stellarator data base in a useful way. But it would not replace the scope of the NCSX program.

- The Committee recommends that the construction decision on QPS be expedited if NCSX is cancelled. However, we find it illogical to cancel a stellarator project that is nearing its final construction phases only to begin a new stellarator with poloidal rather than toroidal quasi-symmetry.

Options for the US stellarator program

- In the absence of NCSX, a restructured US stellarator program could maintain scientific leadership in selected research topics, but would have difficulty playing a significant role in the direction of worldwide stellarator research. International collaboration is already a key element of US stellarator research and would remain so in the absence of NCSX. However, the benefits gained from such collaboration would be diminished without a domestic stellarator experiment on the PoP scale.

- Quasi-symmetry is one of many ways to optimize 3-D configurations; other optimization schemes could be pursued. Without the presence of NCSX, the US stellarator program should consider a variety of approaches to stellarator optimization in proposing a new PoP stellarator project.

- The US has been a leader in theory and computation on three-dimensional confinement; encouragement by OFES of such research would help the US maintain its presence in the international effort. However, the loss of a world-class experiment in the US would hinder the recruitment of young scientists into stellarator theory.