What do international collaborations really mean for fusion?

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In order to maintain the U.S. magnetic fusion program under a declining domestic facilities budget, the Fusion Energy Sciences (FES) program intends to increase participation in "international collaborations" – that is, paying for students, postdocs, research scientists, and professors to do their experimental work on fusion devices in other countries. The purpose of this whitepaper is to ask some questions about what that will actually mean – for the individuals who will actually be doing the traveling, and for the fusion workforce.

1 Magnetic fusion devices are not the same as particle accelerators

The obvious point of comparison when thinking about international collaborations is High-Energy eXperimental (HEX) particle physics. Since the cancellation of the proposed Superconducting SuperCollider (SSC) in 1993, the "energy frontier" has moved to Europe, at the Large Hadron Collider (LHC). Now that the Tevatron at Fermilab has closed, the LHC is the only device in the world equipped to investigate the physics of particle collisions at the energy frontier. Given the very high cost of a hadron accelerator of this size, the only option for U.S. university particle physics programs was to join the various detector collaborations at LHC and contribute equipment and expertise.

In general, this path has been very successful for the HEX community. U.S. physicists are an integral part of designing equipment and interpreting data from the LHC detectors, and U.S. universities maintain robust high-energy physics programs, training new Ph.Ds to maintain the workforce. So it is natural to ask why this strategy couldn't be replicated by FES, replacing the LHC with KSTAR, EAST, and eventually ITER. There are, however, two important differences between HEX and FES. The first has to do with the nature of the two fields, and what are the important parameters, and the second has to do with the eventual goal of the research.

First, consider what parameters are important in particle physics and in fusion. In HEX, new particles such as the Higgs boson are discovered on the "energy frontier". That is, for this type of research, there is one parameter that matters above all else: collision energy. The expected number of Higgs bosons, for example, is more than three orders of magnitude higher at the LHC than on the Tevatron, despite the center-of-mass energy being only 7.8 times as high [1]. Thus it makes scientific sense to have many countries help pay for a single large accelerator and share the scientific output.

For magnetic fusion, in contrast, there are *many* different parameters that matter. One can imagine a time in the future where all that matters is Q, or absolute fusion power, or plasma duration. But as of today, the field is still wide open, with many different things that can be optimized on different machines: plasma temperature, plasma density, β or β_N, heating density, type of heating (ICRF, LH, ECRH, NB), power density, absolute magnetic field, wall material…the point is that a single device, or even a few devices, cannot fill the role in fusion that the LHC does in HEX. Advancing magnetic fusion depends on there being a diversity of approaches, and there is a place in the program for smaller facilities in a way that there is not in particle physics.

The second very important difference between high-energy particle physics and fusion energy science is the eventual goal of the research. In HEX, the goal is, roughly, to discover the fundamental laws of nature and produce an experimentally-validated theory of physics on the smallest and largest scales. This is a result that would benefit all of humanity, and would be impossible for any one country to take advantage of to the exclusion of others. In fusion, by contrast, the goal of the United States (for example) is eventually to have power-producing fusion reactors *in the United States*, ideally built by American companies. In this sense, sending physicists and engineers abroad to aid other countries with their domestic fusion research will benefit humanity, but will almost certainly mean that the U.S. will eventually be buying fusion reactors from Europe, Korea, and China rather than building them at home.

Furthermore, as nuclear devices, fusion reactors have weapons and national security implications that particle accelerators do not. It is entirely conceivable—in fact, likely—that a tokamak with a subcritical fission blanket will be used for military or strategic purposes. For example, uranium could be transmuted to plutonium in the blanket. This is a situation where helping other countries with their fusion energy programs rather than developing it domestically may in fact actually mean providing a strategic advantage to these other countries.

2 Attracting and maintaining a workforce will be difficult

Another very important issue that should be confronted as FES considers offshoring American fusion research is how it will maintain and grow the workforce. Fusion scientists are a dedicated breed, and work hard for long hours to build equipment and analyze data. But they also have families, and their spouses have their own careers, and their children have grandparents.

FESAC surveyed professors from HEX on their experience working at CERN as part of its Collaborations Panel [2]. More recently, I have surveyed HEX graduate students by email. One theme that came out again and again was the need to have at least some personnel *on site* at the collaboration facility for a signficant amount of time: at least six months per year. This was essential for troubleshooting and fostering the sort of active discussion that goes on in the "control rooms" of scientific facilities and often leads to the best ideas.

Fusion energy science should not be an ascetic calling for only single men and women who don't intend to have families, who are willing to pick up and move anywhere in the world. One problem with surveying people from HEX about their experience is that it is a self-selecting sample. The ones who give their opinions are the ones who *didn't* leave the field when the SSC was cancelled, when Fermilab closed down, and when they were told they would have to move their lives to another continent for at least half of each year.

It is not correct to say "the best physicists are the ones who will go wherever the work takes them". There are a large number of people in fusion science who are effective researchers *and* for whom family considerations are important. These are the people who will simply leave the field when the domestic facilities are closed down. They won't be happy about leaving, but most of them won't make a big deal out of it. Their expertise and intelligence will just be quietly lost to the field.

Finally, talking to fellow students and scientists, one gets the sense that working for ITER would be an honor, worth the sacrifice of moving to another continent for a time. Participating in experiments in other countries, from a position of equality, is also something that scientists are enthusiastic about. For example, many scientists from the Max-Planck-Institut in Garching perform experiments on Alcator C-Mod, and Los Alamos has an active collaboration with the Wendelstein 7-X device, sending over personnel and equipment. But this is very different from sending the U.S.'s best people over to new devices overseas *because there are no facilities for them at home*. The feeling will be less of a scientific collaboration among equals, and more of humbly asking for machine time because the U.S. can no longer afford to run world-class experimental fusion facilities. These thoughts typically do not rate mention in official reports, but they are ubiquitous in hallway conversations at fusion labs.

3 Recommendations

There are two things that the FESAC MFE Priorities Panel should recommend in its report . The first is that, if FES plans on going the "particle physics route" and sending scientists to work on fusion facilities abroad, it should *carefully* heed the lessons from the particle physics experience. There has already been a FESAC panel that made a detailed study of the scientific opportunities available with international collaborations – a similarly careful study should be made of the *personnel* considerations that come along with this strategy. Failure to do this prior to closing domestic facilities and opening up money for international collaboration could lead to a sudden loss of a large fraction of the workforce.

Second, the role of U.S. universities in fusion energy science research should not be reduced. The universities are the backbone of the particle physics (CERN) collaboration strategy, and play a vital role in supplying young, unattached people (*i.e.* graduate students) who can travel overseas for long periods of time and then return to the U.S. with their knowledge and experience.

Overall, the move to international collaborations in lieu of a robust domestic program is not favorable for the prospects of an eventual U.S. fusion energy industry. It is imperative that the process be managed carefully, with an eye toward maintaining the workforce, so that the situation does not end up worse than it has to be.

References

[1] Cranmer, K. "Recent developments and current challenges in statistics for particle physics", presented at Statistical Issues in Searches workshop at SLAC, June 2012. Available online. See slide 15.

[2] International Collaboration for Magnetic Fusion Energy, FESAC Panel 2011–2012. Charge letter, membership roster, and final report available at http://fire.pppl.gov/fesac_intl_collab_2011.html.