NEAC International Subcommittee Report
on
Review of U.S./China Collaboration
December 2015

Background

China has the fastest growing nuclear power program in the world with 24 reactors in commercial operation, 26 under construction, and national plans for a total capacity of 58 GWe by 2020 and 150 GWe by 2030. After a 4-year pause of approving new reactor projects post the Fukushima accident, the Chinese government has restarted the approval process with the expectation that 8 new reactor starts will be approved by the end of 2015. Within the next twenty years, it can be anticipated that the U.S. and China will be the two largest nuclear power countries in the world. In both countries, light water reactor technology will dominate for the foreseeable future.

It is in the United States' best interests that China continues to expand commercial nuclear power because it aligns with USG policy regarding climate change. China currently is the largest emitter of CO_2, mainly because of their increasing large coal-fired electricity generation capacity. The Chinese government has been commissioning one large, coal-fired plant per week over recent years to try to match their electricity demand. Since the Chinese have already decided that air pollution and climate change are both real and important to them, they intend to phase out their old and smaller (300 MWe and smaller) coal-fired power plants. Even today, about 300 million Chinese have little or no access to electricity; thus, there is a strong expectation that electricity demand will continue to grow, albeit at a somewhat slower pace, e.g., 4%, than in the recent past. Reduction of the use of fossil fuels to generate power in China is an imperative if climate change is to be addressed seriously on a global basis. Their best near to mid-term approach is the aggressive expansion of commercial nuclear power and renewable energy projects.

In addition to a world leading build program based on light water reactors (LWRs), China has very aggressive Research, Development, and Demonstration (RD&D) programs on advanced reactors, including sodium-cooled fast reactors, high temperature gas-cooled reactors, and molten salt reactors. These RD&D programs include plans for funding of construction and operations for all of these advanced technologies with some form of R&D collaboration with other nations, including Russia, France, and the U.S. The Chinese RD&D programs can be characterized by their ability to emulate and then demonstrate technologies (i.e., provide the funding to move forward with building) rather than coming up with the innovative ideas. They generally look to others to provide the innovation and then, in collaboration with others, "run with it" to provide the demonstration. The Chinese are pursuing these advanced technologies to determine the benefits of nuclear energy for

potential expansion beyond traditional base load electricity generation. In addition to addressing climate change by replacing coal with nuclear, application to low and high temperature process heat, nuclear waste minimization, and improved uranium resource utilization are all of interest to the Chinese with a rapidly growing nuclear capacity and long-term planning.

This gives the U.S. an opportunity to leverage its relatively meager R&D investments by collaborating where it has the innovative ideas (both legacy and more recent). It is also likely that China will continue to perform extensive fuel cycle research, development, and demonstration (RD&D) with their eventual decisions still to be determined on commercial fuel recycle alternatives, including reprocessing and plutonium recycle. The U.S. needs to ensure that future advanced reactor and fuel cycle RD&D collaborations with China are consistent with U.S. nonproliferation objectives.

While the Chinese are willing and able to try multiple promising technologies, the U.S. has not allocated sufficient resources to fund the development and demonstration of advanced reactors in the recent past. Present budgets are such that the principal activities in advanced reactors are in support of international development efforts, and providing some funding to U.S. laboratories and universities to allow them to remain engaged in advanced reactor R&D activities. Most recently, DOE has initiated some exploratory, but relatively small-scale programs to foster new advanced reactor ideas (FOAs for two industry led concepts – to be awarded by the end of 2015) and to look at options for a potential advanced test and/or demonstration reactor (Congressionally mandated Advanced Reactor Planning Study). The U.S. advanced reactor policy still appears to center around keeping options open for potential longer-term applications, e.g., better resource utilization, nuclear waste minimization, process heat applications, etc., rather than focusing on the development of more economic and safer designs that are more likely to be competitive in the U.S. electricity market. Another motivation by the DOE for these advanced reactor initiatives is to attract new young talent to the nuclear energy field.

Nevertheless, even though we have no long-term program to develop and build advanced nuclear systems, collaboration with China is important to the U.S. (at least for a limited term) because it provides opportunities to U.S. companies to engage in commercial nuclear exports, creating domestic jobs and improving the balance of trade with China. In addition, China is making major investments in other nuclear markets, e.g., the U.K. and Romania, constructing new plants in Pakistan, and pursing markets in Turkey, Bulgaria, and South Africa, agreements with existing nuclear countries such as Argentina and "newcomer" countries like Kenya, all to help expand their exports and their influence. China views civil nuclear energy as a key component of its strategic engagement around the world. This political and business strategy will only increase in the future as more developing countries enter into the commercial nuclear power market and look for partners in this endeavor. It would be beneficial to USG interests if U.S. companies were acting in collaboration

and partnering with Chinese companies in this export business because it brings along U.S. government export control protocols.

Collaboration with China has other potential benefits that go well beyond new nuclear power plants. By engaging with the Chinese in matters related to nuclear safety, nuclear security, and human capital development, the decades of U.S. experience in these key areas can be used to influence their programs, helping to make a higher quality global nuclear industry in terms of safety, security, and efficient operations. Furthermore, through academic collaboration, U.S. and Chinese universities can work together in producing the future nuclear workforce. This has a dual benefit of inculcating the concept of a nuclear safety culture on an international level and creating networks among students. This "investment" will result in connections at a personal level that will endure over professional careers and last for decades. The benefit to the U.S. from these ties can be immense. There are examples in which these types of connections have been beneficial with engagement with other countries.

Of course, there are potential pitfalls in collaborating with the Chinese. The principal pitfall is the loss of intellectual property (IP). The Chinese are masters of absorbing IP and furthering it through their vast array of institutes and RD&D programs to rapidly bring it to commercialization while eventually pushing out foreign partners. They gather a tremendous amount of IP from commercial vendors through technology transfer programs that are typically a part of new reactor sales contracts. Given their large budgets to develop enhanced LWRs and advanced reactors, they can utilize U.S. IP developed over decades to bring a technology to the demonstration phase in a much shorter time. This is currently being exhibited by the Chinese with the HTGR and the molten salt technologies. This potential pitfall must be recognized in any collaboration with the Chinese and proper protections instituted, e.g., through commercial technology transfer agreements and DOE 810 authorizations.

The U.S. is engaged in both bilateral and multilateral collaboration with China through the following vehicles:

<u>Bilateral programs</u>

- Peaceful Uses of Nuclear Technology (PUNT),
- U.S. – China Bilateral Civil Nuclear Energy Cooperative Action Plan, and
- DOE – China Academy of Sciences (CAS) Collaboration.

<u>Multilateral programs</u>

- International Framework for Nuclear Energy Cooperation (IFNEC), and
- Generation IV International Forum (GIF).

<u>Charge to the NEAC International Subcommittee (February 2015)</u>

The NEAC International Subcommittee is requested to review the existing bilateral and multilateral nuclear collaboration between the U.S. and China, and make recommendations as to potential approaches and mechanisms to increase the effectiveness of this collaboration to support U.S. Government objectives and initiatives, in particular as they relate to RD&D and the U.S. industry. As part of this review, the risks of collaboration should be considered and recommendations made to minimize any potential negative impact on U.S. interests. Also, recommendations are requested to enhance the benefits of continued and/or additional collaboration.

NEAC International Subcommittee Activities

The International Subcommittee met on May 6-7, 2015 and again on October 29-30, 2015, in Washington DC, to obtain input from a variety of sources, including the Department of Energy, National Laboratories (INL, ORNL, and ANL), universities (UC Berkeley, MIT, Texas A&M, and University of Michigan), the Nuclear Regulatory Commission, and the commercial nuclear industry (Westinghouse Electric Co., NuScale Power, Fraser Energy Consulting, and Lightbridge). The agendas for these two meetings are included at the end of this report.

The information obtained was used to provide input to the Subcommittee members to answer the Charge as requested. The input from these interactions appeared to be generally consistent and thorough, allowing the Subcommittee to state the Findings and make the Recommendations listed below. It should be noted when considering these Findings and Recommendations that the situation is rapidly changing in China with respect to commercial nuclear power. The capabilities of the country to implement nuclear projects have grown in just a few years. The number of entities who are authorized to implement these projects has expanded to three major players with substantial resources. The country is now looking externally into the international market to both build and finance projects, while moving rapidly with their domestic projects.

Findings by the Subcommittee

1. The U.S. and China have a real and tangible shared interest in addressing climate change. This can be a cornerstone upon which to build energy initiatives on a broad basis and, in particular, in nuclear energy.
2. DOE can be an enabler in international nuclear energy collaboration. It provides a non-threating venue because of its primary mission of nuclear energy R&D rather than commercialization and sales. This can be utilized to help further USG policy objectives more broadly than currently seen.
3. Continued close cooperation with China in commercial nuclear energy for both domestic and international projects will benefit U.S. companies, will further U.S. policy interests, and will create domestic jobs because of the proven reputation, innovative technologies, and historical expertise that the U.S. brings to such collaborative initiatives. It appears that the Chinese view collaboration with the U.S. as low risk – they trust us because of the integrity

of U.S. scientists and the USG. However, given past experience of many industrial partners with the Chinese, the benefits to our industry are likely to be short term if we do not advance our own technologies and foster domestic production.

4. U.S. policy could benefit from a closer working relationship with China in the area of nuclear export controls and in enhanced interactions on other aspects of nuclear non-proliferation. The U.S. and China have basic shared interests in seeing that nuclear energy is safe, proliferation resistant, and that there is a manageable method for waste disposal. U.S. laboratory cooperation with China on IAEA safeguards and cyber security for reactor systems would also be beneficial for both countries.
5. U.S. commercial companies appear to have a good grasp of the risks associated with IP control when collaborating with Chinese entities. In the major programs, e.g., the AP1000 deployment projects, proper treatment of IP holds a prominent place in project reviews. For the larger companies, very thorough procedures are in place to carefully monitor and control where the IP is used. In addition, the Department of Commerce's International Trade Administration (ITA) has excellent training and software tools to help smaller companies understand and manage the risks of IP when cooperating with the Chinese.
6. Finally, the USG should appreciate, as part of its long-term strategic approach to nuclear energy, that China views collaboration with the U.S. and with industry in this country as being more important and more critical than does the U.S. This is because China clearly seeks to be a global supplier of nuclear technology. Working with the U.S. is a key component in establishing credibility in the international market place. This strategy is accomplished through initiatives ranging from sending students to study here to creating business arrangements with companies in the nuclear supply chain. While such collaboration will strengthen China as a worldwide competitor, it also serves to achieve U.S. goals in safety, security, nonproliferation, and effective use of nuclear energy and to reduce the global emissions of CO_2.

Recommendations by the Subcommittee

1. Nuclear power should be treated as a strategic matter and not be handled like other energy sources; China is certainly taking this approach. As such, the ***DOE should develop a strategy for international collaboration in the peaceful uses nuclear energy*** that is more than simply accepting opportunities as they arise. Today, collaboration is performed in silos that are not coordinated. The coordination of activities under the auspices of such a plan across USG agencies would be the responsibility of the White House NSC, but DOE can be the principal drafter of this strategic plan in cooperation with other U.S. agencies.
2. ***DOE should look for opportunities for its laboratories, universities, and/or U.S. vendors to perform analytical collaborative benchmark***

problems (similar to those periodically performed under the auspices of the IAEA) on both LWR commercial reactor designs and advanced reactors to maintain critical skills and keep abreast of the latest Chinese designs. Under PUNT activities, the Chinese and U.S. have agreed to do joint PRA work on the CAP1400 design, a variant of the AP1000 being designed by the Chinese. This is the type of work that can help ensure new Chinese designs meet the highest international standards of safety.

3. Understanding the importance for the USG to remain involved in many aspects of nuclear energy globally, nevertheless the ***DOE should decide which of the various reactor technologies make the most sense from a U.S. policy perspective and channel the vast majority of laboratory and other resources into those areas***. Of course, peer-to-peer collaboration will take place as normally occurs in the conduct of scientific and engineering inquiry. These activities are already performed in compliance with export control rules. However, DOE should encourage collaborations that further the goals in the strategic plan through use of its considerable resources.
4. **What the Chinese do with derivative U.S. technologies, e.g., CAP1400, must be carefully monitored.** It is not known to what extent U.S. companies will be involved as such derivative technologies are deployed domestically and/or internationally. The U.S. NRC has not reviewed the changes going from AP1000 to CAP1400, so the safety characteristics are still unknown. The companies that transfer technology to the Chinese have responsibility to monitor derivative designs to protect their IP. **The DOE in its broader reach through collaborative R&D should consider ways of monitoring this also.**
5. The U.S. should not be giving its expertise or IP away simply for the sake of collaboration. ***The DOE should be looking to establish a "forward looking" collaborative approach with the Chinese that credits all the past RD&D that it has supported in advanced technologies***. It appears to the Subcommittee that the new solid fuel molten salt concept has considerable promise in this regard. With a significant Chinese-funded CRADA already in existence with ORNL and other collaborations likely with MIT and the University of California Berkeley, this technology is prime for further leveraging and encouragement by the DOE.
6. The ***U.S. university system should be treated as a strategic asset and an extremely valuable component in the engagement with China***. Universities should be provided with the funding and the policy guidance to effectively support USG policy objectives. University nuclear engineering program links with Chinese institutions are already broad and growing, but generally occur on an ad hoc basis due to individual institutional or faculty initiatives. To encourage collaboration with Chinese universities, DOE could provide "top down" guidance and support (while not interfering with academic freedom). For example, DOE could make available resources sufficient as incentives for U.S. universities to collaborate on building bridges to Chinese universities through exchange programs in the nuclear energy area. Also, additional evaluation credit could be given for NEUP proposals

that include collaboration with Chinese universities/entities. The programs at the University of Michigan, University of California Berkeley, MIT, and Texas A&M are good examples of what can be done and what has been effective. The 100,000 Strong China initiative of the State Department launched in May 2010 is a program that can be used to support specific U.S. interests. Increasing student exchanges in nuclear energy could have significant positive medium and long-term benefits to the U.S. As noted earlier, students from China studying in nuclear engineering programs in this country are exposed to U.S. standards and practices, and gain an expanded appreciation of the importance of nuclear safety culture. Furthermore, the university interactions offer the USG and U.S. companies an additional qualitative and intangible benefit because many Chinese officials and leaders either studied at U.S. universities or have children who are doing so. This creates a unique tie and a favorable environment for engagement. This is a strong advantage for the U.S. that is virtually unmatched by any other country.

7. Greater collaboration between the NRC and the Chinese National Nuclear Safety Authority (NNSA) would be beneficial to both countries in helping to ensure that the highest level of safety is promoted globally. Currently, there is very good collaboration on AP1000 projects (4 units in China and 4 in the U.S. where information and experience is flowing in both directions) through multi-lateral (MDEP) and bi-lateral agreements. An open question is the capacity of the Chinese regulator, NNSA, to approve new designs (which is generally accomplished in less than 2 years) and provide oversight for the ever-increasing fleet of new reactors (the Chinese NNSA has only about 400 staff today, with technical support coming from the National Nuclear and Radiation Safety Center). The ***DOE should continue to look for opportunities under their various programs where the NRC could be "brought along" to help provide capacity training to the Chinese NNSA in selected areas that could improve the overall regulatory environment in China.***

8. Another R&D area in which the Chinese might be interested is accident tolerant fuel. Since the U.S. also has a substantial lead in this area, it is at an advantage in interactions with the Chinese; thus, they should see positive value in collaborating with the U.S. Finally, an area in which the U.S. excels is in the use of state of the art reactor system modeling and safety codes. Possibly, collaboration on advanced modeling and simulation systems would be viewed as a mutually beneficial R&D activity.

9. ***If a serious deployment initiative is not launched in the U.S. for light water-cooled SMRs, collaboration with the Chinese on design finalization and deployment of this U.S. born technology could be a way of ensuring that the U.S. retains influence, market share, and some significant domestic manufacturing in this new technology.*** In doing this, we must be careful to manage the ownership of IP to maximize U.S. content and a return on the DOE investment in its development. The DOE should have some

control of such collaborations because of the DOE-initiated cost-share funding program.

10. The Chinese, as is the U.S., are struggling with what to do with spent nuclear fuel/high level waste. Although their stated long-term strategy (developed through many years of interacting with the Russians and French) includes fuel reprocessing and recycling of plutonium in fast reactors, they are now questioning the economics of this strategy. They understand that a reprocessing plant will cost upwards of US $20 billion and that the other infrastructure required, e.g., a MOX fuel re-fabrication plant, will be very expensive. ***DOE should promote collaboration with China on the open cycle and support companies that supply open fuel cycle technologies.*** **Joint RD&D on the safety and economics of long-term dry storage (e.g., at an away from reactor facility) could be an appealing approach to promoting this strategy.** Nonetheless, since there remains strong interest on the side of the Chinese in reprocessing and a closed fuel cycle, staying engaged through national laboratory interactions would allow the U.S. to remain abreast of their developments for potential future strategic initiatives.

NEAC International Subcommittee Meeting
May 6-7, 2-15
Agenda

May 6, 2015

1:00 pm Introduction and Review of Charge
Regis Matzie, Chair

1:30 pm Opening Remarks and Review of Existing Multilateral and Bilateral Engagements with China
Bob Boudreau, Associate Deputy Assistant Secretary for International Nuclear Energy Policy and Cooperation

2:00 pm U.S. National Laboratory Collaborative R&D with China
Invited Speakers: Jordi Roglans-Ribas, ANL
Harold McFarlane, INL
Larry Satkowiak, ORNL

3:30 pm Challenges in US-China Nuclear R&D Cooperation
Joyce Connery, Director, Nuclear Energy Policy, National Security Council

4:00 pm Subcommittee Discussion
Regis Matzie

4:30 pm Briefing on China PUNT
Ed McGinnis, Deputy Assistant Secretary for International Nuclear Energy Policy and Cooperation

5:00 pm Adjourn

May 7, 2015

8:30 am U.S. University Collaborative R&D with China
Invited Speakers: Lumin Wang, University of Michigan
Mujid Kazimi, MIT
Lee Peddicord, Texas A&M

10:00 am Regulatory Issues in U.S.-China R&D Cooperation
Invited Speaker: Jack Ramsey, Senior Level Advisor
Office of International Programs, U.S. Nuclear Regulatory Commission

10:30 am Break

11:00 am Commercial Company Collaborative R&D with China
Invited Speakers: Mark Fecteau, Westinghouse
Seth Grae, Lightbridge

12:00 pm Lunch

1:00 pm Subcommittee Deliberations

4:00 pm Adjourn

U.S. Department of Energy
Atoms for Peace Conference Room, 5A-118
1000 Independence Ave, SW Washington, DC 20585

DOE NEAC International Subcommittee Meeting
October 29-30, 2015

Room 5A-118, Atoms for Peace Conference Room
U.S. Dept. of Energy, 1000 Independence Ave., SW Washington, DC 20585
Call In Number: 202-287-6351

Agenda

<u>Thursday, October 29</u> (8:30 am start)

1. Introductions, Review of Previous Meeting, Agenda, and Meeting Objectives — 8:30 - 9:00 am
   Regis Matzie, Chair, NEAC International Subcommittee

2. DOE/USG Status Update of Cooperation and Related Developments — 9:00 - 10:00
   - US-China Civil Nuclear Cooperation, Status of the Global Civil Nuclear Market
     Mike Wautlet, Director, Nuclear Energy Policy, National Security Council
   - DOE/NE Cooperation with China
     Ed McGinnis, Deputy Assistant Secretary for International Nuclear Energy Cooperation
   - NNSA Update of the China 123 and Part 810s
     Rich Goorevich, Senior Policy & Regulatory Advisor, NNSA/NA-24

3. Review of Chinese New Plant Build Program — 10:00 - 11:00
   Ron Hagen, Office of Multilateral Cooperation
   - Domestic and Export Builds
   - Designs
   - Modifications of Imported Designs

   Review of Chinese Advanced Reactor Development Program
   Will Lahneman, Office of Bilateral Cooperation
   - What, Where, When, Why, and with Whom?

4. NRC's Cooperation with China's NNSA
   11:00 - 12:00pm
   Lawrence Burkart, Licensing Branch 4 (AP1000), Division of New Reactor Licensing
   Kirk Foggie, Office of New Reactors

Break for Lunch
12:00 - 1:00

5. Value Proposition of Collaboration with China and Risks 1:00 - 2:00
    - Chinese Perspective
      K.P. Lau, Fraser Energy Consulting

    - What are the Real Intellectual Property Risks
      2:00 - 4:00 Commercial Companies Perspective
      Mark Fecteau, Westinghouse
    - National Laboratories Perspective
      David Holcomb, Oak Ridge National Laboratory
    - U.S. Government (Department of Commerce)
      Jon Chesebro, DOC/ITA
    - University Perspective
      Per Peterson, University of California Berkeley

6. NEAC International Subcommittee Discussion
   4:00 4:30 pm

7. Adjourn)

<u>Friday, October 30</u> (8:30 am start)

8. Value Proposition of Collaboration with China and Risks 8:30 – 9:30 am
   U.S. Perspective
   Chris Colbert, NuScale Power

9. How Can the U.S. Build on the Primary Mission of DOE/NE -
   9:30 – 10:15
   Research, Development, and Demonstration (RD&D)
   DOE/NE

Break for Lunch
10:15 – 10:30

10. Subcommittee closed session
    10:30 -12:00 pm

11. Adjourn (12:00 pm)