Workshop on Nuclear Power Growth: Advanced Technologies
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- I support a strong nuclear energy R&D program to enable nuclear power to play a very significant role in reducing U.S. and global carbon emissions.

- In the near to medium term—the next 20 years—any expansion of nuclear power will have to be based on existing technologies—in particular, advanced light-water reactors and the associated facilities to produce fresh fuel and manage spent fuel. R&D can play little role in facilitating an expansion of nuclear energy over this timeframes—and certainly no transformational role in substantially changing the characteristics of nuclear power. That's an important point, nuclear power will have to begin substantial growth within this timeframe if it is to contribute significantly to carbon mitigation. And so we have to consider how to move forward most intelligently with the technologies we have, rather than pretend there will be a technical fix to the challenges posed by the expansion of nuclear power.

- Looking to the longer term, advanced technologies have the potential to increase reactor safety and decrease the overall cost of nuclear-generated electricity, and perhaps to increase proliferation resistance or facilitate radioactive waste management.

- It can be difficult to define some of these goals and to evaluate alternative options. Cost is relatively straightforward to evaluate, and elaborate techniques have been developed to quantify reactor safety, but proliferation resistance has proven very difficult to define, and even more difficult to be confident that a new approach would improve or degrade proliferation resistance. And although we can compare waste mass or volume or heat loading or toxicity, none of these appear to have anything to do with the "waste problem"—the inability to dispose of either spent fuel or high-level waste.

- It's also important to recognize that there are likely to be tradeoffs among these goals. We're unlikely to find a solution that is cheaper, safer, more proliferation resistant, and that improves waste management. And so it's vital to have a sense of which goals are more important, and which are less important.

- I believe that cost reduction is most important but the least talked about in settings such as these. It's most important simply because a new technology won't be deployed in a free market unless it is economically competitive. We can talk all we want about the possible merits of fast reactors for transmuting waste, but they won't be built so long as they are more substantially expensive than LWRs. The only alternative is a command-and-control approach where governments decree that certain things be built in certain numbers.

- Improved waste management is, in my mind, clearly the least important of the four goals for nuclear R&D, but it receives a lot of attention. It's the least important because we already know how to dispose of spent fuel or high-level waste very cheaply and very safely. Although, as I mentioned earlier, we've so far been unable to dispose of waste, we also have a cheap and safe interim solution: dry-cask storage. Reducing the cost of waste disposal will have no impact on the overall economics of nuclear power. Similarly, the hazard posed by a

TW-hour's worth of waste is already so low that reducing it by an additional factor of 10 or 100 or even 1000 to people 100,000 or 1 million years in the future isn't a worthwhile goal. The waste disposal problem is political, not technical, and I think we are deluding ourselves if we believe that current objections to waste disposal will be substantially attenuated if we reduce the amount of waste generated or its long-term toxicity. I am optimistic that these objections will be overcome if we continue on our current path. The experience with WIPP is instructive: major protests over the first shipment of waste, after which shipments become routine and everybody forgets about it. The same pattern is likely with Yucca Mountain. After waste is emplaced and everyone gets used to it, increasing the capacity of YM by a factor of ten or siting a new repository on the next ridge will be much easier than deploying a new set of separation and transmutation facilities.

- Improved safety is more important. It might seem that current technologies are safe enough. Advanced LWRs are estimated to be at least ten times safer than current LWRs, with a risk of a release of radioactivity large enough to cause off-site casualties on the order of one in a million per year. But this depends on well-trained operators a good nuclear safety culture and the proper maintenance and operation of the reactor, which will be difficult to achieve in many parts of the world, and it does not take into account the risk of sabotage or terrorist attack. And so it is worthwhile to explore technologies that would be far more forgiving of operator error and less vulnerable to terrorist attack.

- Like many people here, my greatest concern is that an expansion of nuclear energy not contribute to the spread of nuclear weapons. But, unlike cost and safety, I'm afraid that the potential contribution of advanced technology to reducing the risks of proliferation is limited.

- All fuel cycles involve materials or processes that can be used for weapon purposes. There may be advances in safeguards that can detect the diversion of smaller quantities of materials in a more timely manner. There may also be advances in the ability to detect clandestine facilities, although I'm very pessimistic that this will be possible for centrifuge enrichment facilities. But there will always be the breakout problem, and the political tensions that it generates. As IAEA director general Mohammed El'Baradei has said, any country with an enrichment or reprocessing facility is a virtual nuclear weapon state. And so it would seem that the only way to reduce this risk is to limit the spread of the most dangerous activities, know-how, technologies, and facilities. That is largely a political rather than a technical enterprise.

- That's what GNEP promises to do—limit the spread of enrichment and reprocessing to a handful of supplier states. But the key to GNEP isn't proliferation-resistant reprocessing or fast reactors. The key is to persuade the current supplier states to provide the incentives that would be necessary to persuade other countries not to enrich uranium or reprocess spent fuel. Transmutation strikes me as a Rube Golderg approach to proliferation resistance: we take 20 years to develop S&T technology, make it cheap enough so that fuel-cycle states will deploy it and accept foreign spent fuel but not so cheap and attractive that everyone wants it, then wait another 20 years to build up capacity. I agree that spent-fuel take-back is a vital incentive, but that's something we can do today. The barriers to take-back are political, not technical, and I don't see S&T as helping to lower the barriers. My guess is that we would make more progress on this agenda—both in supplier states and user states—if we framed this as part of a serious effort to establish the basis for a prohibition on nuclear weapons.

- The aspect of GNEP that I find most curious is the effort to increase the proliferation resistance of reprocessing. Why do we care about this if reprocessing is limited to a handful of "safe" countries—mostly the current nuclear-weapon states? It's unlikely that reprocessing can ever be made substantially more proliferation resistant than Purex. Facilities that produce plutonium that is mixed with uranium or transuranics or rare earth fission products can be modified to produce pure plutonium, or plutonium can be separated from the product in a separate process. The more complicated processes involving more radioactive products are likely to complicate material accountancy, increasing MUF and possibly decreasing confidence in non-diversion in states such as Japan.

- There may be an important role for advanced technology, however. I am intrigued by the potential of small, sealed-core reactors with long core lifetimes to transform the proliferation characteristics of nuclear power. The concept is part of GNEP but has received essentially no funding. The reactors would be about one-tenth the size of today's advanced LWRs—on the order of 100 MW. The reactors would be loaded with fuel with a lifetime of 20 or 30 years and would not be suitable for refueling; the reactor would be returned to the manufacturer along with the spent fuel, and the reactor and possibly spent fuel could be recycled. There would be no need for the user country to have any fresh fuel production or spent fuel management capacity. The smaller reactors would be more suitable for developing countries, the lower power density would make the reactors far more forgiving to operator error, and they could be installed below grade to minimize vulnerability to attack.

- A key problem is cost: poor economies of scale would likely make the unit cost per kilowatt for a small reactor twice as great as a large LWR. There might be a niche market for small and expensive reactors, but that won't have much impact. Based on comparisons with other industries, it is plausible that the poor economies of unit cost could be overcome by mass production—building a hundred small reactors on an assembly line, much like Boeing builds aircraft. The interesting thing about the concept is that it would work only if production is concentrated in a few countries or companies who could make the required investment. This would naturally concentrate not only reactor production but also fuel cycle activities, much like aircraft production has been concentrated into two companies—Boeing and Airbus—by market forces.

- If I were designing a nuclear R&D program, I'd invest heavily in small reactors.