The Industrial Physics Forum 2007: The Energy Challenge

Room: 602/603 - Session IPF-MoA

Nuclear Energy

Moderator: J. Hobbs, American Institute of Physics

2:00pm **IPF-MoA1 Status of Fusion Power**, ***R.J. Hawryluk***, Princeton Plasma Physics Laboratory **INVITED**

Fusion is an attractive long-term form of nuclear energy. Experiments on magnetically confined plasmas in the 1990's demonstrated not only the ability to confine plasmas with the temperatures required for a fusion reactor but also produced significant fusion power (up to 10.7 MW in the Tokamak Fusion Test Reactor and 16.1 MW in the Joint European Undertaking for <1sec) using deuterium-tritium fuels. This major step, together with results from a worldwide research effort, has provided confidence in the design of the International Thermonuclear Experimental Reactor (ITER) to produce 500MW (thermal) of fusion power for 400 sec. ITER is an international experiment whose partners are the European Union, India, Japan, the People's Republic of China, the Republic of Korea, the Russian Federation and United States. ITER aims to demonstrate the scientific and technical feasibility of fusion power and will be constructed in Cadarache, France. For the first time, the fusion reactions will provide the majority of the heating for the plasma with an energy gain >10. The design of ITER has identified important scientific and technology issues, which are currently being addressed in facilities around the world. However for a fusion demonstration power plant, further progress on the underlying science and technology is required to achieve ~2500 MW (thermal) continuously with a gain >25 in a device whose size is comparable to ITER. This requires addressing issues associated with plasma boundary due to the higher power and plasma stability due to the need to sustain even higher pressure plasmas at the magnetic field of ITER. Furthermore, efficient continuous operation requires minimizing the external power for controlling the plasma. Experiments on the three main approaches to magnetically confining a plasma, the advanced tokamak, the spherical tokamak, and the stellerator, in parallel with the design and construction of ITER, are exploring innovative solutions required for a demonstration power plant. The advanced tokamak relies on active instability control and a combination of external current drive to increase the fusion power and achieve continuous operation. The spherical tokamak achieves higher fusion power at a given size and magnetic field by decreasing the ratio of the plasma major radius to minor radius. The stellarator is passively stable and does not require external power to drive the plasma current continuously. This research is supported by the U.S. Department of Energy under Contract Number DE-AC02-76CH03073.

2:40pm **IPF-MoA3 The Role of High Temperature Gas Reactors in the Future Development of Nuclear Power**, ***E.M. Campbell***, *F. Venneri*, *A.S. Shenoy*, *C.J. Hamilton*, General Atomics **INVITED**

Given the increased worldwide demand for energy, the desire for energy security and the need to reduce anthropenic influence on the earth's climate, it appears certain that there will be a significant increase in the role of nuclear power. While the early expansion of nuclear power will be dominated by light water reactors with modern safety features and improved economics, advanced Generation IV reactors such as high temperature gas reactors will become increasingly important following the demonstration of commercial scale prototypes in the next decade. High temperature gas reactors have many attractive features arising from the use of inert helium gas as a coolant, graphite as a moderator and fuel encapsulated in a robust TRISO ceramic coating. These features enable the reactors to be passively safe — they employ no safety features with an emergency core coolant reservoir — while not sacrificing attractive economics, and at the same time producing output temperatures in excess of 900ºC. Such temperatures allow for flexibility in siting (even in regions with little or no water availability), and the efficient production of electricity as well as numerous process heat applications such as the large scale production of hydrogen and economic desalination. These latter applications which to date have not used a "nuclear heat source" will become increasingly important in the future and are made possible only by these Generation IV reactors. The fuel form in these reactors enables a wide range of fission fuels to be deployed including uranium, thorium, and actinides including those from spent fuel, allows for extremely deep burn, and provides increased barriers for proliferation. In this presentation the role of gas reactors in an expanding nuclear market will be discussed. Their unique features will be presented including passive safety, economics, modularity, fuel and siting flexibility, applications and symbiosis with other reactors such as fast sodium reactors. An attractive scenario for the large scale deployment of these reactors which addresses fuel availability and waste will also be included.

*Work supported by General Atomics internal funding.

3:40pm **IPF-MoA6 Sustainable Nuclear Energy Production and Nuclear Waste Management**, ***M. Peters***, Argonne National Laboratory **INVITED**

The world energy demand is increasing at a rapid pace. In order to satisfy the demand and protect the environment for future generations, future energy sources must evolve from the current dominance of fossil fuels to a more balanced, sustainable approach to energy production. The future approach must be based on abundant, clean, and economical energy sources. Therefore, because of the growing worldwide demand for energy and need to minimize greenhouse gas emissions, there is a vital and urgent need to establish safe, clean, and secure energy sources for the future. Nuclear energy is already a reliable, abundant, and carbon-free source of electricity for the U.S. and the world. In addition to future electricity production, nuclear energy could be a critical resource for "fueling" the transportation sector (e.g., process heat for hydrogen and synthetic fuels production; electricity for plug-in hybrid and electric vehicles) and for desalinated water. Nuclear energy must experience significant growth to achieve the goals of our future energy system. The most significant technical challenge that must be addressed to allow the necessary expansion is safe, secure, and sustainable nuclear waste management. The nuclear fuel cycle is a key concept when discussing a sustainable future for nuclear energy. The nuclear fuel cycle is a cradle-to-grave concept starting from uranium mining to fuel fabrication to energy production to nuclear waste management. At first order, there are two approaches to the nuclear fuel cycle. An open (or once-through) fuel cycle, as currently planned by the United States, involves treating spent nuclear fuel (SNF) as waste with ultimate disposition in a geologic repository. In contrast, a closed (or recycle) fuel cycle, as currently planned by other countries (e.g., France, Russia, Japan), involves treating SNF as a resource whereby separations and recycling of transuranics (TRU's) in reactors work with geologic disposal. Open fuel cycles require multiple geologic repositories whereas closed fuel cycles can reduce the volume and toxicity of waste, conserve uranium resources, and provide additional energy. Nuclear waste management and lack of a closed fuel cycle are principal impediments to the future viability of the nuclear energy option. In the advanced, closed fuel cycles that are currently being developed in France, Russia, Japan, the United States, China, and India, SNF would be sent to a reprocessing plant where its major constituents are separated into several streams: a TRU stream, to be recycled, and several other streams, including a "clean" uranium waste stream (note that this uranium could be recycled as part of future nuclear fuels), and waste streams containing the fission products. The TRU's are fabricated as fresh nuclear fuel, to be irradiated again in a fission reactor, ideally a fast-neutron system. Approximately 30% of the TRU's are fissioned each time the fuel is irradiated in a low conversion-ratio fast reactor. The remaining 70% stay in the cycle until they are fully fissioned. Even a closed fuel cycle requires a geologic repository to dispose of long-lived fission products and potentially very small amounts of TRU's, the latter being from minor separations process losses. The volume and toxicity of waste requiring geologic disposal is reduced significantly in a closed fuel cycle; however, the doses from the encased radionuclides still require long-term isolation in durable waste forms in geologic repositories. Engineering and technology development will improve the reliability and cost effectiveness of nuclear energy and closed fuel cycle approaches. However, the rapid expansion of nuclear energy technologies required to satisfy the needs of the future will require breakthroughs that will only be possible through a coupling of applied and basic science and engineering. In particular, advanced modeling and simulation tools and approaches integrated with engineering and facilities design will be the avenue for using basic science insights to further the prospects for sustainable nuclear energy and nuclear waste management.

4:20pm **IPF-MoA8 Nuclear Energy Policy**, ***D. Hill***, Idaho National Laboratory **INVITED**

The U.S., through the National Energy Policy and the landmark legislation, Energy Policy Act of 2005, has adopted policies that support a diverse clean energy portfolio, including expanded use of nuclear energy. The nuclear industry is pursuing the business and licensing cases for building at current count, more than thirty new plants over the next decade. Government is sharing the risk that first movers of these new plants will face by cost-sharing the license preparation effort, by sponsoring production tax credits for the first 6,000 MW of new nuclear generating capacity, and through loan guarantees for the low emissions technologies. Additionally, last year, the Bush Administration proposed the Global Nuclear Energy Partnership, a multinational initiative that focuses on developing the technologies and infrastructure that will be needed to support anticipated global expansion of nuclear energy. A key element, advanced recycling of spent nuclear fuel, would address the waste burden associated with the once-through fuel cycle that relies extensively on surface storage and eventually, deep geologic disposal of spent nuclear fuel. Recycling would recover and reuse materials contained in spent fuel by separating them from the waste products without producing plutonium. This paper examines nuclear energy policy in the U.S., outlook for nuclear energy in the U.S. and the world, reasons to move toward a closed fuel cycle and U.S. and international progress on development of advanced fuel cycle technology.

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