NanoNuclear
2012

The 2012 NanoNuclear Workshop
June 6-8, 2012

Gaithersburg Marriott Washingtonian Center
Gaithersburg, Maryland

TMS
The Minerals, Metals & Materials Society

Department of Energy
United States of America

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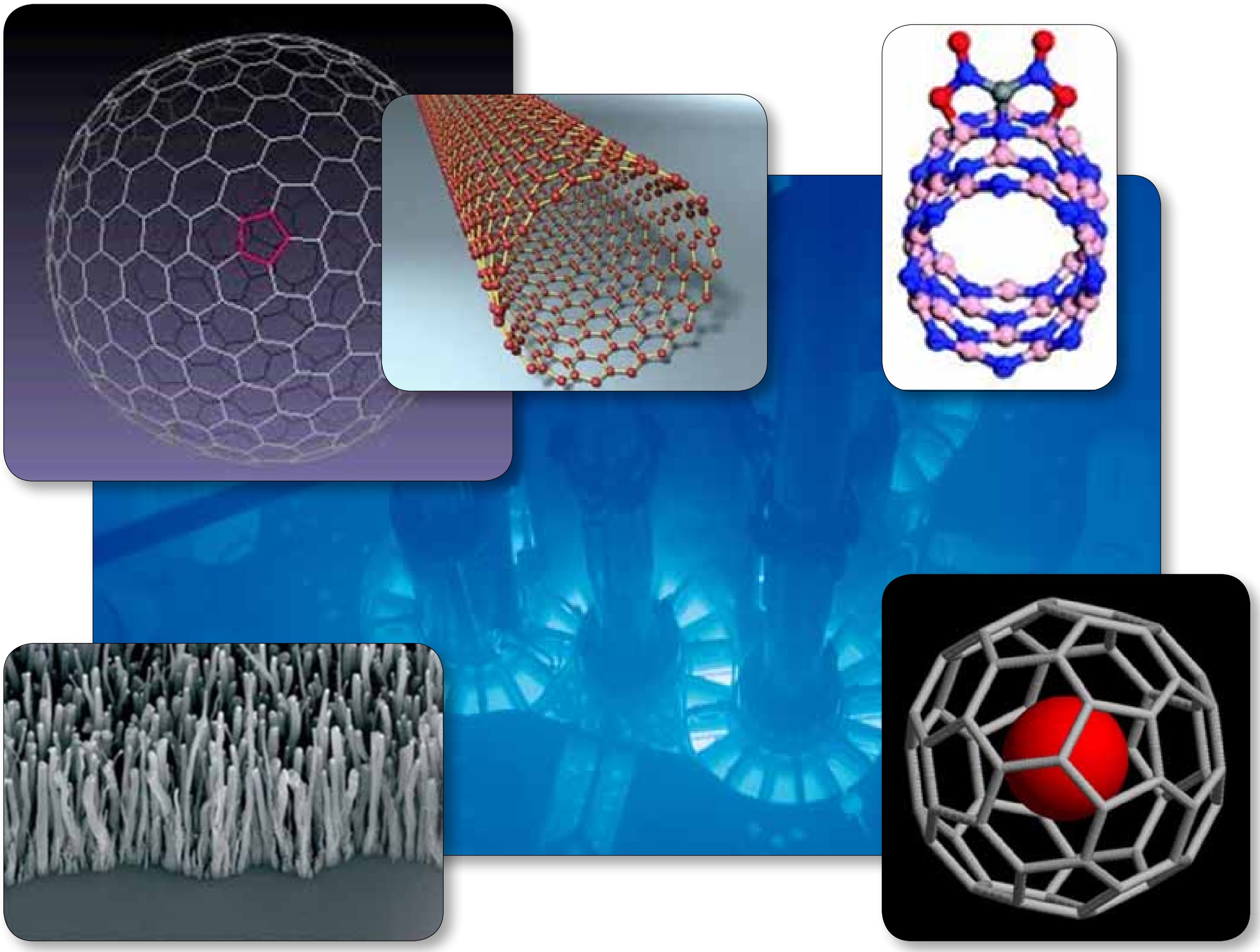


Purpose Statement

NANONUCLEAR
2012

This is the second in a series of linked workshops to begin exploration of the intersection of nanoscience and nuclear technology. Senior nuclear scientists from the DOE National Labs will be directly interacting with researchers renowned for advancements in the field of nanoscience. The objectives are to identify productive lines of research, assess the potential enhancements that could result, determine plausible approaches for conducting the research, and establish metrics for measuring progress and determining success. The results of these efforts will inform national policy development, serve as a roadmap for defining appropriate funding levels, and will define the infrastructure requirements for meaningful development.

There are no a priori guarantees that this unexplored frontier will yield fertile prospects for meaningful work. However, the astounding mechanical, chemical, physical, and thermodynamic properties of nano-structured materials in use in adjacent high tech applications strongly suggests merit in pursuing the inquiry. Likewise, while participation in these workshops offers no guarantee that any particular person, company, or institution stands to reap substantial programmatic roles in nanonuclear research, the path forward (and its distinguishing nuances) will be launched from this platform. This is a pioneering enterprise, pure and simple. How this translates into beneficial enhancements in nuclear technology depends on the insights, imagination, and collaborative spirit of those present at the dawning.

Workshop Agenda

June 6	7:30 AM	Registration, Coffee; Networking	
	8:00 AM	Welcome/Introduction of Key Players	S. Winston
	8:15 AM	Context For Exploring Nano and Nuclear	R. Price
	8:30 AM	Nuclear Energy and the Need for Revolution	P. Lyons
	9:00 AM	US Energy System and Innovation Needs	V. Reis
	9:30 AM	Nano-Technology as a Revolution	V. Colvin
	10:00 AM	Break	
	10:30 AM	Fuel Cycle Technology	K. Pasamehmetoglu
	11:00 AM	Advanced Reactor Technology	R. Hill
	11:30 AM	Nano-technology Overview 1 (History and Status)	D. Mittleman
	12:00 PM	Nano-technology Overview 2	B. Segal
	12:30 PM	Lunch On Own	
		Breakout Sessions	
	2:00 PM	Mechanical Properties/Structures	S. Maloy/J. Sears
	2:00 PM	Chemical Properties/Separations	J. Buelt/T. Nenoff
	2:00 PM	Physics, Nuclear, Thermo-hydraulic Properties	M. Cappiello/TBD
	3:00 PM	Break	
	3:30 PM	Resume Breakout Sessions	
	5:00 PM	Adjourn	
June 7	7:30 AM	Coffee, Networking	
	8:00 AM	Mechanical Properties/Structures	S. Maloy/J. Sears
	8:30 AM	Chemical Properties/Separations	J. Buelt/T. Nenoff
	9:00 AM	Physics, Nuclear, Thermo-hydraulic Properties	M. Cappiello/TBD
	9:30 AM	Break	
	10:00 AM	Resume Breakout Sessions	
	12:00 PM	Lunch On Own	
	1:30 PM	Resume Breakout Sessions	
	3:00 PM	Break	
	3:30 PM	Resume Breakout Sessions	
	5:00 PM	Adjourn	
June 8	7:30 AM	Coffee, Networking	
	8:00 AM	Outbriefs	
	10:00 AM	Break	
	11:15 AM	Recommendations and Next Steps	S. Winston/R. Price
	12:00 PM	Meeting Adjourn	
	1:00 PM	Writers Workshop	Chapter Writers
	5:00 PM	Writers Adjourn	

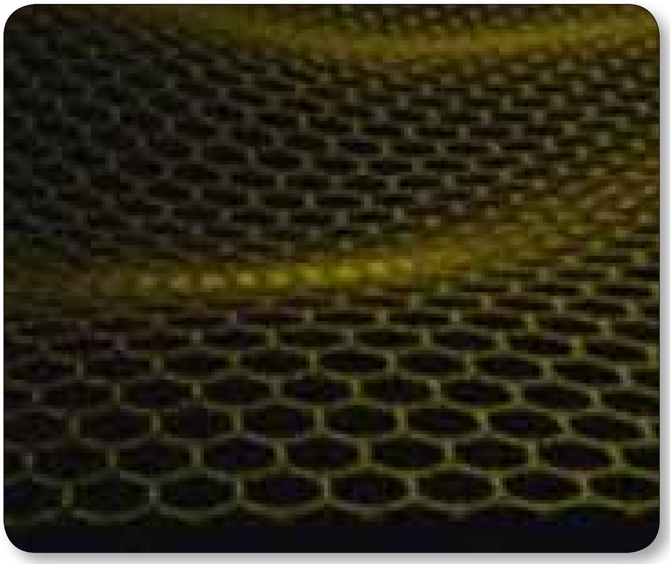
The Advanced Test Reactor (ATR) is a research reactor at the Idaho National Laboratory. This reactor is primarily designed and used to test materials to be used in other, larger-scale and prototype reactors. It can operate at a maximum power of 250 MW and has a "Four Leaf Clover" design that allows for a variety of testing locations. The unique design allows for different flux in various locations and specialized systems also allow for certain experiments to be run at their own temperature and pressure.

The ATR is light water moderated and cooled, with a beryllium neutron reflector. It is pressurized and housed in a stainless steel tank.

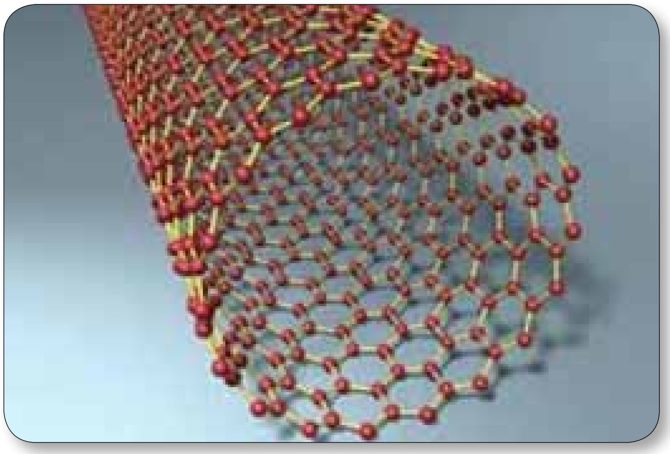
High Flux Isotope Reactor (HFIR)
Oak Ridge National Laboratory
Operating at 85 MW, HFIR is the highest flux reactor-based source of neutrons for research in the United States, and it provides one of the highest steady-state neutron fluxes of any research reactor in the world. The thermal and cold neutrons produced by HFIR are used to study physics, chemistry, materials science, engineering, and biology. The intense neutron flux, constant power density, and constant-length fuel cycles are used by more than 200 researchers each year for neutron scattering research into the fundamental properties of condensed matter.

The neutron scattering research facilities at HFIR contain a world-class collection of instruments used for fundamental and applied research on the structure and dynamics of matter. The reactor is also used for medical, industrial, and research isotope production; research on severe neutron damage to materials; and neutron activation to examine trace elements in the environment. Additionally, the building houses a gamma irradiation facility that uses spent fuel assemblies and is capable of accommodating high gamma dose experiments.

Graphene is an allotrope of carbon. Its structure is one-atom-thick planar sheets of sp2-bonded carbon atoms that are densely packed in a honeycomb crystal lattice. The term graphene was coined as a combination of graphite and the suffix -ene by Hanns-Peter Boehm, who described single-layer carbon foils in 1962. Graphene is most easily visualized as an atomic-scale chicken wire made of carbon atoms and their bonds. The crystalline or "flake" form of graphite consists of many graphene sheets stacked together.

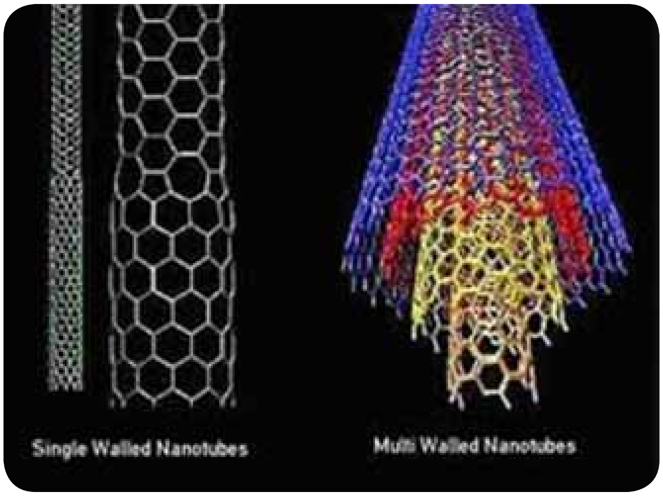


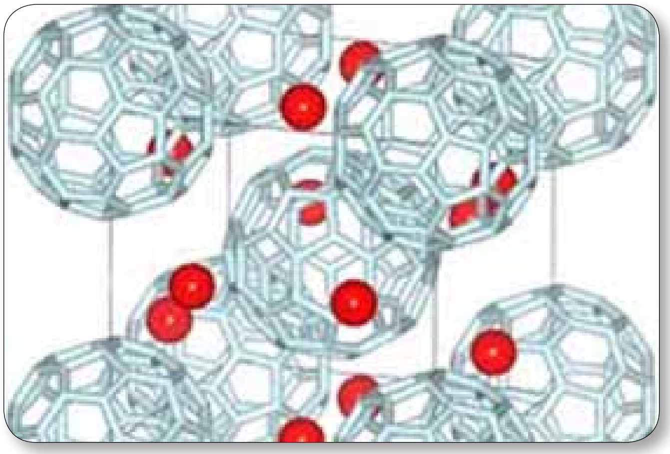
The carbon-carbon bond length in graphene is about 0.142 nanometers. Graphene sheets stack to form graphite with an interplanar spacing of 0.335 nm, which means that a stack of three million sheets would be only one millimeter thick. Graphene is the basic structural element of some carbon allotropes including graphite, charcoal, carbon nanotubes and fullerenes. It can also be considered as an indefinitely large aromatic molecule, the limiting case of the family of flat polycyclic aromatic hydrocarbons.



Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, significantly larger than for any other material. These cylindrical carbon molecules have unusual properties that have been applied to electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials. Nanotubes are members of the fullerene structural family, which also includes the spherical buckyballs, and the ends of a nanotube may be capped with a hemisphere of the buckyball structure. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. These sheets are rolled at specific and discrete ("chiral") angles, and the combination of the rolling angle and radius decides the nanotube properties; for example, whether the individual nanotube shell is a metal or semiconductor. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Individual nanotubes naturally align themselves into "ropes" held together by van der Waals forces, more specifically, pi-stacking.

Applied quantum chemistry, specifically, orbital hybridization best describes chemical bonding in nanotubes. The chemical bonding of nanotubes is composed entirely of sp2 bonds, similar to those of graphite. These bonds, which are stronger than the sp3 bonds found in alkanes, provide nanotubes with their unique strength.

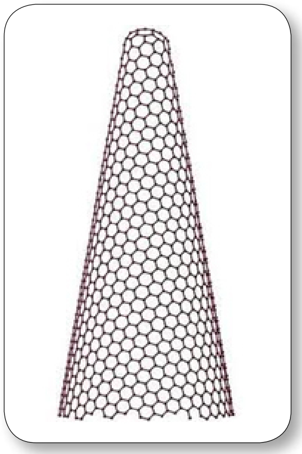


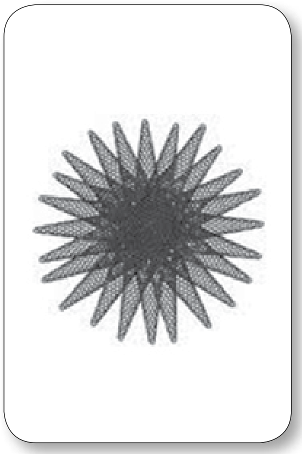


Fullerene or "Buckyball"

A **fullerene** is any molecule composed entirely of carbon in the form of a hollow sphere, ellipsoid, or tube. Spherical fullerenes are also called **buckyballs**, and they resemble the balls used in association football. Cylindrical ones are called carbon nanotubes or buckytubes. Fullerenes are similar in structure to graphite, which is composed of stacked graphene sheets of linked hexagonal rings; but they may also contain pentagonal (or sometimes heptagonal) rings.

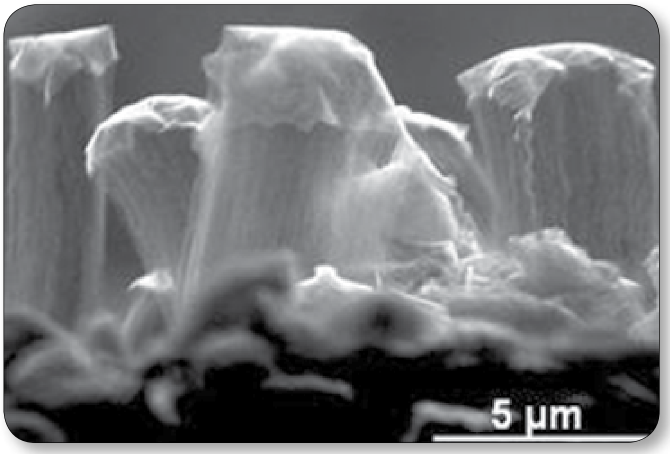
The first fullerene to be discovered, and the family's namesake, buckminsterfullerene (C60), was prepared in 1985 by Richard Smalley, Robert Curl, James Heath, Sean O'Brien, and Harold Kroto at Rice University. The name was an homage to Buckminster Fuller, whose geodesic domes it resembles. Fullerenes have since been found to occur in nature. More recently, fullerenes have been detected in outer space. According to astronomer Letizia Stanghellini, "It's possible that buckyballs from outer space provided seeds for life on Earth."

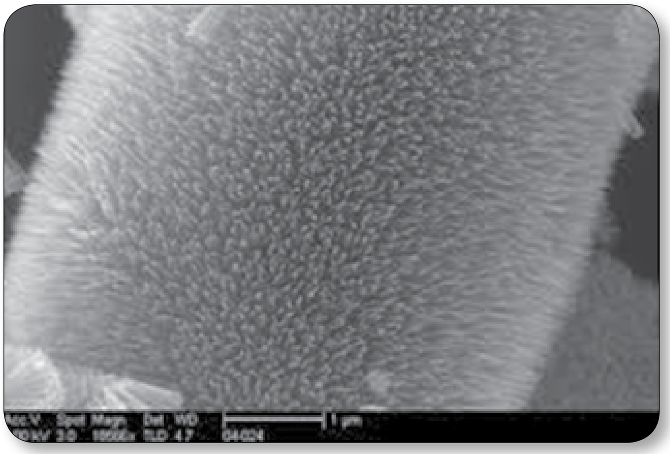




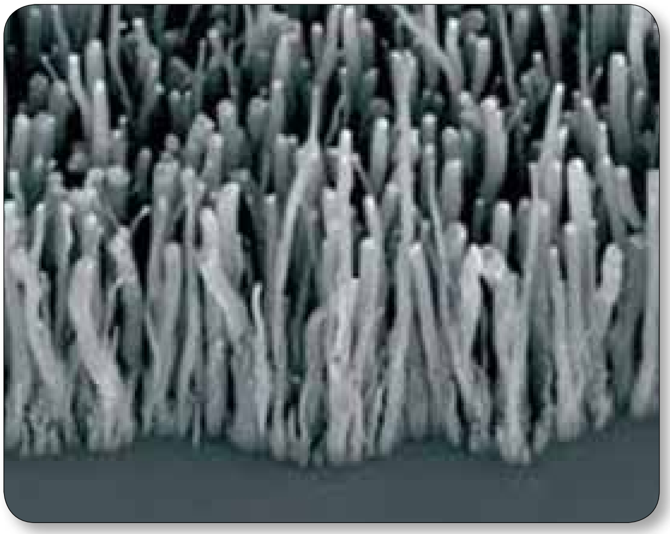
Nanohorns: tubes of graphitic carbon which differ from nanotubes in their "horn-like" shape similar to a sewing thimble giving them numerous applications as both the stiffest and strongest known fibers and because of their unique shape gives them an enormous amount of surface area. The resulting material has found application in proton exchange membrane (PEM) and Polymer Electrolyte (PEFC) fuel cells because they have the dual capability of providing a high surface area conductive layer and open gas paths.

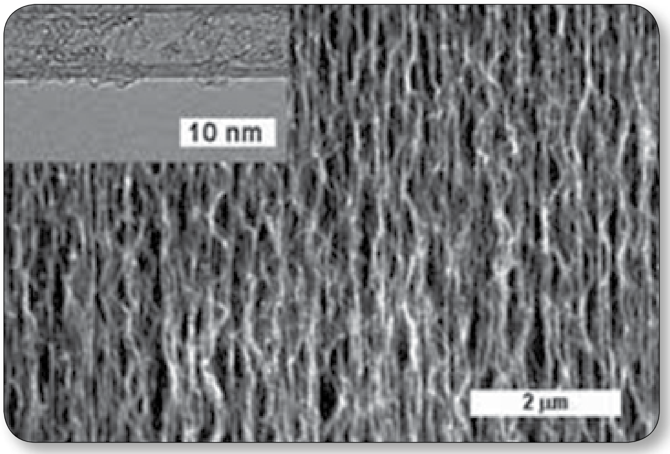
Nanocarpets:

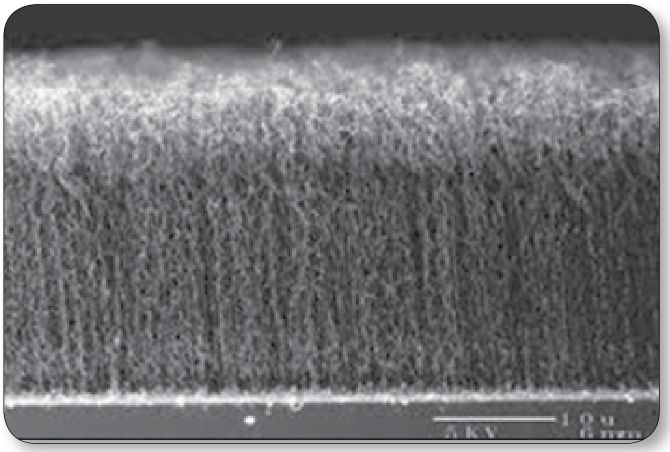




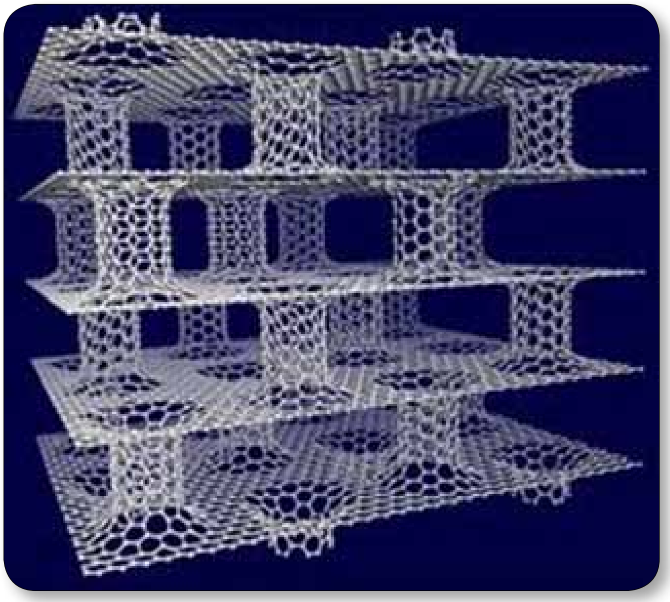
Nanoforests:



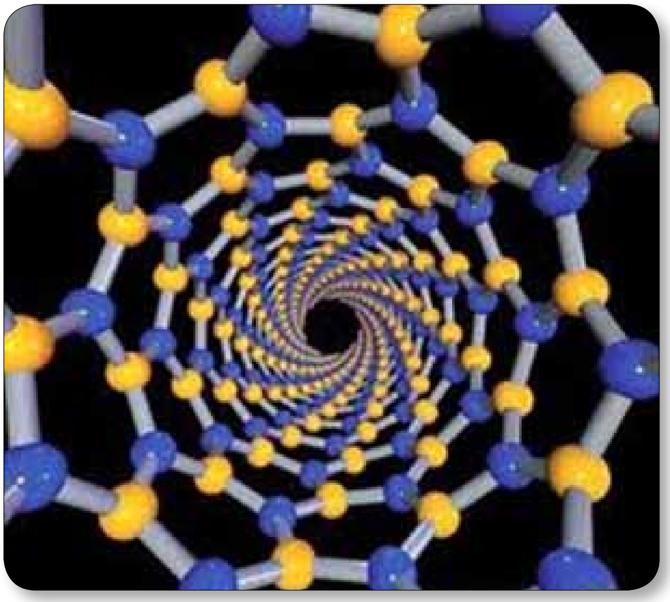


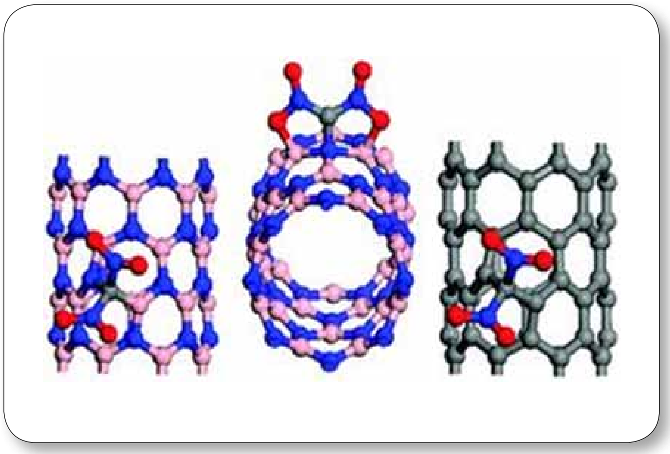


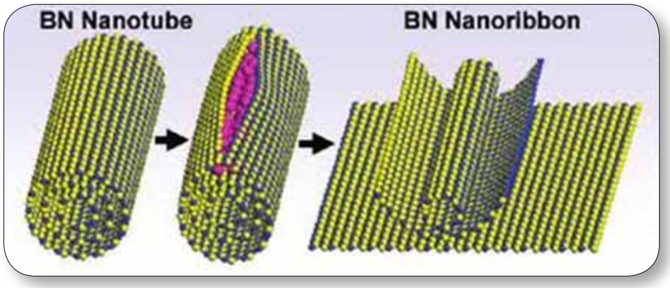
Nanopillars:



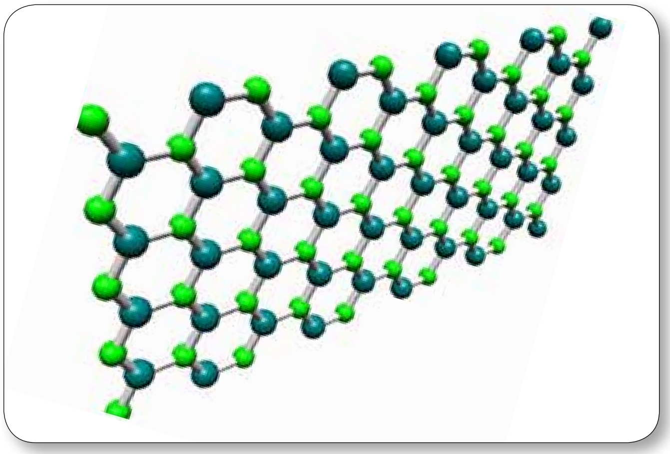
Boron Nitride Nanotubes: Hexagonal boron nitride (h-BN) is a layered material with a graphite-type structure in which planar networks of BN hexagons are regularly stacked. As a structural analogue of carbon nanotubes (CNTs) a BN nanotube (BNNT) was first predicted in 1994 and synthesized the next year.



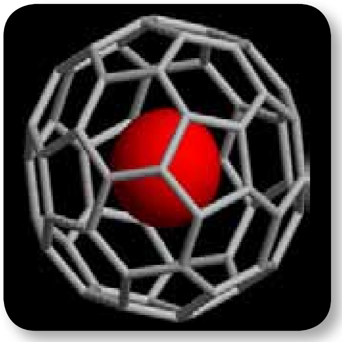




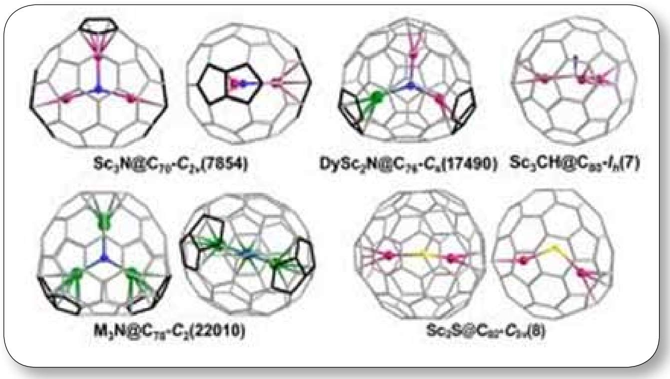
Boron Nitride Nanosheets: a single atom thick layer of boron nitride produced by splitting a boron nitride nanotube.



Endohedral Metallofullerenes: Endohedral fullerenes are fullerenes that have additional atoms, ions, or clusters enclosed within their inner spheres. The first lanthanum C60 complex was synthesized in 1985 called La@C60. The @ sign in the name reflects the notion of a small molecule trapped inside a shell.



Two types of endohedral complexes exist: endohedral metallofullerenes containing metal atoms or metallic compounds and non-metal doped fullerenes. Endohedral metallofullerenes are characterised by the fact that electrons will transfer from the metal atom to the fullerene cage and that the metal atom takes a position off-center in the cage. The size of the charge transfer is not always simple to determine. In most cases it is between 2 and 3 charge units, in the case of the La2@C80 however it can be even about 6 electrons such as in Sc3N@C80 which is better described as [Sc3N]+6@[C80]-6. These anionic fullerene cages are very stable molecules and do not have the reactivity associated with ordinary empty fullerenes.



Band Gap: the span of energies that lie between the valence and conduction bands for insulators and semiconductors.
Barn: a unit of area. Originally used in nuclear physics for expressing the cross sectional area of nuclei and nuclear reactions, today it is used in all fields of high energy physics to express the cross sections of any scattering process, and is best understood as a measure of the probability of interaction between small particles.

Burn-up: a measure of how much energy is extracted from a primary nuclear fuel source. It is measured both as the fraction of fuel atoms that underwent fission in % of fissions per initial metal atom and as the actual energy released per mass of initial fuel in gigawatt-days/metric ton of heavy metal (GWd/MTHM), or similar units. Typical PWR burnup is less than 0.7% of initial U-235.

Chart of the Nuclides: an extensive table that portrays the interrelationship of isotopes of a chemical element and the isotopes of neighboring elements to which it may either be transmuted or to which it may decay. This chart illustrates all of the transmutation and decay pathways between isotopes and elements.

Creep: plastic deformation occurring as a constant volume process, normally at low stresses below the yield stress. The deformation occurs by the motion of dislocations and irradiation-produced defects under the influence of stress. Neutron irradiation produces large quantities of point defects – vacancies and SIAs (self interstitial atoms) – which migrate to and collect at various sinks. With zirconium, the anisotropy of the crystal lattice causes both dislocations and SIAs to be anisotropic, and consequently these occur parallel to the basal plane in the <a> directions of the lattice. Dislocations are sinks for both vacancies and SIAs, but normally it is considered that an edge dislocation attracts SIAs more than vacancies. Dislocations produced by deformation and by irradiation lie on both basal and prism planes. Because of the diffusional anisotropy of SIAs, they tend to be absorbed by dislocations lying on prism planes. The diffusion of vacancies is isotropic, and they tend to be absorbed preferentially by dislocations lying on basal planes. Similarly, SIAs tend to be absorbed at grain boundaries oriented parallel to prism planes and vacancies on boundaries parallel to basal planes. Absorption of either vacancies or SIAs at dislocations of grain boundaries causes plastic strain; positive for SIAs and negative for vacancies. If the absorptions occurred randomly and in non-biased fashion, the net strain would be zero; however in zirconium alloys the built-in anisotropy results in separate positive and negative strains, and in constant volume deformation. Also, in addition to the natural anisotropy of the zirconium crystal lattice, another factor is the concept that anisotropic diffusion is enhanced by stress.

Critical Heat Flux (CHF): describes the thermal limit of a phenomenon where a phase change occurs during heating, which suddenly decreases the efficiency of heat transfer, thus causing localized overheating of the heating surface.

Departure from Nucleate Boiling (DNB): The point at which the heat transfer from a fuel rod rapidly decreases due to the insulating effect of a steam blanket that forms on the rod surface when the temperature continues to increase.

Delayed Hydride Cracking (DHC): Zirconium alloy components can fail by a time-dependent mechanism of cracking if they contain hydrides, sharp flaws and are sufficiently stressed. The mechanism of time-dependent hydride cracking is based on diffusion of hydrogen to the flaw tip, followed by nucleation, growth, and fracture of the flaw-tip hydride. By repeating these processes, a crack can propagate through the component at a rate that, above a threshold stress intensity factor, is mainly dependent on temperature.

Displacements per Atom (dpa): a calculated, hypothetical measure of radiation damage that reflects not only the dose and type of irradiation, but also includes some measure of the material's response to the irradiation. DPA is not a measure of the residual crystal lattice defects actually created in a material, but rather it is a measure of the "damage energy" deposited in the material by the irradiating particles in terms of how many atoms could possibly be permanently displaced from their lattice sites to stable interstitial sites by this damage energy. In each individual radiation damage event, the primary knock-on atom (PKA, an atom that has received kinetic energy through interaction with an irradiating neutron) imparts energy to neighboring atoms, producing a cascade of collisions. Within the affected volume of the collision cascade many atoms are displaced significantly from their lattice sites, creating a near-molten zone in the crystal. But within picoseconds, many of the displaced atoms return to vacant sites, healing much of the damage. The actual number of lattice defects ("permanently" displaced atoms) remaining after the cascade region cools is usually a small fraction of the atoms initially displaced in the cascade. This fraction is often referred to as the "efficiency" of defect production relative to the calculated DPA value, and it can vary considerably depending on the material and the irradiating conditions, including neutron energies and irradiation temperature. Although it does not reflect the actual residual defects produced in the material, DPA has been found to be an extremely useful damage parameter for correlating the effects of radiation damage in the same material irradiated in different neutron environments, and it is the standard damage parameter for nuclear structural materials.

Doppler Broadening: Frequency spreading which causes broadening of single-frequency radiation (e.g., spectral lines) when the radiating bodies (atoms, molecules, etc.) have different velocities. Radiation from each individual radiating body has a different Doppler shift, and the collection of radiations at different frequencies broadens the peak of the line in an intensity-vs-frequency plot.

Fast neutrons: a free neutron with a kinetic energy level close to 1 MeV (100 TJ/kg), hence a speed of 14,000 km/s. They are named fast neutrons to distinguish them from lower-energy thermal neutrons, and high-energy neutrons produced in cosmic showers or accelerators. Fast neutrons are typically produced by nuclear processes such as fission.

Flow Instability: Unstable flow can occur in the form of flow oscillations or flow reversals. Flow oscillations are variations in flow due to void formations or mechanical obstructions from design and manufacturing. A flow oscillation in one reactor coolant channel sometimes causes flow oscillations in the surrounding coolant channels due to flow redistribution. Flow oscillations are undesirable for several reasons. First, sustained flow oscillations can cause undesirable forced mechanical vibration of components. This can lead to failure of those components due to fatigue. Second, flow oscillations can cause system control problems of particular importance in liquid- cooled nuclear reactors because the coolant is also used as the moderator. Third, flow oscillations affect the local heat transfer characteristics and boiling. It has been found through testing that the critical heat flux (CHF) required for departure from nucleate boiling (DNB) can be lowered by as much as 40% when flow is oscillating. This severely reduces the thermal limit and the power density along the length of the reactor core. Again, it has been found through testing that flow oscillations are not a significant problem for some pressurized water reactors unless power is above 150% for the normal flow conditions. Flow oscillations can be a problem during natural circulation operations because of the low flow rates present. During natural circulation, the steam bubbles formed during a flow oscillation may have enough of an effect to actually cause complete flow reversal in the affected channel.

Fluence: the time integral of flux or total incident particles per unit area.

Flux: the rate of particle flow through a defined area per unit time usually measured in neutrons/cm2-s.

k-effective (keff): The "Six-factor formula" is the neutron life-cycle balance equation, which includes six separate factors, the product of which is equal to the ratio of the number of neutrons in any generation to that of the previous one; this parameter is called the effective multiplication factor (k), a.k.a. keff. k = LfρLthfηЄ, where Lf = "fast non-leakage factor"; ρ = "resonance escape probability"; Lth = "thermal non-leakage factor"; f = "thermal fuel utilization factor"; η = "reproduction factor"; Є = "fast-fission factor". k = (Neutrons produced in one generation)/(Neutrons produced in the previous generation) When the reactor is critical, k = 1. When the reactor is subcritical, k < 1. When the reactor is supercritical, k > 1.

Moderator: a neutron moderator is a medium that reduces the speed of fast neutrons, thereby turning them into thermal neutrons capable of sustaining a nuclear chain reaction involving uranium-235.

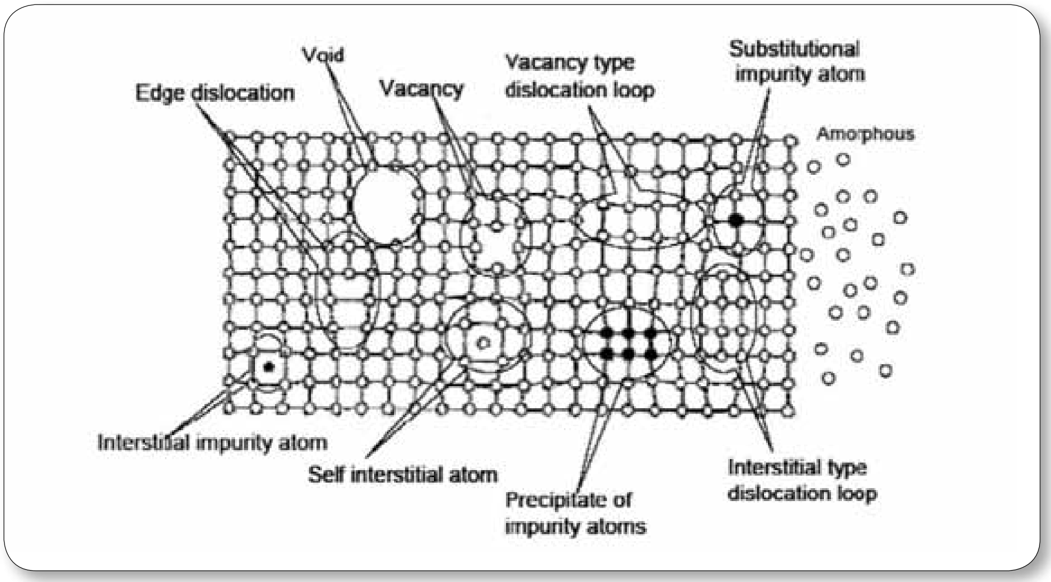
Nuclear Cross Section: used to characterize the probability that a nuclear reaction will occur. The concept of a nuclear cross section can be quantified physically in terms of "characteristic area" where a larger area means a larger probability of interaction. The standard unit for measuring a nuclear cross section (denoted as σ) is the barn, which is equal to 10−28 m^2 or 10−24 cm^2.

Nuclear Transmutation: the conversion of one chemical element or isotope into another. This occurs either through nuclear reactions (in which an outside particle reacts with a nucleus), or through radioactive decay (where no outside particle is needed). Artificial transmutations are those instigated by bombardment of a nucleus with high energy particles or photons resulting in an instability. Neutron capture is a frequently exploited means of causing transmutations, but high energy photons, protons, and electrons of the right energy levels can also be used. The resultant decay chains are described in the chart of the nuclides.

Nucleon: Common name for a constituent particle of the atomic nucleus. At present, applied to protons and neutrons, but may include any other particles found to exist in the nucleus.

Nuclide: A general term referring to all known isotopes, both stable (279) and unstable (about 2,700), of the chemical elements.

Radiation Induced Defects: Radiation induced changes in material properties are the result of microstructural defects. An energetic particle (e.g. neutron or fission fragment) collides with an atom in a material, transferring to it some energy and knocking it out of its lattice position. This primary knock-on atom and the recoiling particle cause additional collisions with other atoms generating a cascade of displaced atoms. Given that the average energy of a fission neutron is ~2 MeV and the threshold energy to displace an atom from its lattice position in metals is ~20–40 eV, a typical number of displaced atoms in a displacement cascade is ~50 000. In most metals, 90–99% of these displaced atoms eventually recombine to vacated lattice positions. It is the remaining non-correctly but stably sited radiation defects and microstructural re-arrangements that constitute the radiation damage that changes the material's microscopic and macroscopic properties. Various types of radiation-induced defects are illustrated in the figure below:



Oxide Dispersion Strengthened Metals: typically consist of a high temperature metal matrix - such as iron aluminide, iron chromium, iron-chromium-aluminium, nickel chromium or nickel aluminide - with small (5-50nm) oxide particles of alumina (Al2O3) or yttria (Y2O3) dispersed within it. Iron-based and nickel-based oxide dispersion strengthened alloys exhibit good corrosion resistance and mechanical properties at elevated temperatures. These alloys also show excellent creep resistance, which stems partly from the dispersion of oxide and other particles, and partly from the very large elongated grain structure.

RAD: A unit of energy absorbed from ionizing radiation, equal to 100 ergs per gram or 0.01 joules per kilogram of irradiated material. It has been replaced as a standard scientific unit by the gray.

Rem: A unit of absorbed radiation in biological tissue. Rem is equal to n times the number of rads, where the factor n is dependent on the type of radiation absorbed.

Reactivity: an expression of the departure from criticality. $\delta k = (k - 1)/k$ When the reactor is critical, $\delta k = 0$. When the reactor is subcritical, $\delta k < 0$. When the reactor is supercritical, $\delta k > 0$. A positive reactivity addition indicates a move toward supercriticality (power increase). A negative reactivity addition indicates a move toward subcriticality (power decrease). Reactivity is also represented by the lowercase Greek letter rho (ρ). Reactivity is commonly expressed in decimals or percentages or pcm (per cent mille) of $\Delta k/k$. When reactivity ρ is expressed in units of delayed neutron fraction β, the unit is called the dollar (and correspondingly, fractions thereof are measured in “cents”).

Stress Corrosion Cracking (SCC): is the growth of cracks in a corrosive environment. It can lead to unexpected sudden failure of normally ductile metals subjected to a tensile stress, especially at elevated temperature in the case of metals. SCC is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. The chemical environment that causes SCC for a given alloy is often one, which is only mildly corrosive to the metal otherwise.

Swelling: the increase of volume and decrease of density of materials subjected to intense neutron radiation. Neutrons impacting the material’s lattice rearrange its atoms, causing buildup of dislocations, voids, and Wigner energy. Many mechanisms of irradiation creep have been proposed. No single mechanism has been accepted as the dominating mechanism and very likely several processes contribute simultaneously. The two most prominent mechanisms are Stress Induced Preferential Absorption (SIPA) and climb and glide. SIPA assumes a bias of the motion of vacancies and SIAs to dislocations depending on the orientation of the Burgers vectors with respect to the applied shear stress. There are several variations of SIPA, including the elasto-diffusion modification that invokes the effect of stress on the diffusion anisotropy itself. Elasto-diffusion appears to have the strongest effect on creep within the SIPA “family”. The most straightforward irradiation creep mechanism is the climb and glide mechanism, by which deformation-producing dislocations are aided in bypassing obstacles to their motion by irradiation-induced point defects. As long as an individual dislocation attracts a net flux of either vacancies or SIAs, it can “climb around” a barrier and under the influence of an applied stress, glide to the next barrier, thereby producing strain and eventually cause a slip step at the material surface. The weak dependence of creep rate on dislocation density suggests that glide may not be the main strain-generating process.
A further contributor to the strain measured in a creep experiment is irradiation growth. Although not strictly in the “creep” category because it occurs in the absence of an applied stress, it is inevitably measured as part of the overall strain in all in-reactor experiments, except for bent beam stress relaxation tests. Irradiation growth results from mechanisms similar to irradiation creep in that it is dependent on the anisotropic properties of the zirconium crystal lattice.

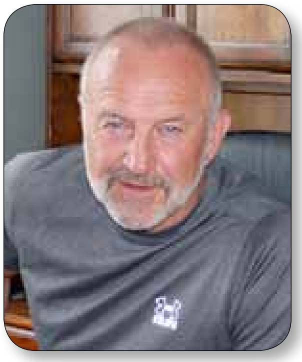
Thermal neutrons: Thermal does not mean hot in an absolute sense, but means in thermal equilibrium with the medium it is interacting with, the reactor’s fuel, moderator and structure, which is much lower energy than the fast neutrons initially produced by fission.

Worth: the general term describing reactivity expressed in units of dollars and cents.

Technical Terms & Technologies

Acronyms

AFC—Advanced Fuel Cycle
AFIT—Air Force Institute of Technology
ANL—Argonne National Laboratory
ATR—Advanced Test Reactor
ATRC—Advanced Test Reactor Critical Facility
BNL—Brookhaven National Laboratory
BNNT—Boron Nitride Nanotubes
BNNS—Boron Nitride Nanosheets
CHF—Critical Heat Flux
CNT—Carbon nanotubes
DHC—Delayed Hydride Cracking
DNBR—Departure from Nucleate Boiling Ratio
DOD—Department of Defense
DOE—Department of Energy
DOT—Department of Transportation
EFPD—Effective Full Power Days
FCRD—Fuel Cycle Research and Development
FIR—Flow Instability Ratio
HFIR—High Flux Isotope Reactor
INL—Idaho National Laboratory
LANL—Los Alamos National Laboratory
LBNL—Lawrence Berkeley National Laboratory
LHGR—Linear Heat Generation Rate
LLNL—Lawrence Livermore National Laboratory
MIT—Massachusetts Institute of Technology
MWD—Mega Watt Days
MWCNT—Multi Wall Carbon Nanotubes
NASA—National Aerospace Administration
NE—DOE Office of Nuclear Energy
NF&M—Nuclear Fuels and Materials
NIA—National Institute of Aerospace
NNI—National Nanotechnology Initiative
NRC—Nuclear Regulatory Commission
ODS—Oxide Dispersion Strengthened
ORNL—Oak Ridge National Laboratory
PCS—Primary Coolant System
PIE—Post Irradiation Examination
PNNL—Pacific Northwest National Laboratory
RIT—Rochester Institute of Technology
RPI—Rensselaer Polytechnic Institute
SAR—Safety Analysis Report
SCC—Stress Corrosion Cracking
SINST—Smalley Institute of Nanoscale Science and Technology
SNL—Sandia National Laboratory
SWCNT—Single Wall Carbon Nanotubes
TAMU—Texas A&M University
TREAT—Transient Reactor Test Facility
TRIGA—Training, Research, Isotope, General Atomics reactor



Steven J. Winston

With nearly 40 years of experience in various aspects of nuclear power, Steve has served in a variety of senior management roles for major companies. Currently providing a diverse range of technical advisory services to select clients, he served as the Vice President of Management and Technical Integration during Lockheed Martin Idaho Technologies Company's tenure as M&O contractor for the Idaho National Engineering Laboratory (now INL). He also served as Vice President for Parsons Engineering, as Vice President and General Manager of AWC-Lockheed (a wholly owned Lockheed subsidiary), and as Manager of Power Plant Design Engineering for Westinghouse Electric Corporation.

Steve is a chemical engineer/nuclear engineer with experience in nuclear fuel reprocessing (at the Idaho Chemical Processing Plant), has conducted Probabilistic Risk Assessments of nuclear power stations, has participated in the development of advanced thermal hydraulics codes (RETRAN), and has overseen major first-of-a-kind research and engineering projects for Westinghouse, Lockheed Martin, and the U.S. Department of Energy . He has managed diverse large-scale projects ranging from disposition of transuranic wastes to design of entire power plants.

Steve is currently a leading proponent of exploring the intersection of nanotechnology and nuclear sciences. This includes the instigation of research in nanoscale methods for accelerator production of medical isotopes, nanostructured prodrugs for targeted alpha therapy and brachytherapy, the use of novel nanostructures and nanomethods to produce lightweight shielding for satellites and nuclear propulsion systems, and a broad array of nanomaterials applications as potential responses to long standing challenges in the safe and efficient production of nuclear energy.

Robert Price

Mr. Robert Price is a United States Department of Energy employee with over twenty–seven years experience of increasing responsibility in nuclear engineering, engineering management, project leadership, program management and strategic planning. Mr. Price is the Director of Systems Engineering and Integration within the Office of Nuclear Energy's Office of Fuel Cycle Technologies. He was appointed to this position in March 2010 and is responsible for managing integration, systems analysis, systems engineering, communications and innovation for the Fuel Cycle technologies program.

Mr. Price holds a Bachelor of Science degree in Aerospace Engineering from the State University of New York at Buffalo and a Master's degree in Engineering Management from The George Washington University. Five years experience with the OECD Nuclear Energy Agency in Paris complements his U.S. government experience.

Mr. Price came to the Department of Energy following almost eight years of service in the U.S. Navy where he held various positions in the nuclear submarine force having qualified as a Submarine Warfare Officer and qualified for appointment as Engineering Officer of a nuclear-powered submarine.

Peter B. Lyons

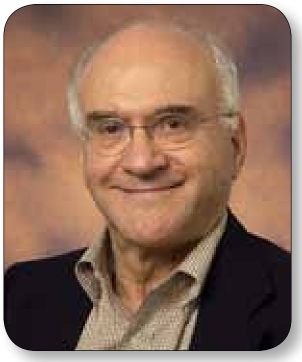
Dr. Peter B. Lyons was confirmed by the Senate as the Assistant Secretary for Nuclear Energy on April 14, 2011. Dr. Lyons was appointed to his previous role as Principal Deputy Assistant Secretary of the Office of Nuclear Energy in September, 2009. As Assistant Secretary, Dr. Lyons is responsible for all programs and activities of the Office of Nuclear Energy.

The Honorable Peter B. Lyons was sworn in as a Commissioner of the Nuclear Regulatory Commission on January 25, 2005 and served until his term ended on June 30, 2009. At the NRC, Dr. Lyons focused on the safety of operating reactors and on the importance of learning from operating experience, even as new reactor licensing and possible construction emerged. He emphasized that NRC and its licensees remain strong and vigilant components of the Nation's integrated defenses against terrorism, and was a consistent voice for improving partnerships with international regulatory agencies. He emphasized active and forward-looking research programs to support sound regulatory decisions, address current issues and anticipate future ones. He was also a strong proponent of science and technology education, recruiting for diversity, employee training and development programs, and an open and collaborative working environment.

From 1969 to 1996, Dr. Lyons worked in progressively more responsible positions at the Los Alamos National Laboratory. During that time he served as Director for Industrial Partnerships, Deputy Associate Director for Energy and Environment, and Deputy Associate Director-Defense Research and Applications. While at Los Alamos, he spent over a decade supporting nuclear test diagnostics. Before becoming a Commissioner, Dr. Lyons served as Science Advisor on the staff of U.S. Senator Pete Domenici and the Senate Committee on Energy and Natural Resources where he focused on military and civilian uses of nuclear technology, national science policy, and nuclear non-proliferation. Dr. Lyons has published more than 100 technical papers, holds three patents related to fiber optics and plasma diagnostics, and served as chairman of the NATO Nuclear Effects Task Group for five years.

Dr. Lyons was raised in Nevada. He received his doctorate in nuclear astrophysics from the California Institute of Technology in 1969 and earned his undergraduate degree in physics and mathematics from the University of Arizona in 1964. Dr. Lyons is a Fellow of the American Nuclear Society, a Fellow of the American Physical Society, was elected to 16 years on the Los Alamos School Board and spent six years on the University of New Mexico-Los Alamos Branch Advisory Board.

Dr. Lyons is a resident of Virginia.



Victor H. Reis

Dr. Victor H. Reis is Senior Advisor; Office of the Under Secretary for Science, Department of Energy, where he is working on various DOE issues – mostly involving small modular nuclear reactors. He is a member of the Strategic Advisory Group of the U.S. Strategic Command. He returned to the DOE in 2005 to help formulate the Global Nuclear Energy Partnership.

Dr. Reis led the development of the DOE's Stockpile Stewardship Program when he was Assistant Secretary for Defense Programs in the U.S. Department of Energy.

His past government appointments include serving as Director of Defense Research and Engineering (DDR&E) in the Defense Department; Director of the Defense Advanced Research Projects Agency (DARPA) and Assistant Director for National Security and Space, Office of Science and Technology Policy, Executive Office of the President, (OSTP).

He was Senior Vice President for Strategic Planning at SAIC, Senior Staff Member at MIT Lincoln Laboratory and has held other industrial research and management positions. He has chaired and served on numerous government and laboratory advisory committees for the DOD, CIA, NASA, NNSA, U.S. Navy and Los Alamos, Sandia, Argonne and Idaho National Labs.

Dr. Reis earned a B.M.E. in Mechanical Engineering from the Rensselaer Polytechnic Institute, (1957) an M.Eng. in Mechanical Engineering from Yale University (1958); and an M.A. and Ph.D.(1962) from Princeton University. He has authored numerous scientific and policy publications and his awards include two Department of Defense Distinguished Public Service Medals, the Department of Energy James R. Schlesinger Award and an Honorary medal from the French Atomic Energy Commission.

Vicki Colvin

Dr. Vicki Colvin is the Kenneth S. Pitzer-Schlumberger Professor of Chemistry and Professor of Chemical and Biomolecular Engineering at Rice University. A well-respected scientist, both locally and nationally, Vicki was appointed Vice Provost of Research in June 2011. In this role, she works with faculty colleagues to take Rice's $134.3 million research portfolio to the next level.

Vicki joined Rice in 1996, when she was recruited by the University to expand its nanotechnology program. In 2001, she became the first Director of Rice's Shared Equipment Authority, a nationally recognized model of infrastructure management that today manages more than 80 pieces of highly sophisticated research equipment. Most recently, she has served as the Director of the Center for Biological and Environmental Nanotechnology (CBEN), which stands as one of the nation's first nanoscience and engineering centers and as Rice's largest NSF center. She has also recently served as Faculty Director of the Smalley Institute for Nanoscale Science and Technology.

Vicki's current research explores how nanoscale particles interact with the environment and living systems. Her research draws on both synthetic chemistry for the preparation and control of novel nanophase systems, and on physical chemistry for the investigation of these systems' unusual behavior. At present, the focus of her research projects is on the unique and responsive behavior of nanoparticles in complex systems such as cells, organisms, and the environment. On one hand, her research group looks toward understanding the implications of nanotechnology. She leads a multi-million dollar EPA grant to evaluate the bioavailability of nanoparticles in the aquatic natural environment. On the other hand, her group applies their fundamental knowledge of nanoparticles and their interactions to solve problems related to water purification and targeted cell death.

Colleagues hold Vicki's research in high esteem. She received both a Beckman Young Investigator award and an Alfred P. Sloan Research Fellowship in 2000, and in that same year was named one of Discover Magazine's "Top 20 Scientists to Watch." Her research in low-field magnetic separation of nanocrystals was named one of the "Top Five Nanotech Breakthroughs of 2006" by the Forbes/Wolfe Nanotech Report, and resulted in her being named a "Best and Brightest Honoree" by Esquire Magazine the following year. In 2007, Vicki was named a Fellow of the American Association for the Advancement of Science (AAAS), the world's largest general scientific society, and in early 2011, she was named a Fellow of the American Institute for Medical and Biological Engineering.

The author/co-author of more than 100 articles, Vicki is a frequent contributor to Science, Advanced Materials, Physical Review Letters, and other peer-reviewed journals. She holds five patents, with eight patent applications in process. A highly successfully principal investigator, she has been awarded more than 20 grants, bringing more than $30 million to the University. In addition, Vicki is highly engaged in professional activities. Currently, she serves as the chairperson for the NIH review panel on Nanomedicine; as an external advisor to the journal Small; and as a board member for the Strategic Environmental Research and Development Program (SERDP), an environmental science and technology program funded by the U.S. Department of Defense (DOD) and implemented in partnership with the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

In the recent past, Vicki served as a member of the President's Council of Advisors for Science and Technology (2010), the Intelligence Science Board (2009-2010), and the Nano Health-Environment Commented Database (2008-2010).

Vicki's accomplishments, however, are not limited to research. She is also an outstanding teacher, as evidenced by the numerous accolades she has received for her teaching abilities. Among these are the Phi Beta Kappa's Teaching Prize (1998-1999) and the Camille Dreyfus Teacher Scholar Award (2002).

Vicki received her Bachelor of Science degree in chemistry and physics from Stanford University in 1988, and in 1994 obtained her Ph.D. in chemistry from the University of California, Berkeley, where she focused on the electronic structure of semiconductor nanocrystals. During her time at UC, Berkeley, she was awarded the American Chemical Society's Victor K. LaMer Award for her work in colloid and surface chemistry. Vicki completed her postdoctoral work at AT&T Bell Labs; while there, she conducted research on vibrational spectroscopy of glasses and polymers, as well as on photonic applications of nanocomposite photopolymers

Kemal Pasamehmetoglu

Dr. Kemal Pasamehmetoglu holds a doctorate in mechanical engineering from the University of Central Florida and has more than 25 years of research engineering experience within the national laboratory system. He has been with INL since 2004, most recently serving as the Associate Laboratory Director for the Nuclear Science & Technology Directorate. Prior to his time at INL, he held senior technical leadership positions at Los Alamos National Laboratory. Kemal also serves as the national technical director (NTD) for Fuel Cycle Research and Development in the Advanced Fuel Cycle Initiative. During his tenure as a division director and as a NTD he has transformed nuclear fuels capabilities in the nation and at INL into world-leading endeavors.

Robert Hill

Dr. Robert Hill completed his Ph.D. in Nuclear Engineering at Purdue University in 1987. He has worked at Argonne National Laboratory for the last 24 years with research focus on reactor physics, fast reactor core design, plutonium disposition, and waste management. His current position is Technical Director - Advanced Nuclear Energy R&D. He has lead research groups working on reactor physics analysis, advanced modeling and simulation, fuel cycle and systems dynamics modeling, criticality safety, and nuclear data.

In current DOE Programs, Dr. Hill is the National Technical Director for multi-Laboratory Advanced Reactor Concepts R&D; this work includes modeling and simulation, advanced structural materials, energy conversion technology, nuclear data, and system integration. He also serves as U.S. technical representative for the Generation-IV Sodium Cooled Fast Reactor. Previous Program contributions include extensive transmutation and fuel cycle analysis activities in the DOE Advanced Fuel Cycle Initiative.

Daniel Mittleman

Dr. Daniel M. Mittleman is a professor in the Department of Electrical and Computer Engineering at Rice, working in the research area of terahertz science and technology. As Interim Director of the Smalley Institute, Prof. Mittleman is responsible for maintaining the vision and direction needed to achieve the Institute's short and long-term goals, ensuring effective execution of the Institute's initiatives and promoting the accomplishments of the faculty, students, and components that comprise the Smalley Institute.

Among his many achievements, Prof. Mittleman is Faculty Director of LANCER (The Lockheed Martin Advanced Nanotechnology Center of Excellence at Rice University), which pursues discovery in nanotechnology that is relevant to Lockheed Martin's technology future. Dan has also been involved with undergraduate research internships in nanotechnology as a co-principal investigator for the National Science Foundation grant that enabled Rice to expand its summer NanoJapan program. Within his own discipline, Dr. Mittleman's significant research contributions to terahertz radiation imaging, sensing and spectroscopy were acknowledged by his peers, who selected him as a 2011 fellow of the Institute of Electrical and Electronics Engineers.

Prof. Mittleman joined the Rice faculty in 1996 after working at AT&T's Bell Laboratories. He received a Bachelor of Science in physics from the Massachusetts Institute of Technology and earned a master's degree and doctorate in physics from the University of California-Berkeley. He is also a fellow of the Optical Society of America.

Brent M. Segal

Dr. Brent M. Segal is a Director of Research Science at Lockheed Martin and Chief Technologist for Lockheed Martin Nanosystems following the acquisition of the Nantero Government Business in 2008. In his role at Lockheed Martin, Brent has a broad charter to integrate nanotechnology throughout the Lockheed Martin product portfolio. In addition Brent is active in the Healthcare, Energy and Cleantech spaces acting as a technology scout bringing small companies and university projects to Lockheed Martin. He assists with government program management for projects involving sensors, nanoelectronics, and materials science with DOD, DOE, and other customers. Brent received a B.S. in Biochemistry from Reed College and a PhD in Chemistry from Harvard University.

Prior to joining Lockheed Martin, Brent co-founded and served as the Chief Operating Officer of Nantero, a leading Nanotechnology company where he generated more than 100 patents and applications. Nantero raised $31.5 M in three private equity rounds (DFJ, CRV and Globespan) and secured government programs totaling in excess of $50 M.
In his spare time Brent enjoys NFL football, specifically monitoring the 49ers. Brent's passion for energy issues has led him to explore deals involving reduction of global CO2 levels through the use of renewable energy sources such as biofuels, photovoltaics, wind power and fuel cells.

Stuart Maloy

Dr. Stuart Maloy has been a Technical Staff Member at Los Alamos National Laboratory for 22 years and is the core materials technical leader for the Fuel Cycle Research and Development's Advanced Fuels campaign at LANL. He has a Bachelors ('89) Masters ('91) and PhD ('94) in Materials Science from Case Western Reserve University. He has applied his expertise to characterizing and testing the properties of metallic and ceramic materials in extreme environments such as under neutron and proton irradiation at reactor relevant temperatures. This includes testing the mechanical properties (fracture toughness and tensile properties) of Mod 9Cr-1Mo, HT-9, 316L, 304L, Inconel 718, Al6061-T6 and Al5052 after high energy proton and neutron irradiations using accelerators and fast reactors. Characterization of materials after testing includes using transmission electron microscopy for analyzing defects such as dislocations, twins and second phases, using high resolution electron microscopy to characterize defects at an atomic level and nanoscale mechanical testing. Stuart has >120 peer reviewed technical publications and numerous presentations.

James Sears

Dr. James W. Sears is the Executive Director of the Quad Cities Manufacturing Laboratory (QMCL), a Not-for-Profit (501.c.3) Research and Development Company embedded within the Rock Island Arsenal - Joint Manufacturing and Technology Center (JMTC) and Director of Additive Manufacturing at the South Dakota School of Mines & Technology. He is also Chief Technical Officer (CTO) for Black Hills Nanosystems, a startup company working on safe armament.

Jim received his B.S. Mechanical Engineering Degree from University of Illinois (1981) and while with Pratt & Whitney Aircraft, West Palm Beach, FL., he finished his M.S. and in 1985 returned to University of Illinois for a Ph.D. in Mechanical Engineering (1988). His research interests include rapid solidification processing, powder metallurgy, plasma and laser processing, spray deposition and fabrication with nano-particles. Jim has written over 80 published papers and holds one U.S. Patent. He is a member of the Board for The Minerals, Metals, & Materials Society (TMS) and Chair for their Material Processing and Manufacturing Division (MPMD)

Professional Memberships and Duties:
MPIF- Professional Development, Roadmap, Conference Committee, Publications and Advanced Particulate Materials Association (APMA) - Technical Liaison
TMS – MPMD Division Chairman and TMS Board member, Past Chairman Powder Materials Committee, JOM Advisor Powder Materials 96-98,
ASM, ASME and LIA (Laser Institute of America)
Chairman of the Penn State Laser Processing Industrial Consortium (2002)
Chairman of the Optomec Lens User Group (2002-2004)
Technical Advisory Board (Nova-Centrix, Austin, TX) (2006-2008)
Co-organizer for the Laser Additive Manufacturing Workshop 2009, 2010 & 2011

James Buelt

Currently, Mr. Buelt is assisting with sector management transition duties for the Nuclear Energy Sector at PNNL. Through February, 2012, Jim has been the manager of the Nuclear Energy Sector at Pacific Northwest National Laboratory. In this role, he was responsible for developing the relationship and business with the DOE Office of Nuclear Energy and the nuclear industry, which currently totals approximately $15 million/yr at PNNL. He served as the face to the client for all of PNNL's nuclear energy science and engineering activities. He was responsible for the development and execution of the nuclear energy strategy for the Laboratory on how to best deploy its scientific and facility resources for the safe, secure, and economic expansion of nuclear power.

During Jim's 36-year career with Battelle at PNNL, he has been a sector manager, technical group manager, nuclear facility manager, product line manager, project manager, and senior development engineer. His responsibilities have centered on the development of radioactive and chemical waste treatment and immobilization processes. He is the holder of several patents on In Situ Vitrification and other environmental cleanup methods. From 1976 to 2002, Jim was the product line manager for one of Battelle's most prominent product lines; Process and Measurement Technology. In this role, he was responsible for building and managing a business of over $40 million in contract R&D composed of approximately 130 active projects.

In 2002, Jim became the lead technical manager for the Radiochemical Processing Laboratory, PNNL's Hazard Category II Nuclear Facility, designed to conduct research on highly active and dispersible radioactive and nuclear materials. He was responsible for the safety basis of the facility, as well as the development and performance of over 80 research and support staff and held this position for four years.

Prior to becoming the sector manager, he was the acting manager of the Nuclear Safety and Technology Product Line, responsible for the expert delivery of the nuclear technology portfolio of projects at the Laboratory, totaling approximately $40 million/yr in annual sales and business volume.

B.S., Oregon State University, Chemical Engineering, 1975

Tina Nenoff

Dr. Tina Nenoff is a Distinguished Member of the Technical Staff at Sandia National Laboratories in Albuquerque, NM. She established her research there after receiving her Ph.D. in Chemistry from the University of California, Santa Barbara under the guidance of her advisor Dr. Galen Stucky. Her current research interests are in the structure/ property relationships in novel nanoporous and nanoparticle phases. Research areas of interest include: novel materials for the removal and fixation of radioisotopes and elements; novel nanoparticle phase formation via radioloysis; and inorganic thin film membranes for light gas and organic molecule separations and catalysis.

She is a 2011 Fellow of the American Chemical Society (ACS), and a member of the ACS as well as the Material Research Society (MRS) and International Zeolite Association (IZA). She holds leadership positions in both the ACS and IZA. She is the chair of the 2011 Nanoporous Materials Gordon Research Conference. She is member of the editorial board of Chemistry of Materials and Industrial Engineering and Chemical Research ACS journals, a co-editor of the MRS Bulletin on Hydrogen Separation Membranes (Oct 2006), and a reviewer for numerous journals. Dr. Nenoff has published 145+ papers in various material science and chemistry journals, holds 10 US Patents and has presented at over 100 national and international conferences.

Michael W. Cappiello

Mr. Cappiello is currently a senior nuclear engineer providing consulting services thru TechSource Inc. His expertise is in nuclear fuel cycle, reactor design, and reactor safety. He spent most of his career at Los Alamos National Laboratory. While at Los Alamos he contributed to multiple programs and projects including, commercial reactor safety, space reactor design, production reactor safety, critical experiments, accelerator production of tritium, spallation target design and nuclear fuel cycle development. He participated in the development and application of the Transient Reactor Analysis Code, a transient, multi-dimensional two-phase flow code that is used for light water reactor Loss of Coolant Accident analysis. Prior to joining Los Alamos National Laboratory, Mr. Cappiello worked for the Westinghouse Hanford Company as an Engineer on the Fast Flux Test Facility project. Mr. Cappiello was the lead design engineer for core test article designs and a member of fuel load and start –up team.

Notes

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