Enabling Algorithm for Uncertainty Quantification and Sensitivity Analysis

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Abstract

Uncertainty quantification requires repeated model executions in order to capture the impact of input nuclear data uncertainty on the responses of interest. Statistical sampling methods, such as Monte Carlo approach, have been widely used to complete uncertainty quantification. Despite their ease of implementation, the computational cost increases exponentially with the number of input parameters – the curse of dimensionality. In this poster, we will present our recently developed techniques, such as reduced order modeling, exact-to-precision generalized perturbation theory, and generalized perturbation theory free, to reduce the large dimensionality of nuclear reactor systems.

Moderator/ Reflector/ Shielding Construction for a DD Compact Neutron Generator

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Abstract

A deuterium-deuterium neutron generator is being used for in vivo quantification of metals using neutron activation analysis (NAA). A properly designed moderator/reflector/shielding construction can help optimize the NAA system and reduce radiation exposure to the subjects. Simple moderator/reflector/shielding geometry can lead to a less than optimal sensitivity for the NAA-system. Complex designs are being simulated and constructed to compare the performance of the NAA system.

Behavior and Design of Steel-Plate Composite Walls Subjected to Impact and Impulse Loads

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Abstract

Steel-plate composite concrete (SC) walls consist of poured concrete between two studded steel plates and have recently been incorporated into nuclear power plant (NPP) designs in several countries in lieu of conventional reinforced concrete (RC). When installed in NPP facilities, SC walls may be required to resist the effects of extreme loadings such as tornado missiles, aircraft impact, and explosion-generated pressure pulses. An experimental and analytical research program investigating the behavior of SC walls under these loads is being carried out at Purdue University's Bowen Laboratory and the US Army Corps of Engineers Engineering Research and Development Center. Experimental results indicate that the same level of protection can be provided by an SC wall which is thinner than an RC wall. Results of these studies have led to improved understanding of behavior and recommendations to design SC walls to resist perforation from missile threats. Continuing research is leading to design recommendations for the global behavior of SC walls subjected to impact loads and blast pressures. This poster highlights the results from this on-going research program.

A novel application of cosmic rays for spent nuclear fuel monitoring

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Abstract

Storage of spent nuclear fuel is at the center of public debate about the future of nuclear energy in the United States. Since the early 1950's, when the first nuclear power plant began to produce electricity, vast numbers of containers and dry casks house, frequently unknown, waste that include spent nuclear fuel, concrete and voids. Threats, both insider and outsider, associated with accumulation of spent nuclear fuel may continue to become increasingly sophisticated necessitating the development of innovative technologies that minimize materials diversion. Conventional methods for examining the interior of materials e.g., X-rays, are limited by the fact that they cannot penetrate very dense well-shielded objects. Cosmic ray muons have the potential to allow for non-destructive assessment of nuclear material accountancy with the aim to independently identify weapons grade material such as nuclear fuel assemblies stored within sealed dense dry casks. Cosmic muons are relativistic charged particles continuously generated by high energy cosmic rays entering Earth's atmosphere with the ability to penetrate high density material allowing the distribution of material within the object to be inferred from the muon tracks. The proposed project focuses on advancing the mathematical framework, simulation, signal processing and imaging technology for spent nuclear fuel monitoring applications. The developed methodology allows the determination of the presence, structure and geometry of spent nuclear fuel assemblies from muon transport

measurements. Advantages of cosmic muon tomography include the utilization of the passive nature of muons, the lack of radiological sources and the absence of any artificial radiological dose.

Mesoscale simulation of phonon mediated thermal transport in UO2: Perturbation theory based Monte Carlo solution of Boltzmann Transport Equation

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Abstract
Safety of nuclear reactors depends on the reliability of materials under harsh radioactive conditions inside the core of the reactor. The worst part originates from radiation induced damaging effects that lead to microstructural and compositional changes and ultimately can cause material failure. To design materials with enhanced radiation resistant properties, the behavior of materials under irradiation need to be well understood and reliable predictive theoretical models need to be established along with experimental verification techniques. As it is the most widely used nuclear fuel, the advancement of the nuclear technology passes necessarily through a complete understanding of uranium dioxide's properties on every aspect. The revival of vigorous research in the nuclear energy field had instigated a wide interest in UO2 in an attempt to study its mechanical, thermal and electronic properties, among others. Fuel thermal conductivity controls the fuel operating temperature, and hence affecting nuclear fuel performance and many important processes. There are several factors that can contribute to the change of thermal conductivity under irradiation, most significantly are the change of oxygen-to-metal ratio and defects concentrations. Studying phonon transport represents an adequate paradigm to understand heat transfer phenomena in crystalline semiconductor and insulator materials at the nanoscale level. Unlike phenomenological heat diffusion models, which cannot be applied at this length scale, phonon transport theory can capture the microstructure and nanostructure effects on the thermal conductivity. Boltzmann Transport Equation (BTE) provides the capability of tracking phonon evolution in phase space, however solving BTE exactly is not possible in most of the realistic cases. We present a Monte Carlo solution of BTE for phonons in uranium dioxide with various levels of defects. BTE is linearized by introducing the Relaxation Time Approximation (RTA). Individual phonon relaxation times, timescale measure of the scattering strength of each phonon interaction processes (causing transition between phonon states), are calculated by Fermi’s Golden Rule under time dependent perturbation theory approximation. Total relaxation time, for each phonon, is calculated by adding individual phonon relaxation times (by all possible mechanisms) together using Matthiessen’s rule. The simulation scheme accounts for all acoustic and optical branches of the dispersion relationships and considers the 3D representation of the actual shape of the UO2 Brillouin zone (truncated octahedron). Experimental dispersion data of UO2 in high symmetry directions were employed to model phonon anisotropic dispersions. Unlike most other works on solving this equation by Monte Carlo method, the momentum and energy conservation laws for phonon-phonon interactions in uranium dioxide are treated exactly by considering only the interactions that obey the pertinent conservation laws. Using periodic boundary conditions, our results illustrate the diffusion limit of phonon transport in uranium dioxide, and make possible the prediction of thermal conductivity. A simple kinetic theory model is also implemented in which conductivity is calculated using phonon heat capacity, velocities, and scattering time-scales. The effect of temperature and defect concentration on conductivity is predicted with both models and the results are compared with experimental data available in the literature. This research was supported as a part of the Energy Frontier Research Center for Materials Science of Nuclear Fuel funded by the U.S. Department of Energy, Office of Basic Energy Sciences under award number FWP 1356, through subcontract number 00122223 at Purdue University.

Measurement of ^{41}Ca by Accelerator Mass Spectrometry (AMS)

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Abstract
We have been developing a ^{41}Ca as measured by AMS as a novel technique for measuring bone balance for the last 15 years. The analytical advantages include small variation, the ability to follow changes in bone over the lifetime of the subject with one small dose, and safety (a typical dose is as dangerous as eating 2 bananas). Few studies have demonstrated a direct relationship between the results of conventional methods of measuring bone metabolism and ^{41}Ca data measured by AMS. We show correlations between urinary ^{41}Ca:Ca ratios and conventionally employed molecular and biochemical markers that predict bone turnover. This increases our ability to translate the ^{41}Ca measures into meaningful parameters related to skeletal health. In addition, this technology allows us to screen and compare efficacy of nutrient and botanical interventions on protecting against bone loss. Finally, we will discuss the limited amount of dose material available and our current work and challenges on producing ^{41}Ca for human studies.

nTRACER Practical Numerical Reactor for High-Fidelity LWR Analysis

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Abstract

The development and verification of a practical numerical reactor (PNR) formed by integrating a subchannel thermal/hydraulic solver into the nTRACER direct whole core transport code developed are presented. In order to accomplish high-fidelity and practicality needed for the applications to routine design analyses of power reactors, the accuracy and the parallel computing efficiency of the direct whole core transport methods, the subgroup method for resonance treatment, the Krylov subspace based depletion method, were improved and realistic modeling features such as axial spacer grid modeling and burnup-dependent gap conductance were implemented. Its accuracy and performance was verified by comparing with the measurement data obtained for three pressurized water reactor cores. It was demonstrated that accurate and detailed multi-physic simulation of power reactors is practically realizable without any prior calculations or adjustments.

Modular Connection Technologies for SC Walls of SMRs

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Abstract

Steel-plate composite (SC) structures have been used to expedite construction of the third generation of nuclear power plants. SC walls have proven to be extremely efficient for fabrication, erection, and construction of nuclear power plants, as evidenced by the construction progress of the AP1000® plants in Sanmen, China. Therefore, they are being considered seriously as a candidate for optimizing and facilitating the next generation of Small Modular Reactors (SMRs).

The challenge for SC walls is that there is no governing or applicable design code or standard in the US that can be used for their design, inspection, and review. The current ACI 349 code applies only to conventional RC walls and cannot be easily extended to SC walls. This has been a significant challenge for the NRC reviewers and extended the licensing schedule for nuclear power plants using SC walls. Connections between SC-to-SC walls and SC-to-RC walls or slabs have been particular challenging because: (i) there are no clear performance requirements, and (ii) there are no pre-qualified and tested connections. This research project conducts fundamental experimental and analytical work to address these challenges particularly for the SC walls and connections for small modular reactors.

The overall goal of the project is to develop and disseminate new knowledge in terms of design details, benchmarked numerical models, and experimental results concerning SC wall connections to other SC walls, RC slabs, and the concrete basemat. The project will directly address an area of exploration identified in the Nuclear Energy Enabling Technologies (NEET) and Small Modular Reactor (SMR) workshop reports, namely, assembly and material innovation to enhance modular building techniques such as advances in composite structures.

Validation of a Neutron Activation Analysis (NAA)

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Abstract

System to Quantify Manganese *In Vivo*" and here is the abstract "Manganese (Mn) is an essential trace element to human health. However, overexposure to Mn can lead to various diseases, especially neurological disorders. There is by now no ideal way to assess the long term cumulative Mn exposure level. We hypothesize that bone Mn can be a desirable biomarker since bone is one of the main storage organs for Mn (~40%) and Mn releases slowly from bone. In this project, a novel transportable neutron activation analysis (NAA) system has been developed to quantify Mn in human hand bone *in vivo*. An advanced deuterium-deuterium (DD) neutron generator was used as the neutron source, a neutron moderating/ reflecting/ shielding construction was built to optimize the neutron characteristics, and a high efficiency HPGe detector was used to measure the Mn characteristic g-rays. With the currently detection limit (DL) of 0.37 ppm, this system is promising for human studies."

Sub-cooled Boiling Model for CFD Applications

Deoras Prabhudharwadkar, Avinash Vaidheeswaran, Takashi Hibiki , Martin A. Lopez de Bertodano
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Abstract :

The wall boiling boundary condition for the energy equation of a CFD two-fluid model is investigated. The wall heat flux is divided into three components, viz., single phase convection, evaporation and quenching at the heated wall. The last two use the following closure parameters:

- Bubble nucleation site density
- Bubble departure diameter
- Bubble departure frequency

The present study involves an assessment of three existing models for site density and frequency: UCLA, Purdue and RPI, validated with new Freon data sets where the bubble diameter has been measured.

Design of Steel-plate composite (SC) walls Subjected to In-Plane and Out-of-Plane Shear Forces

Kadir C. Sener, Saahastaranshu R. Bhardwaj, Amit H. Varma, Thomas G. Bradt
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Abstract

This poster will summarize the experimental database of SC walls subjected to in-plane and out-of-plane shear Forces. The experimental database includes the in-plane and out-of-plane tests conducted at Purdue University. The poster also briefly discusses on-going experiments to study the SC walls subjected to combined in-plane and out-of-plane loading.

The experimental database for in-plane shear forces on SC walls with and without flanges is discussed. Tri-linear analytical model to determine the in-plane strength of SC walls is also presented. The results of these experiments are compared with the strength equations for in-plane shear provided in Appendix N9 of upcoming AISC N690s1.

Similarly, the experimental database for SC walls subjected to out-of-plane shear forces is discussed. The experimental strength for out-of-plane shear loading is compared with the strength obtained using Equations provided in ACI 349 and Appendix N9 of upcoming AISC N690s1.

The poster also discusses the ongoing experiments to study the effect of combined in-plane and out-of-plane shear loading on SC walls. The test matrix and the test set up is briefly discussed.

Radiation Detection using Graphene Field Effect Transistors

Zachary Shollar, Dr. Robert Bean, Purdue University, Nuclear Engineering,

Abstract

Radiation detection using semiconductor technology is well understood and appears to have reached its limit. Graphene offers to enhance the detection capabilities of these systems by using its superior electron mobility and variable band gap. A graphene layer on top of an insulator and semiconductor substrate acts as a field effect transistor. Ionization occurs as incident radiation deposits energy in the semiconductor substrate; producing electron charges that migrate to the insulator layer and collect beneath the graphene. Collection and migration of these electron charges produce an electric field, which alters the electronic state of the graphene, varying its resistivity. This change in resistivity is measured and related back to the incident radiation. Previous research has shown proof of concept, but further understanding of the electronic response to radiation is needed. The initial design will verify the graphene's resistance change in response to radiation. The detector system design is being continuously evaluated as device construction progresses. Planned experiments will characterize saturation time, drain time, regime of resistivity change, and bias voltage response characteristics.

Portable XRF technology to quantify lead in bone *in vivo*

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Marc Weisskopf' Harvard School of Public Health, Boston, MA,
Linda H. Nie' School of Health Sciences, Purdue University, West Lafayette, IN

Abstract

Lead is a ubiquitous toxin, and bone lead has been correlated with adverse health effects on many systems in the body. With recent advancements in portable XRF technology and calibration methods, we have developed a system to measure lead in bone *in vivo*. The main goals in this study were to improve the sensitivity of the system, determine the best calibration method, and validate the system for *in vivo* measurement. We investigated four calibration methods, namely background subtraction, bone calibration, bone adjustment calibration, and traditional peak fitting. System calibration is important, as with larger soft tissue thickness the detected lead x-ray signals can be low and difficult to quantify. Using these calibration methods we measured the bare cadaver bone and goat bone samples with Lucite used to replicate soft tissue, and cadaver bone with and without intact soft tissue. There was strong correlation between the K x-ray fluorescence (KXRF) and portable XRF bone lead results for cadaver and goat bones with and without Lucite and soft tissue. Our results suggest that the best calibration method for use with *in vivo* data is the background subtraction method, and that the technology needs to be validated in a larger human population.

Empowering Predictive Simulation for Nuclear Systems: Improving Accuracy and Efficiency

Congjian Wang, Purdue University, West Lafayette, IN

Abstract

The major focus of this research is to develop some efficient algorithms to address the explosion in dimensionality whether at the input parameter level or at the response level. By way of examples, these new developments could be employed to core simulations, design optimizations, as well as sensitivity analysis and uncertainty quantifications.

Core Design Study of Stationary Liquid Fuel Fast Reactor for TRU Burning

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Abstract

For effective burning of TRU element, TRU conversion ratio a transformational advanced reactor concept stationary liquid fuel fast reactor (SLFFR) is proposed. The reactor can achieve a zero TRU conversion ratio while securing inherent safety characteristics based on stationary motel metallic fuel. In this work, a compact core design of a 1000 MWt TRU-burning SLFFR was developed using TRU-Ce-Co fuel, Ta-10W fuel container, and sodium coolant. Detailed neutronics, and thermal-fluidic analyses were performed to develop a compact core design. The analysis results demonstrated that the SLFFR of a zero TRU conversion would be feasible while satisfying the conservatively imposed design constraints. The safety analyses for hypothetical accidents are performed as well. These results confirmed that the sufficiently large negative feedback of the prompt fuel expansion provides the inherent safety characteristics of SLFFR.