

Nuclear Nonproliferation Modeling and Simulation (N²MS) Training at Virginia Tech

Alireza Haghighat

Virginia Tech

Nuclear Science and Engineering Lab (NSEL)

Nuclear Engineering Program, Mechanical Engineering Department

Arlington, VA

Advances in Nuclear Nonproliferation Technology and Policy Conference,
September 25-28, 2016, Santa Fe, NM

Outline

- Virginia Tech Nuclear Engineering Program (NEP) & Virginia Tech Transport Theory Group (VT³G)
- Nuclear Nonproliferation Modeling and Simulation (N²MS)
 - Subject matters and Courses
 - VT³G computational tools
 - textbooks and notebooks,
 - outreach activities, and
 - future plans.

Nuclear Program @ VT (nuclear.ncr.vt.edu)

- In 2007, under leadership of Dean Benson and former department head of Mechanical Engineering (ME) (Prof. Ball), the **nuclear engineering program (NEP)** was established at ME

Director

Prof. Alireza Haghighat, since March 2016

Graduate degrees (approved for Jan 2014)

MENG, MS and PhD degrees

Faculty

- Tenure & tenure-track
 - 1 Full Prof., 2 Assistant Profs., 1 new hire (Full Professor)
- Others: 1 Assoc. Prof. of Practice; 8 Affiliate faculty members

Education & Research

- VT Nuclear Program is engaged in different applications including ***power, security, medicine and policy***

Number of Graduates

- Before 2014, 30 Graduate certificates
- 2014, 1 MS
- 2015, 2 PhD's , 3 MENG
- 2016, 3 MENG

Campuses

- Blacksburg & Arlington

Research Areas

- Nuclear materials & Fuel
- Particle Transport Methods
- Reactor Physics
- Reactor Shielding
- Radiation detection
- Reactor Safety & Thermal-Hydraulics

Applications

- *Medical Imaging*
- *Nuclear Nonproliferation & Policy*
- *Nuclear Security & Safeguards*
- *Reactor Design*

Nuclear Science and Engineering Lab (NSEL) @ Arlington

NSEL at Arlington Operates under auspices of ICTAS* and Mechanical Engineering Department. It engages with various entities/organizations at Virginia Tech and beyond to address different applications including power, security, medicine, and policy (<http://nsel.ncr.vt.edu>)




*Institute of Critical Technology and Applied Science

• Faculty

- **VT-NCR** - Profs. Ahram, Khademian, and Roberts (from SPIA) and Prof. Schmid (from STS)
- **VT-Blacksburg** - Profs. Battaglia (ME), Hendricks (MSE), Hin (NE & MSE), Huber, Mariani and Vogelaar (Physics), Liu (NE), and Tafti (ME); Drs. Polys and Rajamohan (*Visionarium*)
- **Beyond VT** – Profs. Petrovic and Rahnema, and Dr. Yi (Georgia Tech), and I²S-LWR* group (Cambridge (UK), INL, Michigan, Poly Tech of Milan (Italy), U of Idaho, U of Tennessee, and Westinghouse); ANL, ORNL, INL;); Prof. Millet and Blair, and Admiral Leidig (from USNA); Prof. Afanasev (GWU)
- **Current Students with Virginia Tech Transport Theory Group (VT³G)**
 - Mohammad Al-hashish, Dennis Deardorff, Mohsen Hosseinian, Valerio Mascolino, Nate Roskoff, & Meng-Jen Wang.

NSEL Collaborations

Virginia Tech	Activity	Campus
Physics Department	Antineutrino detector - CHANDLER; GEM*STAR project	Blacksburg
Nuclear Engineering Program	Education & research	Blacksburg
School of Public and International Affairs (SPIA) & Department of Science and Technology in Society	Nuclear Science, Technology, and Policy (NSTP)	NCR
Federation of American Scientists	Taskforce on LEU nuclear fueled naval vessels	DC
US Naval Academy (USNA) (signed a partnership agreement, Aug. 2015)	Initiated benchmarking of the RAPID code system using USNA's subcritical facility (for nuclear safeguards)	Annapolis, MD
Naval Surface Warfare Center, Carderock Division (NSWCCD)	Tandem linear accelerator research; small modular reactor use in military	MD
Georgia Tech (lead) with 10 other organizations including VT	Design of Integral Inherently Safe LWR reactor system design	
Collaboration among NE, Physics, ME & MSE (advanced reactor design)	Safe, Secure, Sustainable Nuclear Power (<i>S³NPower</i>)	Blacksburg, ICTAS
Collaboration with the VT <i>Visionarium</i> Center	First-of-a-kind Environment for the Creation of a Collaborative Virtual Reality System	Blacksburg



VNEC nonprofit organization

Organization	Activities	Location
Virginia Nuclear Energy Consortium (VNEC) nonprofit organization*	<ul style="list-style-type: none"> Promotion of nuclear industry, education and research Membership include: AREVA, B&W, Dominion, GE, Newport News Shipbuilding, UVA, VCU, and VT Prof. Haghghat served as Chairman of the Board, Jan 2015 to July 2016 	Virginia

*On June 6, 2016, with help from NEI, VNEC organized the first *Virginia Nuclear Energy Summit*, and Prof. Haghghat gave an opening talk and participated in two panel discussions.

NNSA - Nonproliferation

- Competencies

- Remove, eliminate, and minimize the use of proliferation-sensitive materials.
- Safeguard and secure materials, technologies, and facilities.
- Detect and prevent the illicit trafficking of nuclear/radiological materials, technology, information, and expertise.

- *Provide R&D technology solutions for treaty monitoring, minimizing the use of proliferation-sensitive materials, and the application of safeguards and security.*
- *Provide unique technical/policy solutions and develop programs/strategies to reduce nuclear/radiological dangers.*

Need for Detection Technologies

➤ Research activities

- Various detection systems that mostly rely on radiation/particle detection
 - Difficulty - detectors provide counts and spectra, but do not provide accurate information on actual source (material composition and distribution)
- Advanced computation techniques
 - Generally, too slow, so it is used for testing scenarios and doing post-event analysis

➤ VT3G's activities

- Development of novel, problem-dependent techniques and tools that use simultaneous measurement and computation plus statistical inference

Need for Workforce Training

- Nuclear systems and their attributes
- Detection system and limitations for nonproliferation applications
- Computational methodologies and codes, their advantage/disadvantage for nonproliferation applications

N²SM Training at VT

- **Nuclear fuel cycles** and their components, and issues related to materials accountability and safeguards
- **Reactor systems**, reactor physics theory, and neutron diffusion theory and formulations
 - Multigroup and finite-volume formulations for solving diffusion equations; accuracy and limitations of these formulations
 - Computational methods and codes, and their limitations
- **Monte Carlo methods** with application to particle transport
 - Random processes and numbers; generation of random numbers
 - Variance reduction techniques (for acceleration of Monte Carlo methods) including hybrid Monte Carlo and deterministic with the use of deterministic importance function
- **Deterministic methods for particle transport**
 - Forward Linear Boltzmann Equation (LBE) versus the “importance” function
 - Importance function
 - Concept
 - Application, e.g., detector response, variance reduction of MC, cross-section generation
 - Theory and equations including integro-differential and integral LBE
 - Numerical techniques for solving the LBE, and their application and limitations
 - Computer codes and their limitations
- **Detection techniques and devices** for various particles including neutron, gamma, beta, and alpha

N²MS Courses at VT

Course #	Title
NSEG 5124	Nuclear Reactor Analysis
NSEG 5134	Monte Carlo Methods for Particle Transport
NSEG 5204	Nuclear Fuel Cycle
NSEG 5604	Radiation Detection and Shielding
NSEG 6124	Particle Transport Theory, Methods, and Application
NSEG 6134	Advanced Reactor Physics*
NSEG 6154	Advanced Numerical Particle Transport theory*

*Offered if there is sufficient number of students

VT-N²SM

Training on Numerical methods & Computer programming

- **NSEG 5124** – students develop a 1-D finite-volume diffusion code for solving eigenvalue and fixed-source problems.
- **NSEG 5134** – develop codes for random number generation, testing randomness, and techniques for sampling probability density functions; develop a 1-D Monte Carlo code system that includes algorithms for
 - testing different sampling techniques,
 - tallying approaches,
 - variance reduction, and
 - determination of statistical uncertainty and precision of results.
 - Analysis of the results of a Monte Carlo simulation for ensuring that the solution is unbiased and precise for both fixed source and eigenvalue problems.
- **NSEG 6124** – derivation of numerical formulations for solving integro-differential and integral forms of the LBE, and learn about issues such as accuracy, convergence and stability.

Training on Production codes

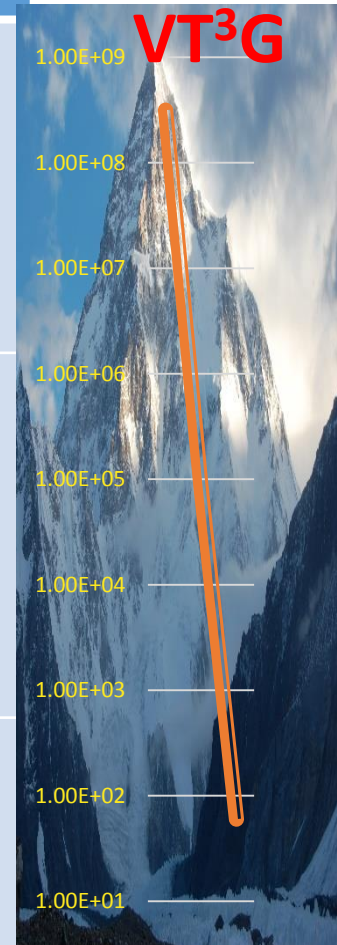
- In addition to the publicly available computer codes
- VT³G's students become trained in the use of in-house production codes and development of new techniques and codes

VT³G – Accomplishments

- Over the past 30 years, Prof. Haghghat and his students have been engaged in:
 - Development of various novel techniques & formulations
 - Development of advanced methodologies and codes for solving real-world problems, accurately and fast.
 - Application to
 - nuclear power,
 - nuclear nonproliferation and safeguards, and
 - radiation diagnostics and therapy.

VT³G : 30-year Journey

Year	Methodology	Computer code	Wall-clock time
2016	MRT	RAPID	Minutes & Seconds
2015	MRT	TITAN-IR	
2013	MRT	AIMS	
2009	MRT	INSPCTs	
2007	Hybrid MC-det. (AVR)	ADIES (e^-)	Days & Hours
2005	Hybrid det. – det.	TITAN (n, γ)	
1997	Hybrid MC-det. (automated VR - AVR)	A ³ MCNP (n, γ)	
1996	Parallel (3-D)	PENTRAN (n, γ)	Years & Months
1992	Vector & parallel (2-D)		
1989	Parallel processing (1-D)		
1986	Vector processing (1-D)		



Out-reach programs

- Numerous mini workshops at national and international conferences (e.g., INMM and topical meetings by reactor physics, mathematics and computation, and radiation protection and shielding divisions of ANS); planning a 3-hour workshop at the upcoming ICRS13-RPSD2016 meeting, Oct 2-6, 2016, Paris, France (<https://fr.xing-events.com/icrs13-rpsd2016.html>)
- Week-long workshop on '*Particle Transport Methodologies for Simulation of Nuclear Systems*'; 13 workshops have been held since 1995; last one was held in 2011 at Virginia Tech (<http://www.cpe.vt.edu/transport>)
- 3-day workshop on Methodologies for Spent Nuclear Fuel Pool Simulations (Safety and Safeguards), June 2015 at VT (<http://www.cpe.vt.edu/nuclear>)

Course Materials

- Lecture notes,
 - select textbooks,
 - technical papers & reports by VT³G and others,
 - hand-outs on special topics
 - access to VT³G code systems.
 - Select sections of the workshop manuals
- My text book on *Monte Carlo Methods for Particle Transport* (Jan 2015)
<http://www.crcpress.com/product/isbn/9781466592537>
(VT library provides access to my recently published book entitled.)

Ongoing & Future Activities

- In collaboration with School of Public and International Affairs (SPIA) and Department of Science Technology in Society (STS), I am working on a proposal for the establishment of a graduate Certificate* entitled '*Nuclear Science, Technology, and Policy (NSTP)*.'

*This Certificate will provide a unique capability at VT for the training of a cadre of engineers and scientists that can contribute to the formation of nuclear policies.

Virtual Reality

In collaboration with VT *Visionarium* and Adv. Comp. Research (ACR), we have started a new project entitled:

A first-of-a-kind environment for the creation of a Virtual Reality System (VRS)

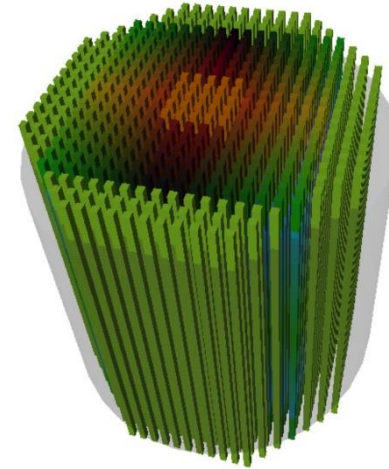
- A VRS can benefit both education and research as follows:
 - offering theoretical and experimental **courses**, especially **distance learning** courses and those with laboratories or experiments involving hazardous materials
 - **training** of professionals
 - **analysis** of results of modeling and simulation of systems
 - development of **tools for management of emergencies**

Virtual Reality - Phase 1

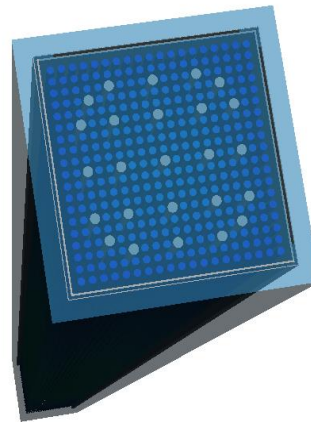
- Two of my graduate students (*Nate Roskoff and Val Maslcolino*) are working with me and *Drs. Polys and Rajamohan* and a student from School of Arts and Design in this project
- Tasks
 - Development of a **connectivity environment** between the visualization systems in *Blacksburg and Arlington*. This will make possible seamless interaction in a virtual environment between collaborators that are geographically separated.
 - Development of a **VRS for a spent nuclear fuel pool**. This virtual model tool includes our RAPID code system for monitoring the pool in real time.
- We have developed software using *Paraview* and *x3dom* packages (examples are available at <http://nse.lncr.vt.edu/vrs.html>)

Examples

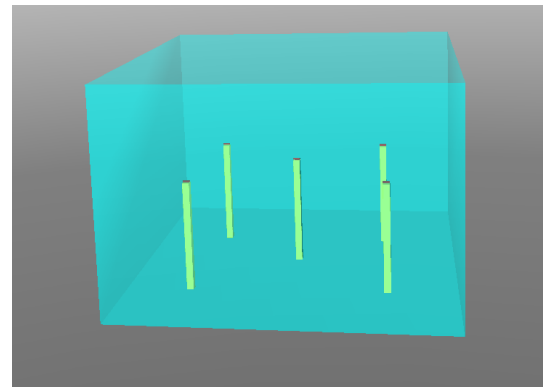
- Prototype S3NPower



- Typical PWR Fuel Assembly



- Virtual Spent Fuel Pool & real-time RAPID calculation



Ongoing & Future Work

- We are planning to extend our VRS work, and development of virtual reality experimentation (VRE) modules* for radiation physics and detection laboratories (located at different sites), and novel nonproliferation and safeguards technologies.

*These modules will assist us in offering the experimental courses to a larger groups of people, and provide more effective training before hands-on experimentation.

Thanks!

Question?