NNSA Consortium for Nonproliferation Enabling Capabilities (CNEC)

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Establishing and Advancing Nonproliferation and Nuclear Policy Education at U.S. Nuclear Science and Engineering Programs
ANS Annual Meeting 2017
Chair: Charles Ferguson, President, Federation of Atomic Scientists

CNEC's goal and objectives

Goal: Develop **new methods** and **new talent** to solve **future challenges** to nuclear nonproliferation by bringing together a **multidisciplinary team** from the physical sciences, data science, and political science

Objectives:

- Develop a multidisciplinary team: integrate data science (mathematics, statistics, computer science & engineering) with nuclear science (NE, physics) and political science

- Focus on future challenges: clandestine weapons development, illicit procurement networks, nuclear smuggling

- Conduct innovative research: produce new tools that enable proliferation detection

- Train new talent: engage students in nonproliferation R&D jointly conducted by universities and national laboratories

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CNEC thrust areas

Our research objectives focus on 4 thrust areas:

- *Signatures and observables* (S&O):
exploit S&O to detect proliferation activities

- *Simulation, analysis, and modeling* (SAM):
develop new SAM methods for detecting, localizing, identifying, and characterizing SNM

- *Data fusion and analytic techniques* (DFAT):
apply multi-source DFAT to detect and characterize proliferation activities

- *Replacement of dangerous radiological sources* (RDRS): develop viable replacements for potentially dangerous radiological sources used in industry
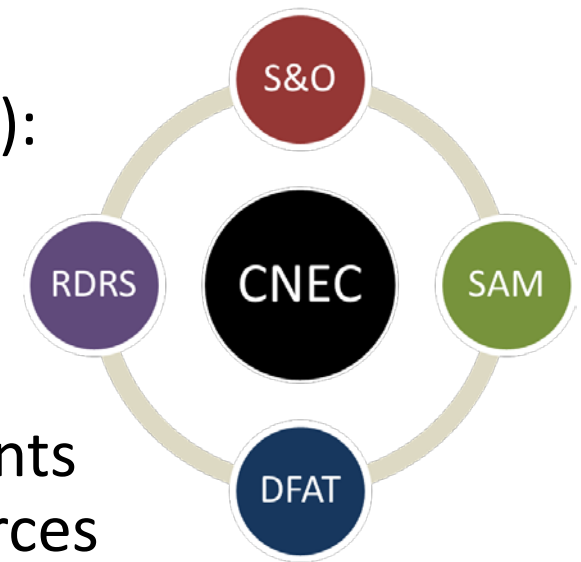
CNEC's partners
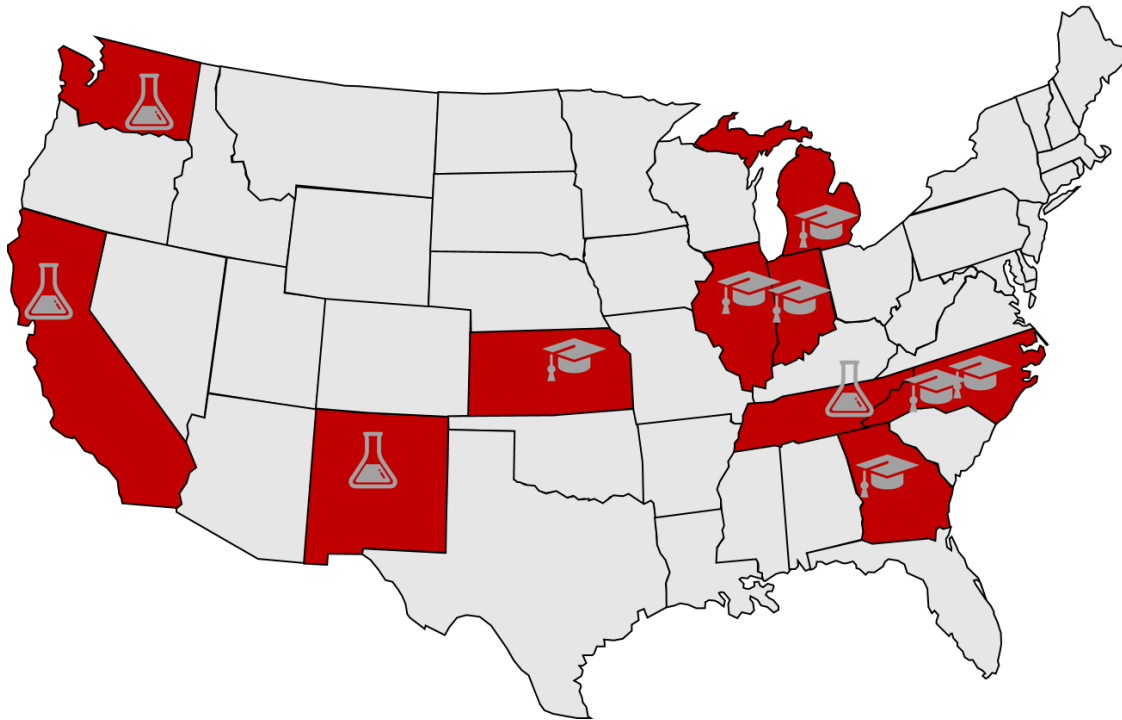
NC STATE UNIVERSITY

Georgia Institute of Technology

UNIVERSITY OF MICHIGAN

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

A·T
North Carolina Agricultural and Technical State University

KANSAS STATE UNIVERSITY

OAK RIDGE National Laboratory

LL

Los Alamos NATIONAL LABORATORY EST. 1943

Pacific Northwest NATIONAL LABORATORY

PURDUE UNIVERSITY

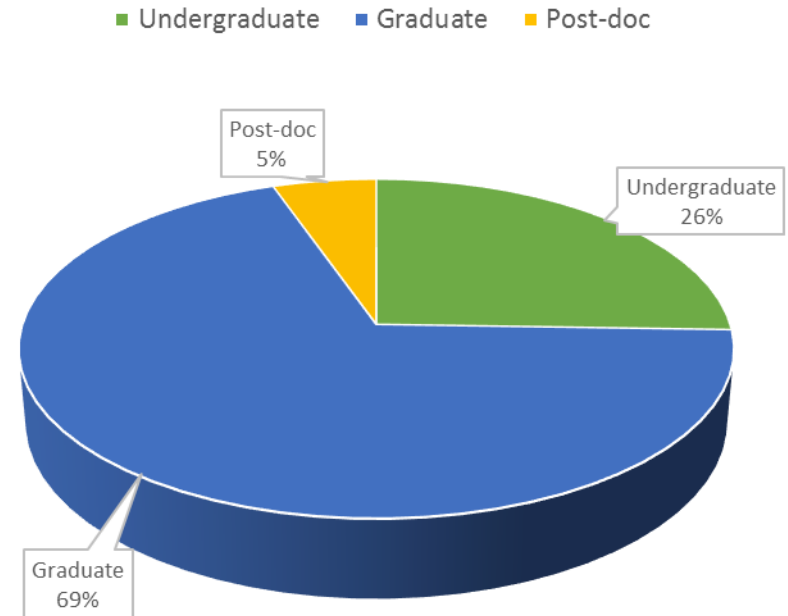Robin Gardner
Chief Scientist
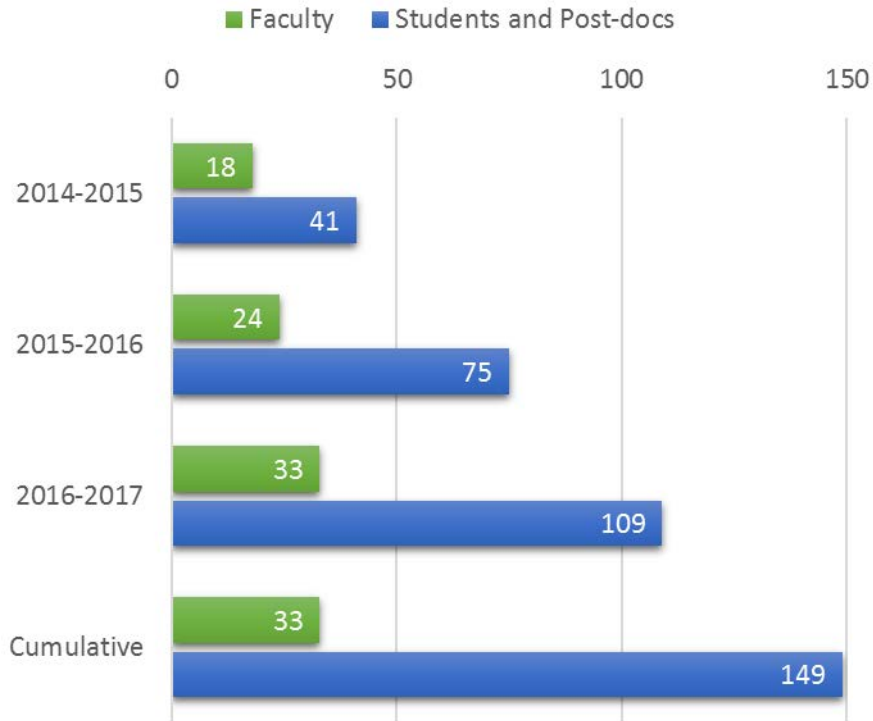
Yousry Azmy
Director

Stefani Buster
Project Manager

John Mattingly
Technical Director

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CNEC's university researchers

182 university researchers from 7 fields:
Nuclear Engineering • Mathematics • Physics • Computer Science
Electrical Engineering • Statistics • Political Science

Signatures and observables (S&O)

- **Goal**: exploit signatures and observables that enable the *phenomenological* detection of proliferation activities

- **Enabling capabilities**:
  - Develop sensor network data collection strategies
  - Apply machine learning tools
  - Characterize backgrounds
  - Develop novel statistical approaches to improving signal-to-noise

Clair Sullivan, UIUC
S&O Leader

- **Challenge problem**: locate a point source of radiation in an urban environment containing fluctuating background and nuisance sources

- **Accomplishments**:
  - Exploiting spatial correlation in sensor responses to locate sources in fluctuating background
  - Developing methods to predict background from time-series of measurements
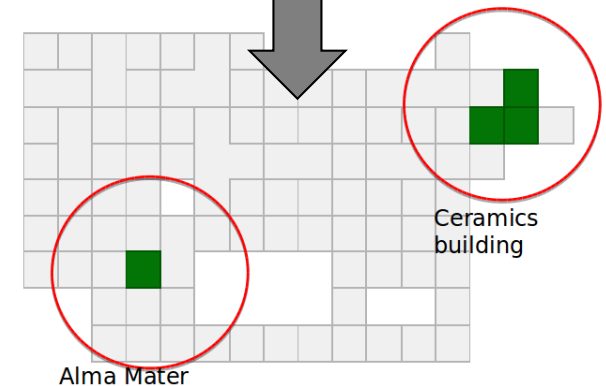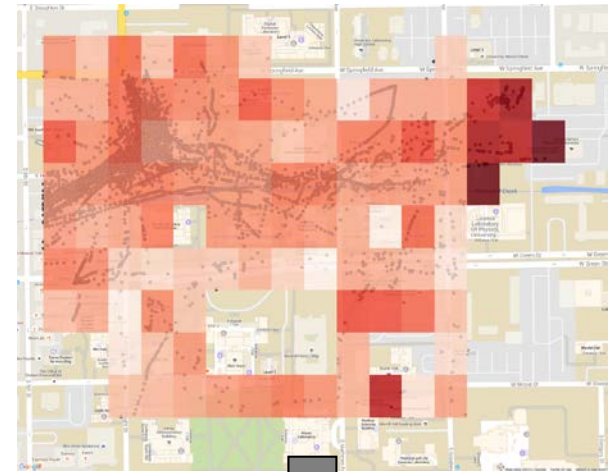
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S&O research highlights

Integrating geospatial analysis techniques in urban source search

- Geotagging roving radiation sensor measurements enhances sensitivity to anomalous sources

- Students: Karl Roth (CNEC fellow) and Myeonghun Jeong (post-doc)

Local Indicators of Spatial Association (LISA)

Ceramics building

Alma Mater

LISA-identified hot-spots
100% true-positive / 0% false positive

Simulation, analysis, and modeling (SAM)

- **Goal**: develop new simulation, analysis, and modeling methods to detect, locate, identify, and characterize SNM

John Mattingly, NCSU
SAM Leader

- **Enabling capabilities**:
  - Predict sensor responses in challenging operational scenarios
  - Infer properties of radiation sources from measured sensor responses
  - Integrate SA/UQ into forward simulations and inverse analyses

- **Challenge problem**: locate a point source of radiation in an urban environment using a network of sensors

- **Accomplishments**:
  - Developing a platform for evaluating alternative methods to locate a point source using a sensor network in a cluttered, noisy urban environment
  - Developing and evaluating alternative methods for source localization and sensor network optimization
  - Developing methods for computationally efficient deterministic and stochastic radiation transport simulations in heterogeneous environments

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SAM research highlights

Locating a source in an urban environment

- Bayesian inference using a computationally inexpensive physics model can locate a source in a cluttered urban environment

- Students: Jason Hite, Katie Schmidt, Jared Cook, Razvan Stefanescu (post-doc)
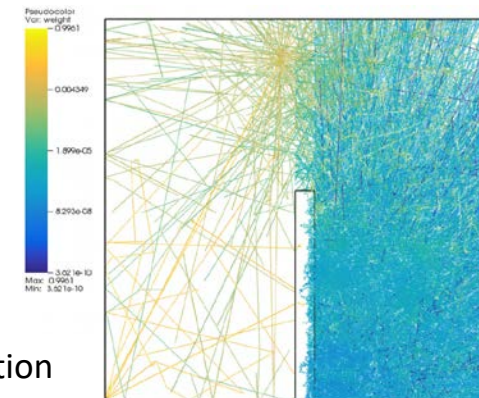
- Lab collaborator: ORNL

Optimizing transport simulations for precision and cost

- Transport models can be optimized to simultaneously reduce uncertainty and computational expense

- Student: Joel Kulesza

- Lab collaborator: LANL

Locating a Source in an Urban Environment

◇ Detector ● Source ▇ Building

Optimizing Transport Simulation Precision and Cost

Data fusion and analytic techniques (DFAT)

- **Goal**: apply multi-source data fusion and analytic techniques to enable the *data-driven* discovery of nuclear proliferation activities

Alyson Wilson, NCSU
DFAT Leader

- **Enabling capabilities**:
  - Collect, fuse, and analyze data from multiple streams to support the identification of proliferation signatures
  - Develop approximate simulation and modeling methods for interpreting observations
  - Develop methods to formulate decisions about sequential data collection from multiple streams

- **Challenge problem**:
  - Detect and characterize proliferation events and proliferation enterprise networks

- **Accomplishments**:
  - Developing cooperative pursuit strategies for evasive adversary
  - Developing methods to data-mine the Bitcoin network to detect illicit transactions
  - Exploiting social media to enhance detection of natural disasters
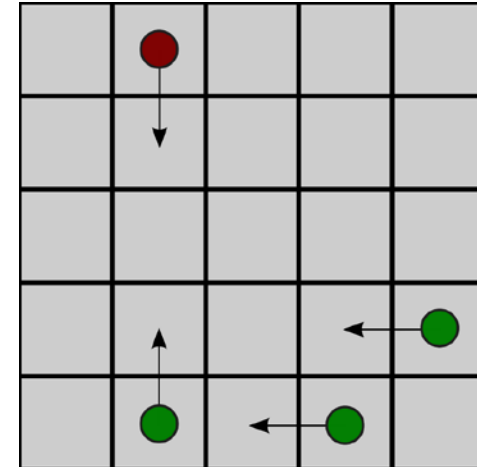
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DFAT research highlights

**Cooperative search for pursuing evasive adversary**

- Adversary's movement can be predicted from pursuers' sequential observations using Bayesian inference

- Student: Nick Meyer (CNEC fellow)

- Lab collaborator: PNNL

Pursuit of Evasive Adversary

Detecting illicit Bitcoin transactions

- Graph analysis of Bitcoin exchanges could be used to detect money laundering

- Student: Stephen Ranshous

- Lab collaborator: PNNL
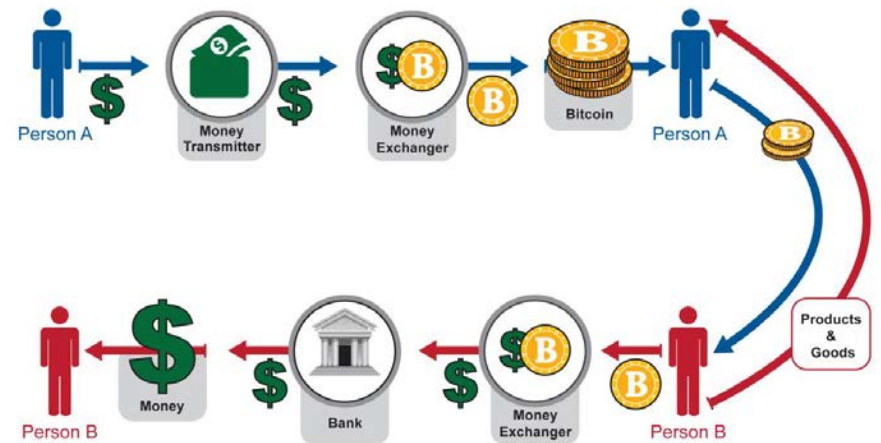
Structure of Bitcoin exchange

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Replacement of dangerous radiological sources (RDRS)

- **Goal**: replace potentially dangerous (chemical and nuclear) radiation sources in industrial and medical instruments with safer alternatives

Bill Dunn, KSU
RDRS Leader

- **Enabling capabilities**:
  - Apply inverse analyses of neutron inelastic scatter and capture gamma measurements to infer rock elemental composition and density
  - Construct experiments to benchmark Monte Carlo predictions of new instrument performance

- **Challenge problem**: optimize design of oil-well logging tool that replaces AmBe neutron source and ^{137}Cs gamma source with DT generator

- **Accomplishments**:
  - Developing advanced inverse analyses that enable replacement of AmBe and ^{137}Cs with a DT generator
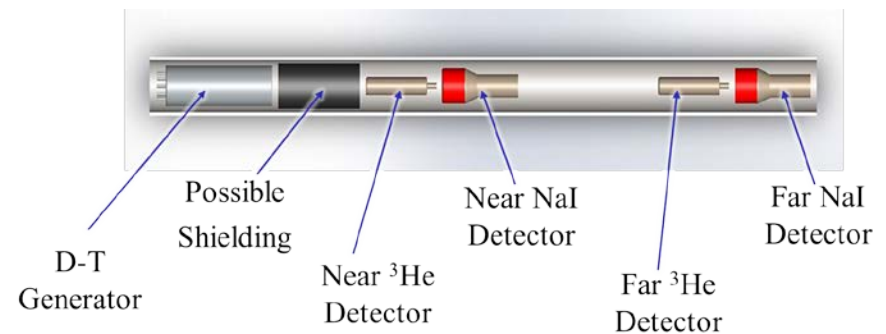 - Constructing a prototype oil-well logging tool to benchmark Monte Carlo simulations of performance

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RDRS research highlight

Oil-well logging tool benchmark testbed

- KSU assembled a prototype oil-well logging tool that replaces AmBe and ^{137}Cs sources with a DT generator

- KSU also constructed a simulated down-hole environment to test regression methods for estimating composition of surrounding medium

- Students: Maria Pinilla, Aaron Hellinger, Long Vo

D-T Generator | Possible Shielding | Near ³He Detector | Near NaI Detector | Far ³He Detector | Far NaI Detector
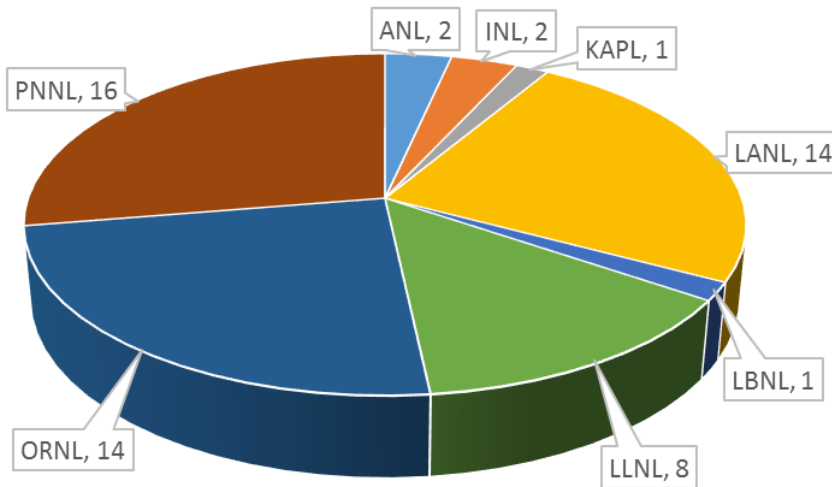
Dissemination

- 47 peer-reviewed journal articles
- 85 conference proceedings papers
- 18 theses and dissertations
- 63 presentations, seminars, and colloquia
  at other universities and national laboratories

Imre Pazsit (Chalmers), John Mattingly
(NCSU), and James Peltz (NNSA)
M&C 2017 Special Session Chairs

- Special session on *Radiation Source Localization* at IEEE
  Multisensor Fusion Conference in Germany in September 2016
- Panel session on *NNSA Academic Consortia* at ANS Advances in
  Nonproliferation Technology and Policy meeting in Santa Fe in
  September 2016
- Four special sessions on *Inverse Problems in Nuclear
  Nonproliferation* at ANS Mathematics & Computation (M&C)
  meeting in Korea in April 2017
- Sessions on *Threat Material Detection* and *Radiation Data
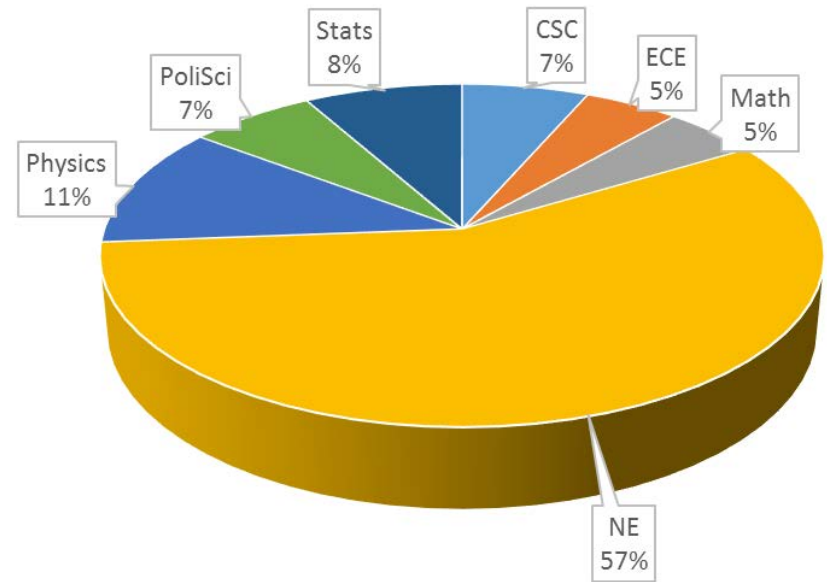 Analytics* at IRRMA-X meeting in Chicago in July 2017

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CNEC student internships at national labs

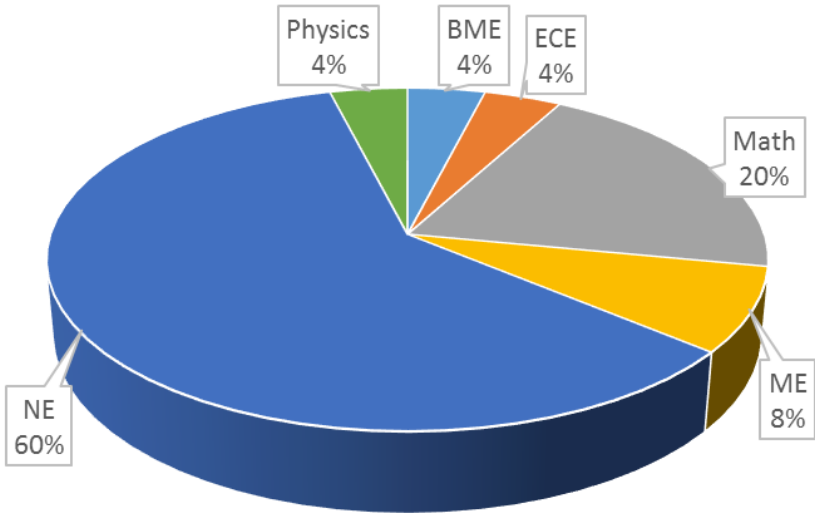- 58 student internships at 8 national labs including 2017
- 27 new internships in Summer 2017
- 48 lab projects seeking students identified by lab POCs

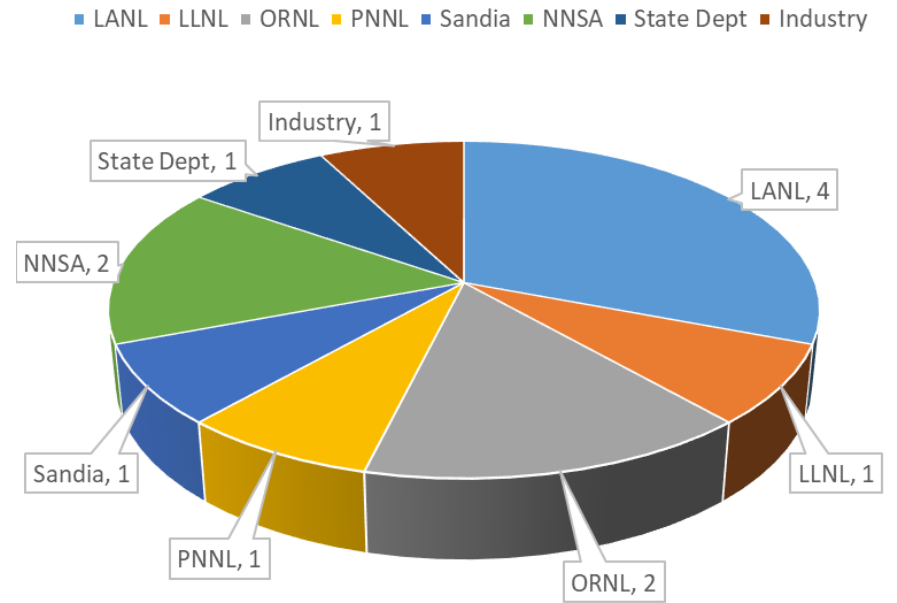# CNEC student graduations

Pie chart (left) legend: BS, MS, PhD
- BS, 7
- MS, 7
- PhD, 11
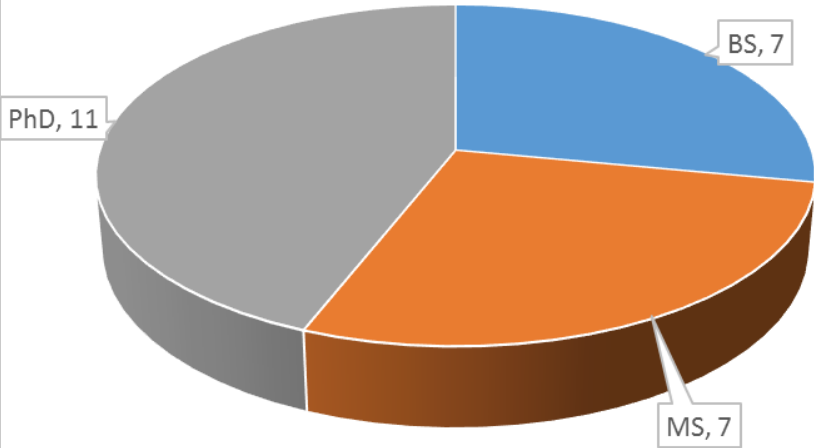
Pie chart (right) legend: BME, ECE, Math, ME, NE, Physics
- Physics 4%
- BME 4%
- ECE 4%
- Math 20%
- ME 8%
- NE 60%

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CNEC student & post-doc placement
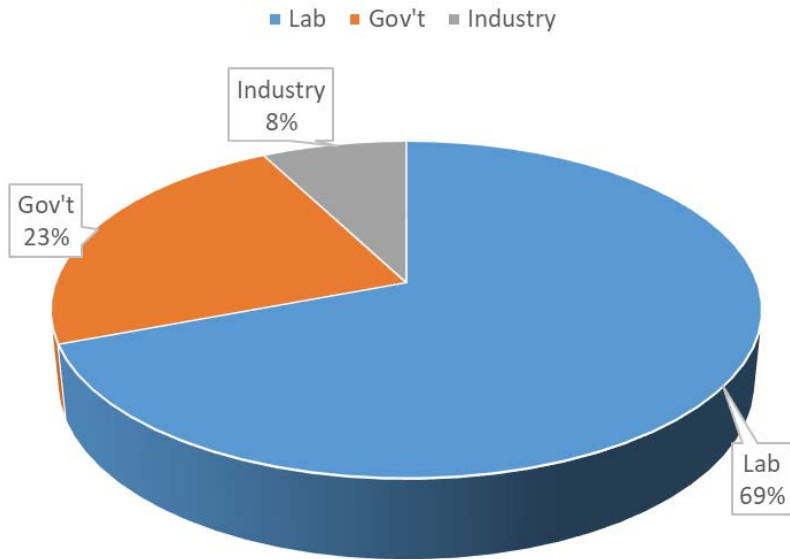
Experiments with Cat I SNM at Nevada National Security Site

- CNEC conducted the first university-directed experiments with Category I SNM at the Device Assembly Facility (DAF) on the Nevada National Security Site in 2015

- Students measured weapons-grade plutonium metal and highly enriched uranium metal using gamma and neutron instruments

- Three experiments were conducted in summer 2015

- We returned in summer 2016 to conduct two new experiments

- Four new experiments are scheduled for summer 2017

- These data are central to several research projects

- They are also being integrated into several courses at the CNEC universities
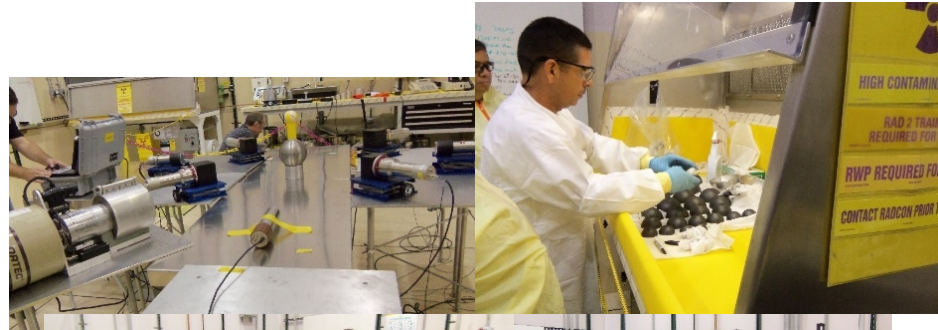
University and high school outreach programs

- University student and faculty outreach:
  - CNEC-hosted seminars for students and faculty
  - Invited talks by CNEC investigators at other universities and national laboratories

Lisa Marshall, NCSU
Director of Outreach

Bernadette Kirk
Outreach Consultant

- High school student and educator outreach:
  - Young Investigators' Summer Program
  - Science Teachers' Workshop in Nuclear Engineering
  - Research lectures and hands-on lab experiments

Young Investigators' Summer Program 2015

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Faculty development program

- NCSU committed to recruit and develop 2 new faculty specializing in nuclear security R&D
- These new faculty will be jointly supported by the NCSU College of Engineering and ORNL via joint faculty appointments (JFAs)

Rob Hayes, NCSU
CNEC ORNL JFA

- In Fall 2015, we hired Robert (Rob) Hayes
  - Specialties: nuclear emergency response and consequence assessment using environmental sampling and retrospective dosimetry
  - Prior experience: WIPP (assessed consequences of offsite release following waste container explosion) and RSL (served as radiological emergency responder)
- Rob is an ORNL JFA in the Nuclear Security Modeling group

- In Spring 2017, we interviewed 3 new candidates for a second JFA
- A new professor specializing in nuclear security R&D will join the NCSU NE faculty in Fall 2017

Ph.D. fellowship program

- CNEC sponsors a competitive fellowship program for Ph.D. students
  - The intent of the fellowship is to foster promising Ph.D. research in nuclear nonproliferation both **within and without** the consortium
  - Proposed research can be in the physical sciences, engineering, or social sciences - it must be novel and clearly support nuclear nonproliferation
  - Applicants are evaluated on the merit of their research proposal, CV, and GPA
  - Students from institutions outside the consortium are **equally** eligible

Bill Martin, UM
Fellowship Comm. Chair

Year	Fellow	University	Research topic
2015-2016	Jennifer Nguyen	Michigan	Pulse shape discrimination and timing resolution in stilbene with silicon photomultipliers
	Dylan Hoagland	NCSU	Accelerated iterative solutions of radiation transport problems
	Karl Roth	Illinois	Application of big data analytics to radiation sensor networks
	Raffi Yessayan	NCSU	Deterministic radiation transport on unstructured meshes using massively parallel platforms
2016-2017	Carl Britt	Tennessee	Classifier fusion and other machine learning methods applied to mobile radiation sensors
	Alexander Clark	NCSU	Fission physics parameter estimation using neutron multiplicity counting experiments
	Samuel Cope	NCSU	Assessing radiological release source term from air monitoring
	Adam Drescher	UT Austin	Applying gamma coincidence spectroscopy to characterize irradiated nuclear material
	Joel Kulesza	Michigan	Optimization of hybrid deterministic / Monte Carlo radiation transport methods
	Nicholas Meyer	NCSU	Tracking nuclear material using allocation algorithms for sequential decision problems
	Connor Awe	Duke	Detection of coherent neutrino-nucleus scattering
	Samuel Hedges	Duke	Experiments at Spallation Neutron Source to characterize coherent neutrino-nucleus scattering
	Scott Richards	Tennessee	Reduce cost of physics-based fissile material depletion calculations

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Nuclear engineering and political science collaboration

- NCSU School of Public and International Affairs (SPIA) is directed by the departments of Political Science (PS) and Public Affairs (PA)

- There are three PS faculty whose research and courses focus on nonproliferation:
  - Bill Boettcher
  - Mark Nance
  - Robert Reardon

- SPIA offers a Master of International Studies (MIS) degree
- SPIA created a new specialized *Nonproliferation Policy* track for the MIS in 2015

- SPIA and NE created a new graduate certificate program in nuclear nonproliferation in 2016

Graduate certificate in
Nuclear Nonproliferation Science and Policy (NNSP)

- Objective: provide a cross-disciplinary education on the technical and global policy issues of nuclear nonproliferation

- Motivation: the implementation of new nonproliferation initiatives will fall to a rising generation of workers with interdisciplinary backgrounds in technology and policy

Bill Boettcher, NCSU
Certificate Coordinator

- Structure:
  - Interdisciplinary mix of 4 graduate courses in nuclear engineering and political science
  - Many courses are available via distance education
  - Open to graduate students in the physical sciences, engineering, and social sciences **and** off-campus post-graduate professionals

- 8 students enrolled, 2 completed:
  - 5 nuclear engineering
  - 2 political science
  - 1 mathematics

Sample of certificate program courses

Course	Title
NE 512	Nuclear Fuel Cycles
NE 520	Radiation and Reactor Fundamentals
NE 521	Principles of Radiation Measurement
NE 541	Nuclear Nonproliferation Technology and Policy
NE 795	Characterization of Special Nuclear Material
PS 531	International Law
PS 533	Global Problems and Policies
PS 5**	Science, Technology & International Security
PS 5**	Nuclear Nonproliferation Policy & Process
PS 5**	Nuclear Weapons Strategy and Proliferation

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Cornerstone courses in NNSP certificate: NE541

NE541: *Nuclear Nonproliferation Technology and Policy*

- NE course originally developed in 2009 for NNSA Next-Generation Safeguards Initiative (NGSI)
- Topics:
  - International nonproliferation agreements (NPT, SALT, START, CTBT, FMCT, NWFZs...)
  - Advanced technologies that enable verification of compliance
- Guest lectures by ORNL scientists, including:
  - Nuclear export control
  - Uranium enrichment safeguards
  - Spent fuel safeguards
  - Post-detonation nuclear forensics
- Guest lectures by NCSU Political Science faculty:
  - Nuclear weapons strategy
  - International negotiations
- One-week hands-on workshop at ORNL

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Cornerstone courses in NNSP certificate: PS598

PS598: *Nuclear Nonproliferation Policy & Process*

- New PS course developed in 2015
- Topics:
  - History and status of international nuclear nonproliferation regime
  - Supply- and demand-side explanations for nuclear proliferation
  - Current efforts to achieve "global zero"
  - Evolution of current US nonproliferation policy regarding Iran and DPRK
  - Influence of emerging technologies on future nonproliferation initiatives

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Summary

- CNEC's primary objective is the education and training of new scientists to meet the future challenges of nuclear nonproliferation

- NCSU has an institutional commitment to support interdisciplinary education in nuclear nonproliferation science and policy
  - Mature nonproliferation research and education programs in Nuclear Engineering (NE) and Political Science (PS)
  - Supported by multiple faculty in both departments
  - Active collaboration between NE and PS in research and course development
  - New interdisciplinary graduate certificate in nonproliferation science and policy

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