



Penn State's Nuclear Engineering Program in the Nuclear Renaissance

**Dr. Jack Brenizer
Professor of Mechanical and Nuclear Engineering
Program Chair of Nuclear Engineering
Pennsylvania State University**

May 21, 2007



PSU Nuclear Engineering Goals

- Turn out the best nuclear engineering students in the country
- Have the top ranked B.S. NE program in the U.S.
- Have the top ranked Graduate NE programs in the U.S.
- Be the first place recruiters visit
- Be the first place people turn to for research projects
- Involve our alumni - PSNES



Penn State University

- Founded in 1855 as an agricultural college
- Admitted its first class in 1859
- Awarded more than a half-million degrees
- Pennsylvania's largest source of baccalaureate degrees at least since the 1930s
- Administrative and research hub at the University Park campus, Penn State has 23 additional locations across Pennsylvania
 - 2006 Enrollment– 40,500 (UP); total: 83,721



College of Engineering

- Established in 1896
- Mission is to produce graduates who are world-class engineers: aware of the world, solidly grounded in fundamentals, technically broad in thinking, effective in group operations, versatile, and customer oriented
- Faculty
 - 284 full-time tenured and tenure-track members at University Park
 - 124 full-time members at other Penn State locations
- Administers more than \$92.6 million annually in research expenditures, which is supported by industry and federal partners



NATIONAL RANKINGS

- PSU ENGINEERING ranks among the largest and highest quality institutions in the U.S.
 - Awarded over 82,000 Engineering Degrees
 - 34,000 alumni work in Pennsylvania
- U.S. News & World Report:
 - Ranked 16th for best undergraduate engineering program
 - Ranked 21st for best graduate engineering program



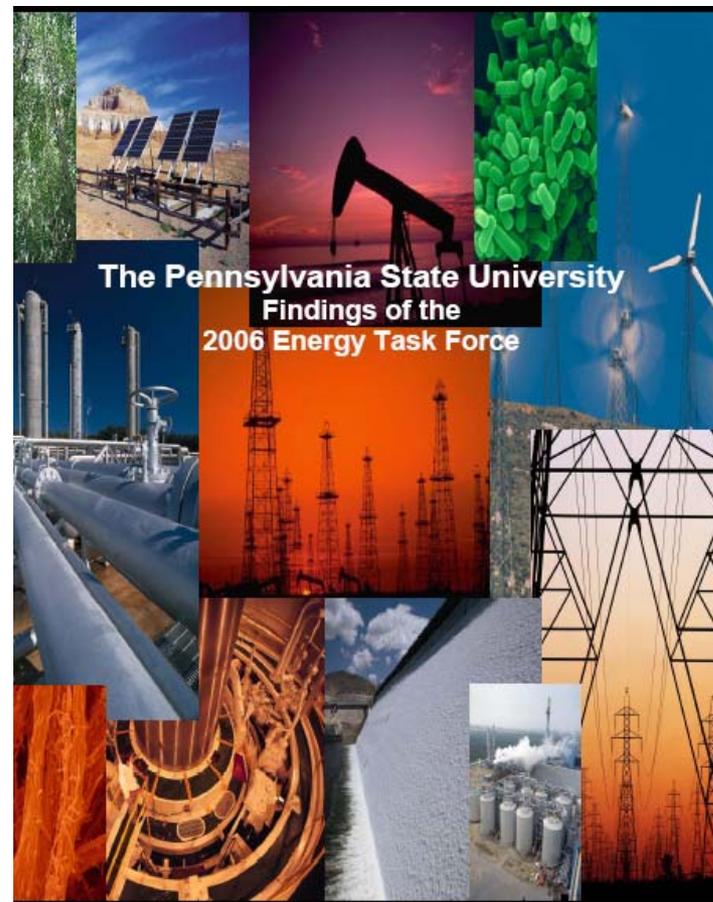
New University Initiative In The Area Of Energy

**Formation of the Penn State Institutes
of Energy and the Environment**

**Along with the institute, there will be
24 new faculty positions campus
wide (6 per year)**

**MNE Department held a retreat to
determine focus areas**

**College of Engineering held a retreat
on March 31st to determine the
focus areas**





Nuclear Engineering History

- Nuclear Engineering programs began at many universities in the early to mid-60's
- Often started as graduate degree programs
- Later added an undergraduate degree in nuclear engineering
- Penn State Nuclear Engineering
 - 1955 – Research reactor went critical**
 - 1959 – Dept. formed; M.S. degree offered**
 - 1961 – first graduate degree granted**
 - 1963 – Ph.D program initiated**
 - 1966 – first Ph.D. conferred**
 - 1968 – initiated B.S. degree program**
 - 1998 – ME and NE Departments merged**



Department of Mechanical and Nuclear Engineering Structure

- Two separate degree programs
 - Nuclear Engineering – (105 UG, 51 Grad)
 - Mechanical Engineering – (661 UG, 175 Grad)
- NE enrollment breakdown (Fall 06)
 - B.S. – 105
 - M.S. – 23
 - Ph.D. – 28
 - M.Eng. – >94 distance (off-campus)



NucE Factoids

- Pro nuclear atmosphere in US, prospect of new plants & jobs attracting undergraduates
- Undergraduate enrollment was increasing at steady 12% rate from 2000 to 2005
 - Very little UG recruiting last year
 - About the same enrollment (UG) this AY
- Approximately 33% of NE majors chose to go with concurrent degrees
- Offer a Master's of Engineering in Nuclear Engineering via distance education
- Colloquium series – improved and expanded



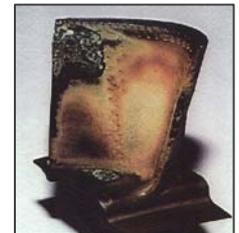
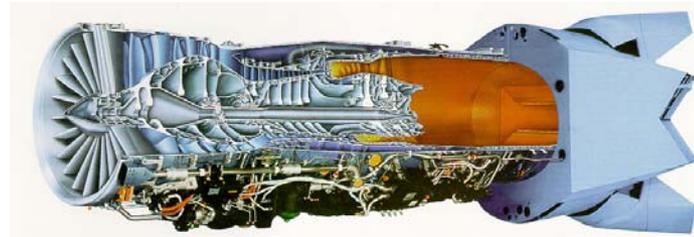
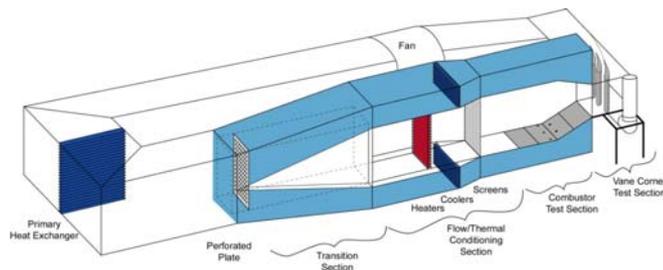
New Faculty Hires

Dr. Karen A. Thole, MNE Department Head, 2006



**BSME and MSME, University of Illinois
PhD, University of Texas, Austin
Post-Doc, University of Karlsruhe, Germany**

**Assistant Professor, 1994-99, University of Wisconsin-Madison
Assistant Professor – Professor, 1999-2006, Virginia Tech
Assistant Department Head, 2004-06, Virginia Tech
William S. Cross Professor, 2005-06, Virginia Tech**





New Assistant Professor in Nuclear Engineering

- **Faculty opening was for an Assistant Professor in nuclear engineering with overlap in mechanical engineering**
 - **Dr. Seungjin Kim**
 - **1999 PhD in Nuclear Engineering, Purdue University**
 - **2000 Post-Doc, Purdue University**
 - **2003 Assistant Professor, Univ of Missouri-Rolla**
 - **Area of expertise is thermal hydraulics**



Nuclear Engineering Enrollments and Degrees Survey, 2005 Data

Number 58

Oak Ridge Institute for Science and Education

2006

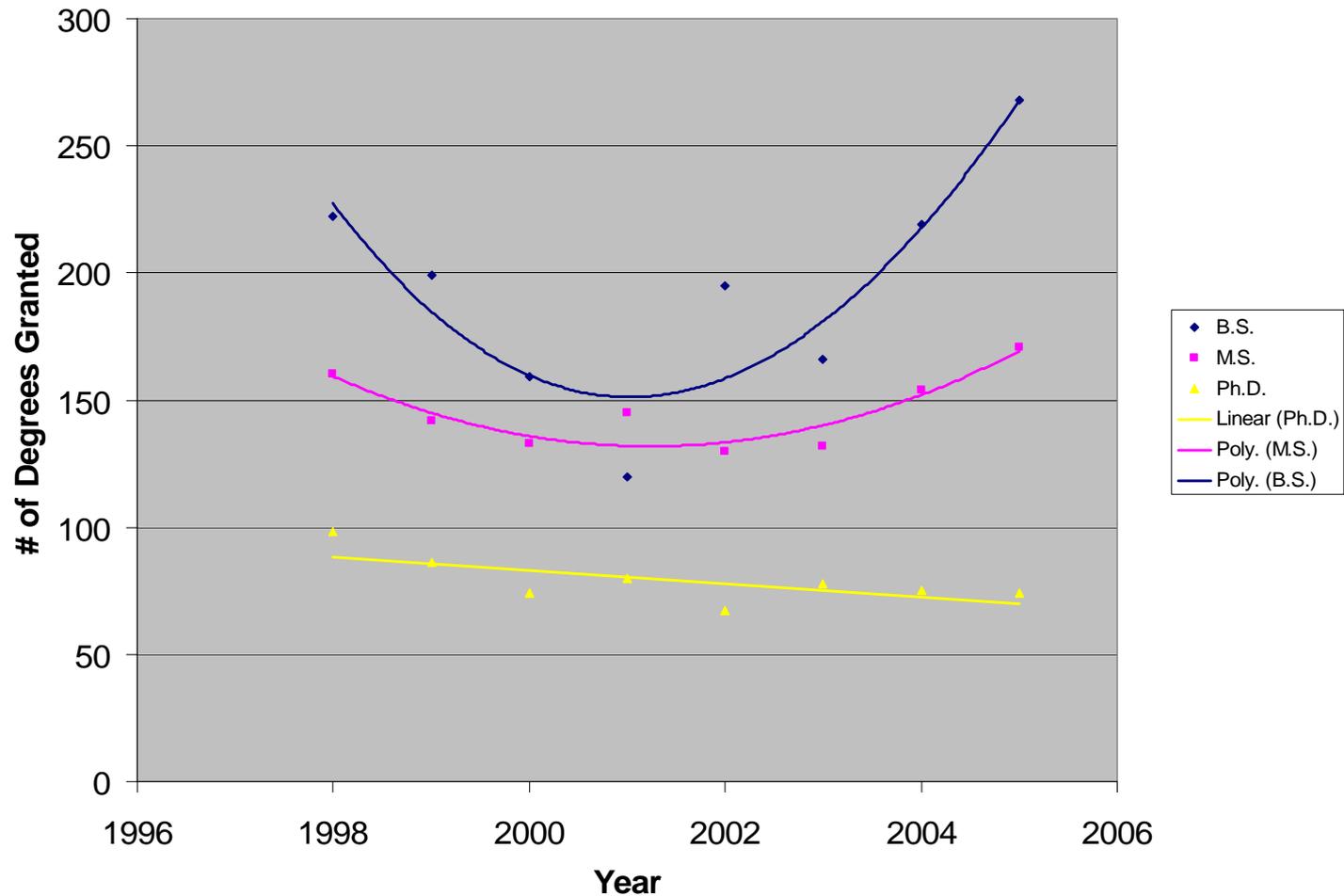
Table 1. Nuclear Engineering Degrees, 1998-2005

Year	Degrees		
	B.S.	M.S.	Ph.D.
2005	268	171	74
2004	219	154	75
2003	166	132	78
2002	195*	130	67
2001	120	145	80
2000	159	133	74
1999	199	142	86
1998	222	160	98

*Three programs were discontinued/out-of-scope after 2002 and not included in the 2003 survey. These three programs reported a total of 17 B.S. degrees in 2002.

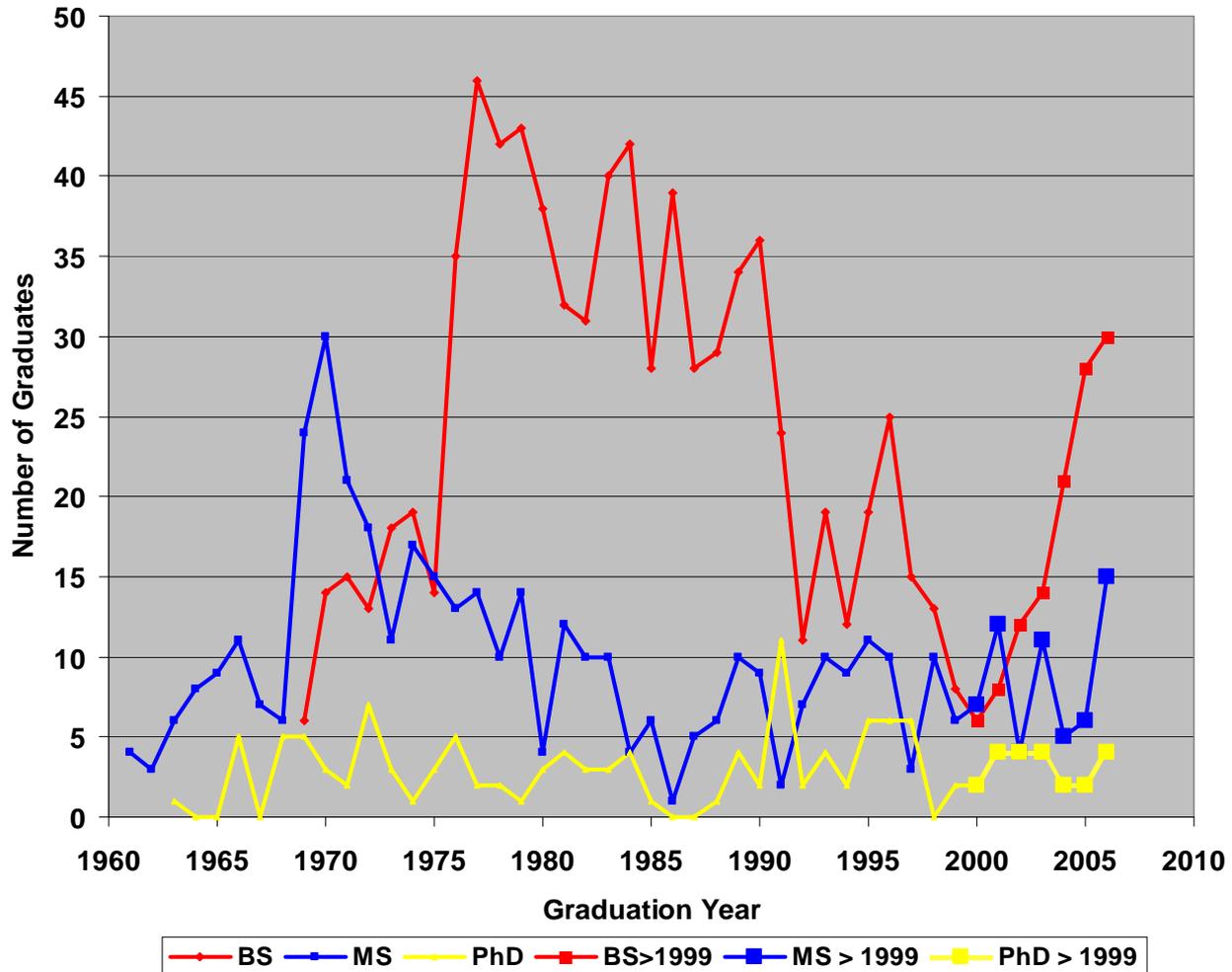


Nuclear Engineering Degrees, AY 1998-2005





PSU NE Degrees



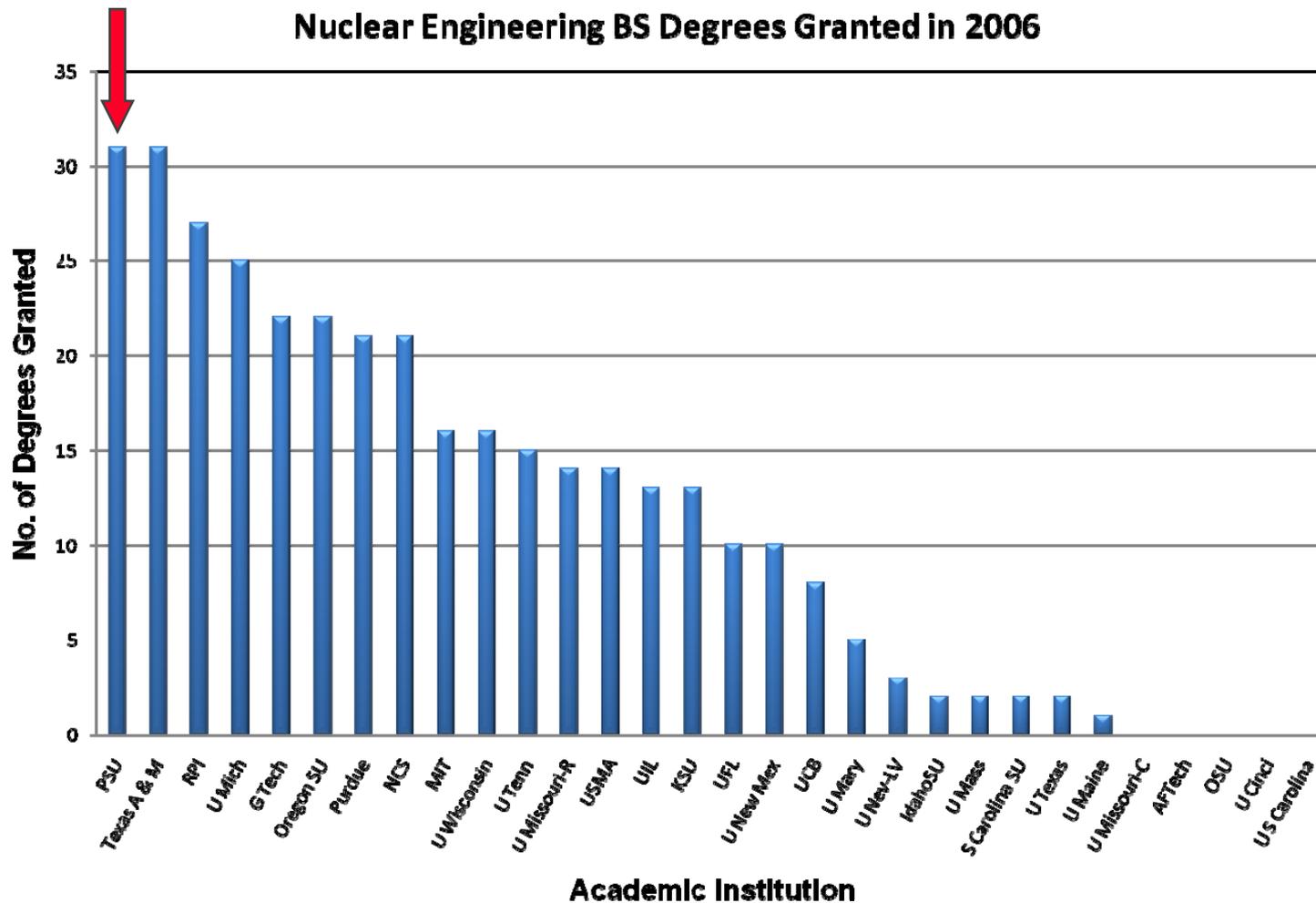


Undergraduate Programs

B.S. in Nuclear Engineering

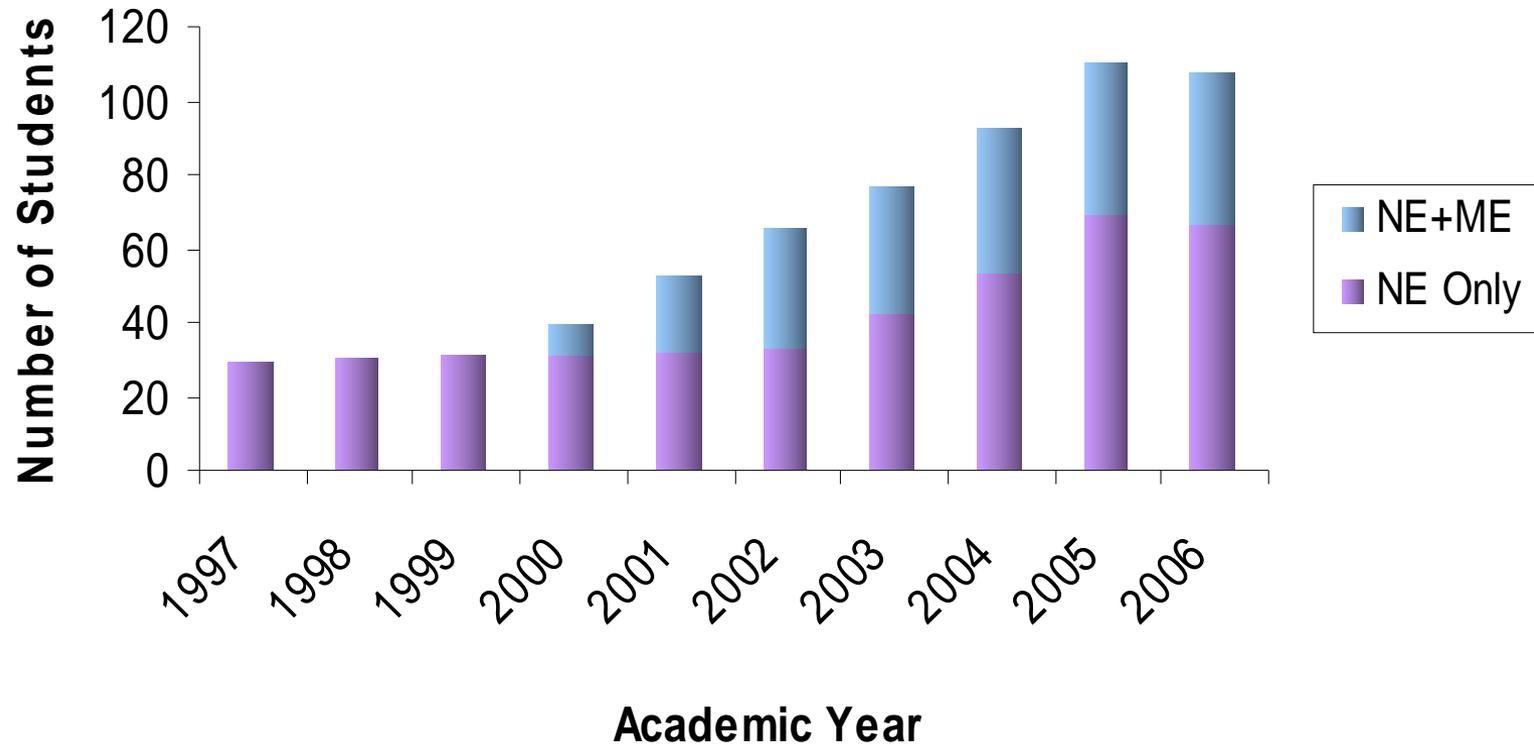


Nuclear Engineering BS Degrees Granted in 2006





NUCLEAR ENGINEERING JUNIORS AND SENIORS



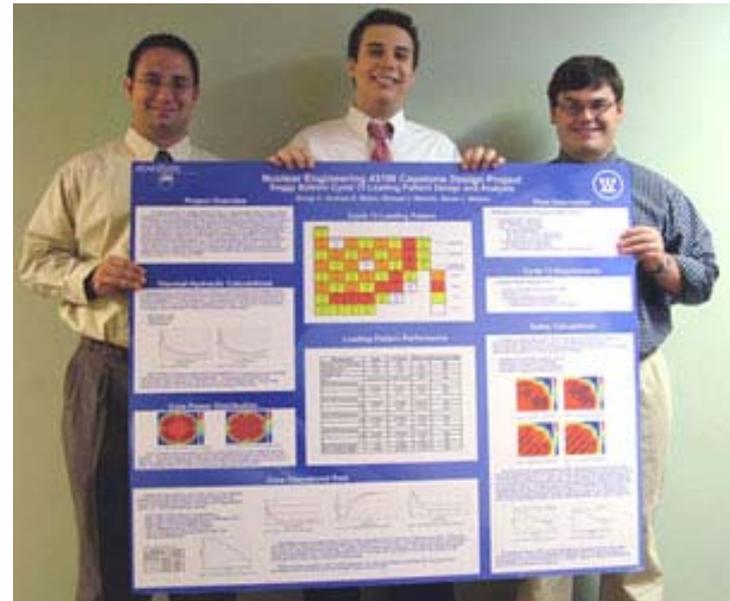


Student Recognition in Student Competitions in 06-07



**Penn State FSAE Team
2nd Place at the 26th Annual
Competition - 140 teams from
14 countries, May 2006**

**Penn State ANS Student Design
Team - 1st Place at the ANS
Competition, November 2006**





Graduate Programs In Nuclear Engineering

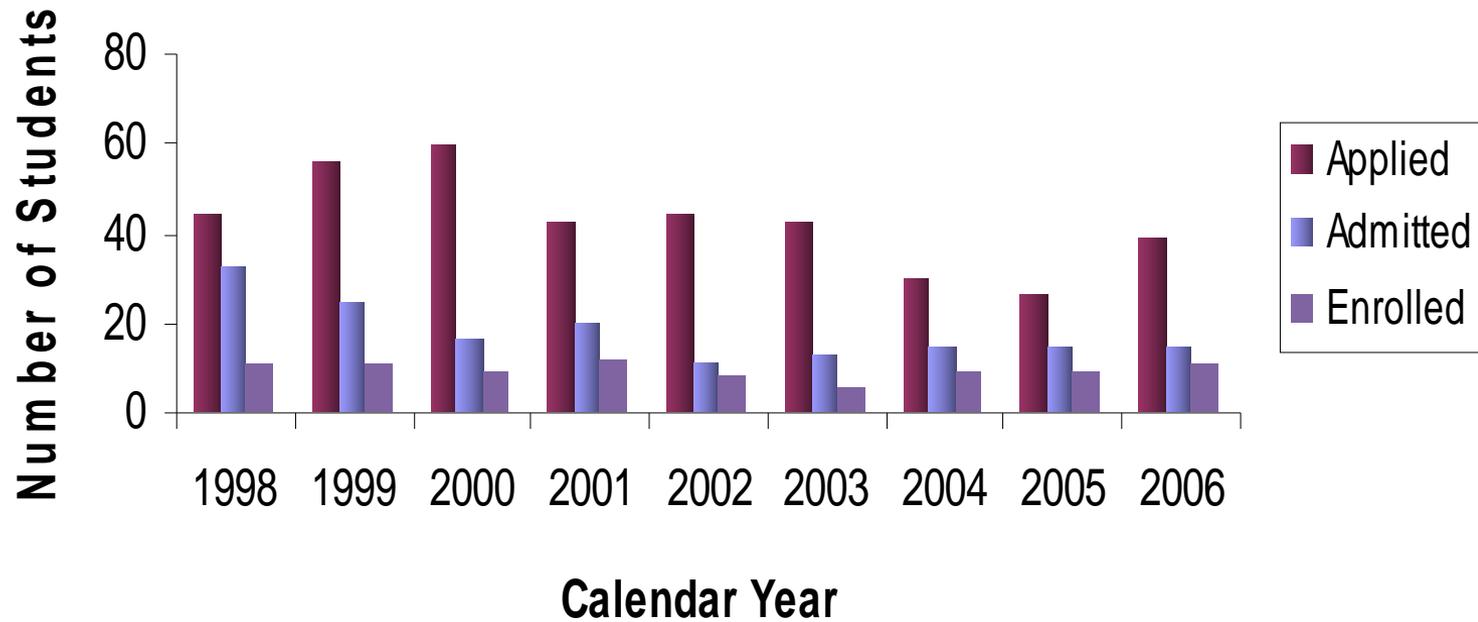
M.S.

M.Eng.

Ph.D.



NE GRADUATE ADMISSIONS



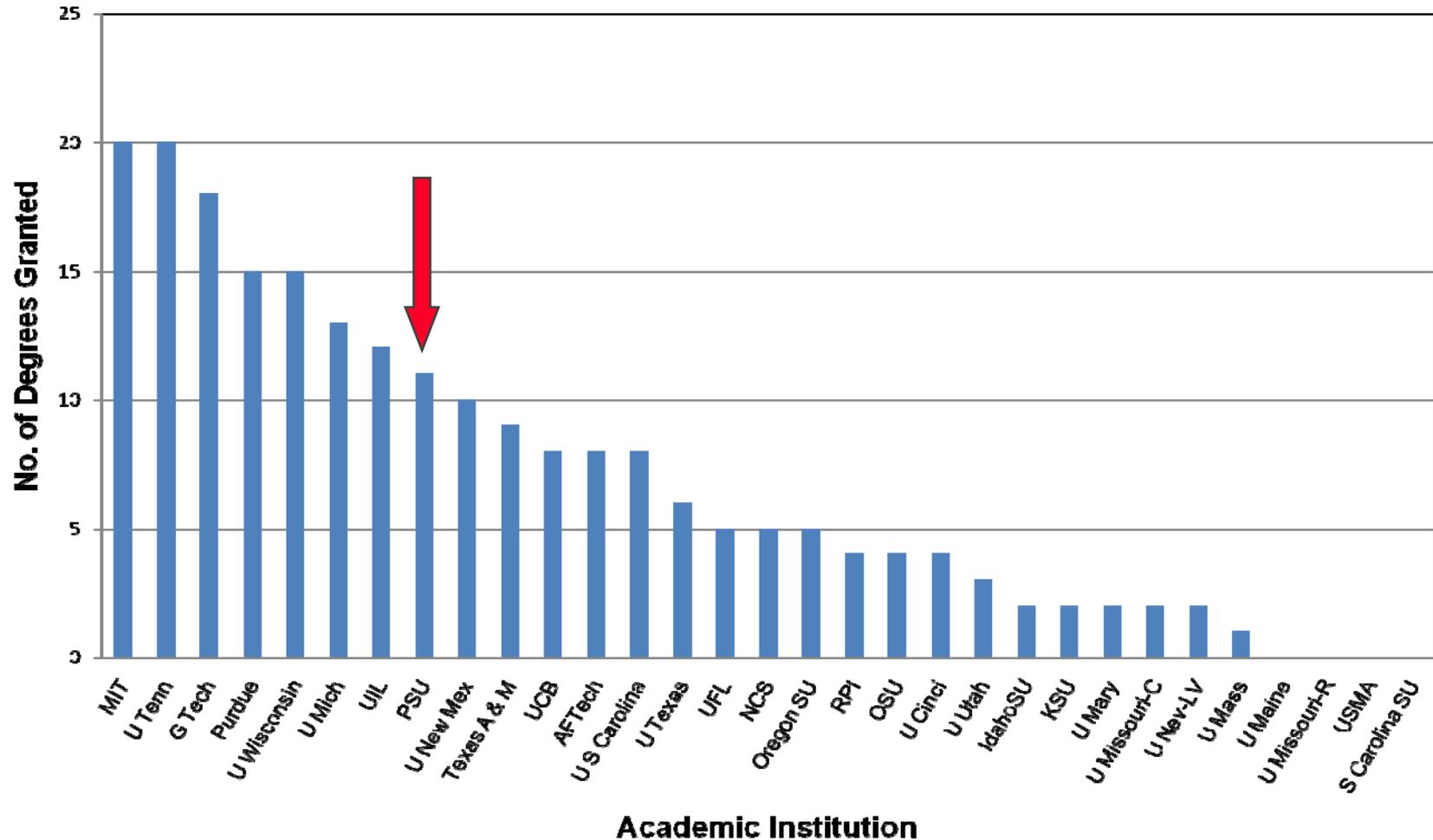


NucE Graduate Programs

- Grant an average of 12 graduate degrees per year
 - ~ 8 M.S.
 - 3-4 Ph.D.
- Active research programs in both nuclear power and nuclear science
 - Interdisciplinary research
 - Good mix of industry and federal funding
 - Currently working on projects sponsored by
 - DOE
 - NRC
 - Naval Reactors (Bettis and KAPL)
 - PSU Nuclear Engineering has an excellent reputation for delivering the results in a timely manner
- DHS is seeking help from these same departments and agencies

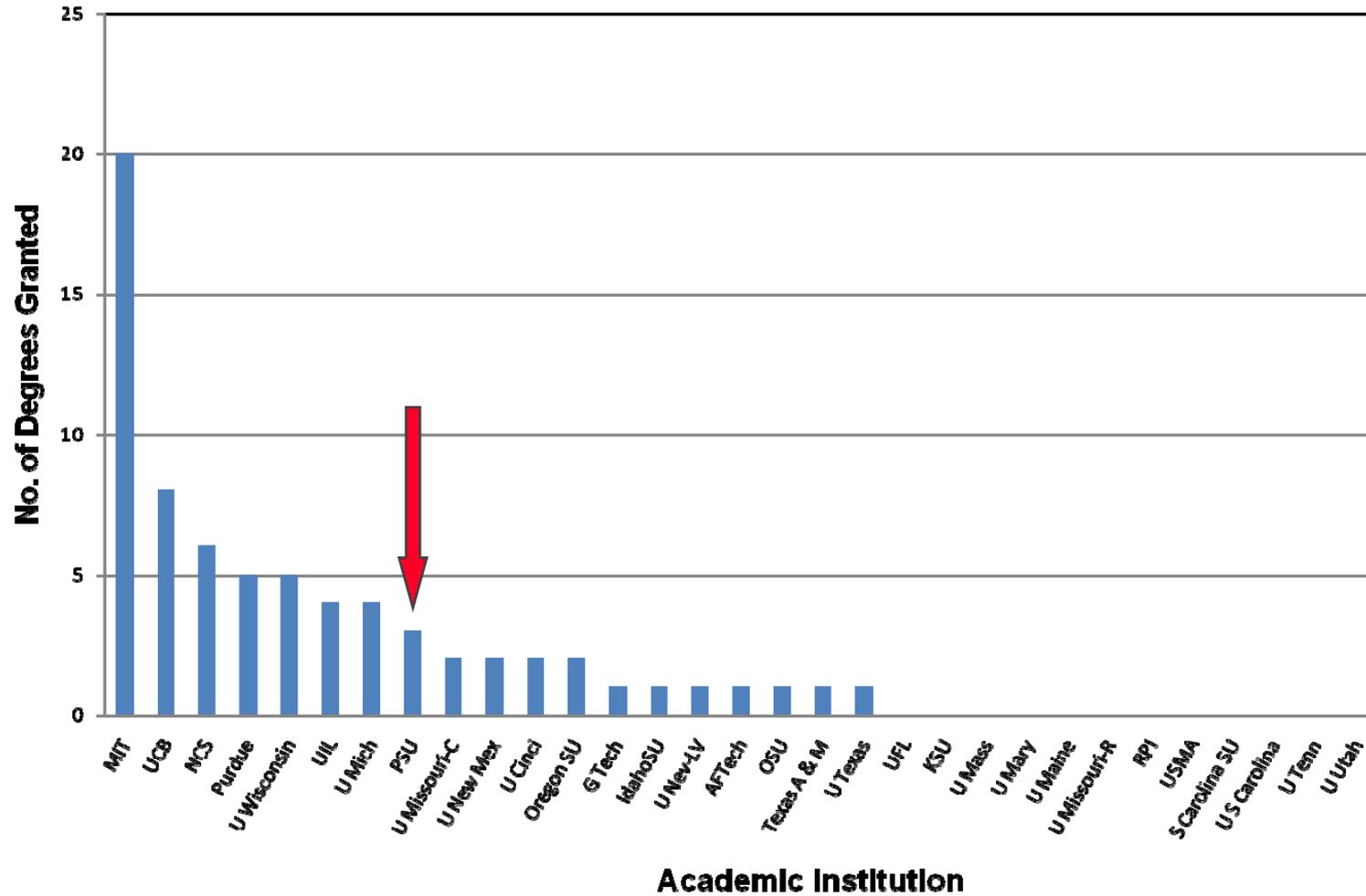


Nuclear Engineering MS Degrees Granted in 2006





Nuclear Engineering PhD Degrees Granted in 2006



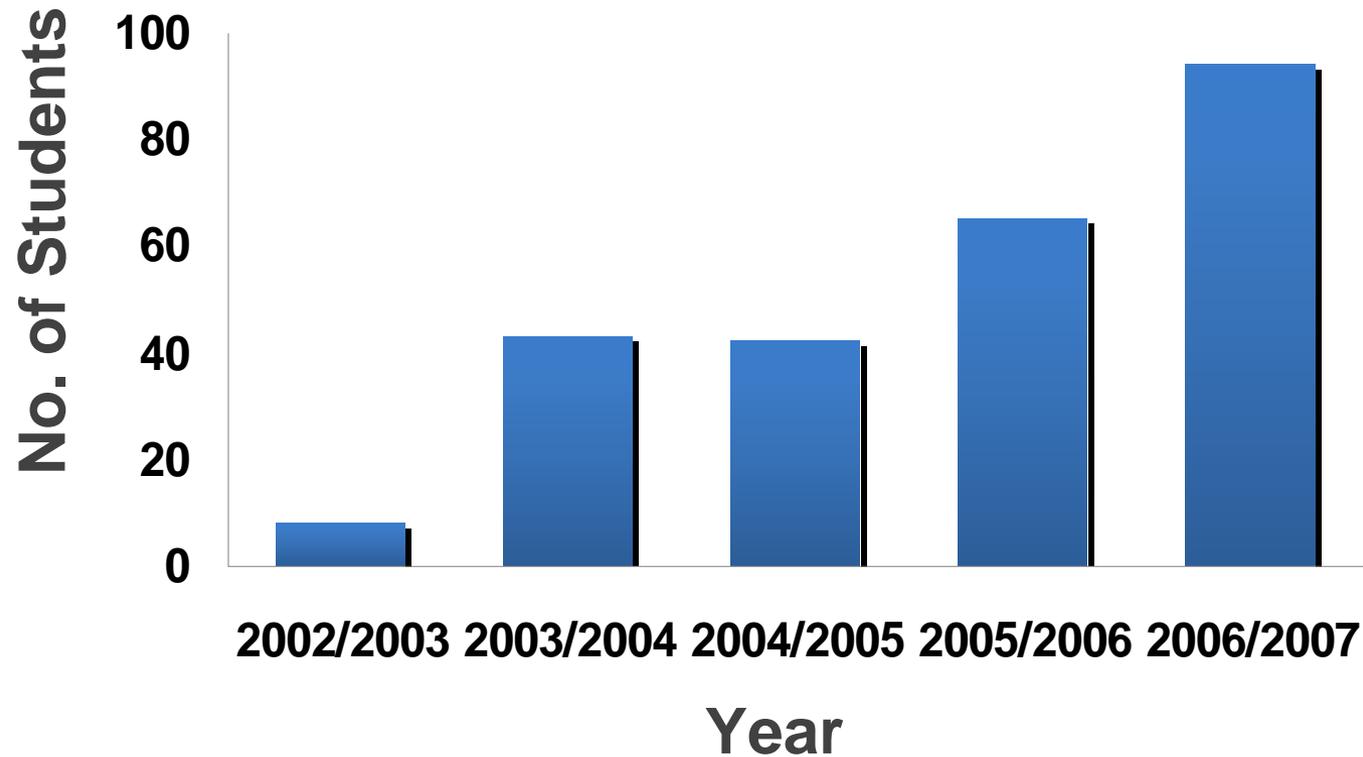


NE Distance Education

- Penn State Nuclear Engineering is currently offering a **Master of Engineering in Nuclear Engineering** via distance education
 - Program started Summer session 2002
 - Enrollment now over 94 students
 - Taught to Westinghouse, NR, Bettis, KAPL, others
 - http://www.engr.psu.edu/cde/nuclear_engineering.htm
- Course delivery is specifically designed to accommodate the non-traditional adult learner
- All distance classes are blended with resident course offerings



Distance Learning NucE MEng Enrollment Su'02 – Sp '07



- **On April 7, 2006 a meeting was held with Naval Reactors (NR) to discuss graduate education opportunities at Penn State**
- **One area of focus was the existing Nuclear Engineering Master of Engineering distance education program**
- **Potential students include active duty Naval Officers and civilian staff at NR, Bettis, and KAPL**
- **NR was looking for course credits that could be transferred to PSU**
 - **The officers will be pursuing the degree while on a 2 year shore duty**
 - **Officers will need more than the current Penn State limit of 10 transfer credits**

- **PSU reviewed feasibility and potential mapping of classes at the Bettis Reactor Engineering School (BRES) to the Nuclear Engineering curriculum**
- **Because class notes, homework, and even exams often contained classified material the committee members needed at least a DOD Secret clearance to review the material**
- **Members are from the Mechanical and Nuclear Engineering programs:**
 - **John Mahaffy (Chair), Associate Professor of Nuclear Engineering**
 - **Eric Patterson, member of the M.E. graduate faculty, ARL staff**
 - **Justin Watson, PhD candidate in Nuclear Engineering, ARL staff**
 - **Vaughn Whisker, PhD candidate in Nuclear Engineering, ARL staff**

- **BETTIS Reactor Engineering School has been in continuous operation since 1954**
- **Navy Officers from NROTC and NUPOC programs (primarily Engineering B.S.)**
- **Average age is 23 years**
- **Average Undergraduate GPA is 3.7**
- **Graduates of Cornell, CMU, Illinois, MIT, Notre Dame, PSU, Purdue, RPI, ...**

BRES Course	BRES Contact Hours	PSU Course Number	PSU Contact Hours
Reactor Plant Dynamics, Control & Safety	74	597D,/597K +	45
Reactor & Power Plant Design	Plant Design (20) Core Design (25) (Reactor) Heat Transfer & Fluid Flow Is Needed for this class	431W	60
Reactor Theory	66	403	45
Radiological Fundamentals and Shielding Design	52	408	45
Materials	76	409	45
(Reactor) Heat Transfer & Fluid Flow	74	430	45

The Nuclear Engineering Program had two separate requests

- **Approval to transfer selected BRES courses to Penn State for course credit**
- **Permission for incoming students to transfer up to 12 credits in the listed BRES courses towards the Master of Engineering degree in nuclear engineering**



BRES Course Transfer

- NucE faculty members unanimously approved the proposed mapping
- Reviewed with COE Deans Wormley and Mason
- Thole, Brenizer and Mason reviewed with Associate Dean of Graduate school
- Formal proposal approved by Graduate School in April 2007
- Will be valuable addition to our NucE outreach

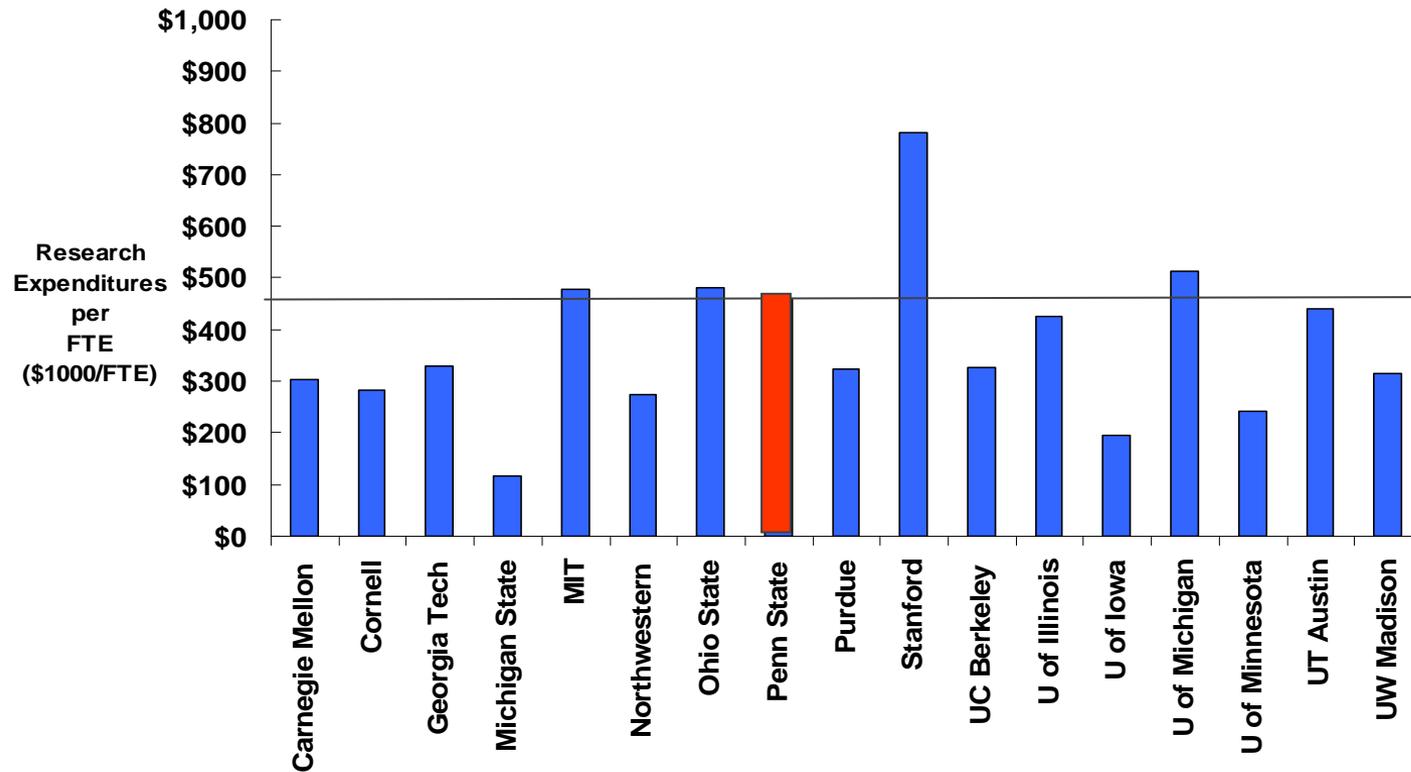
PENNSSTATE



Faculty Research Interests



MNE Total Research Expenditures

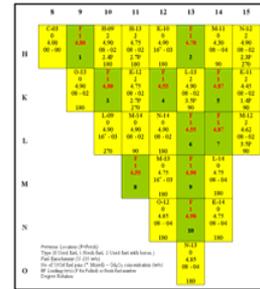


- MNE's total research expenditures were \$22M

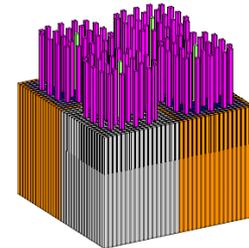


Nuclear Engineering Energy Research

- Modeling of current and future reactor cores, systems and components
 - Computational modeling of reactor cores and radiation sources – **Azmy, Hochreiter, Ivanov, Mahaffy** (NRC, ORNL, Exelon, Westinghouse, AREVA, ECOM)
 - Reactor control systems space nuclear thermal propulsion modeling and control – **Edwards** (NASA)
 - Improving the NRC’s TRAC/RELAP Advanced Computational Engine (TRACE) the current safety analysis tool, used on ESBWR, AP1000, and existing plants- **Mahaffy, Hochreiter** (NRC, OECD/NEA)
 - Reactor fuel management and optimization of fuel utilization – **Ivanov** (Exelon, Westinghouse, AREVA, GE)



OECD/NEA c5g7 MOX benchmark geometry
Unradged Configuration

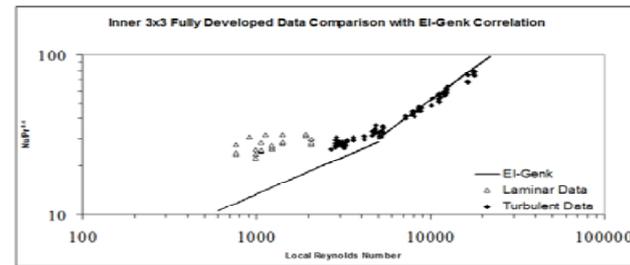
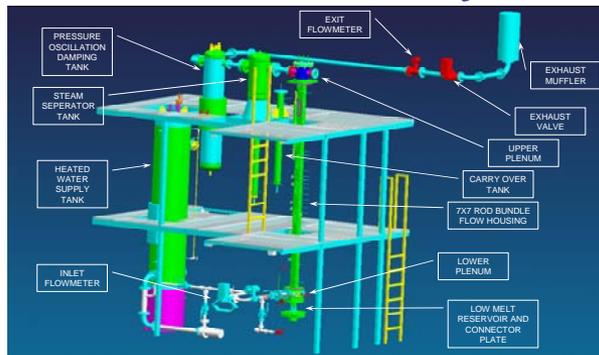




Nuclear Engineering Energy Research

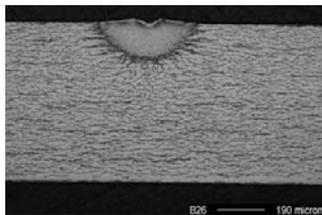
- Large-scale core experimental heat-transfer measurements & safety studies – Hochreiter, Cheung & Lin (NRC, Westinghouse, Bettis)
- Analysis of current and proposed reactor designs and proposed components used in severe accident management – Hochreiter & Cheung (Westinghouse, AREVA, NRC,)

RBHT Test Facility

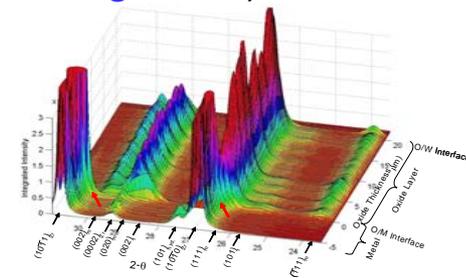


• El-Genk $Nu_{F,L} = [2.97 - 1.76(P/D)]Re^{0.56(P/D) - 0.3}Pr^{0.4}$
 $Nu_{F,T} = Nu_{D,B} [0.028(P/D) - 0.006]$

- Studying the fundamental mechanisms of corrosion of zirconium alloys & nuclear materials damage – Motta (ANL, DOE, CEA, SWRi, Westinghouse)



Artificially produced hydride blister to simulate in-reactor blister





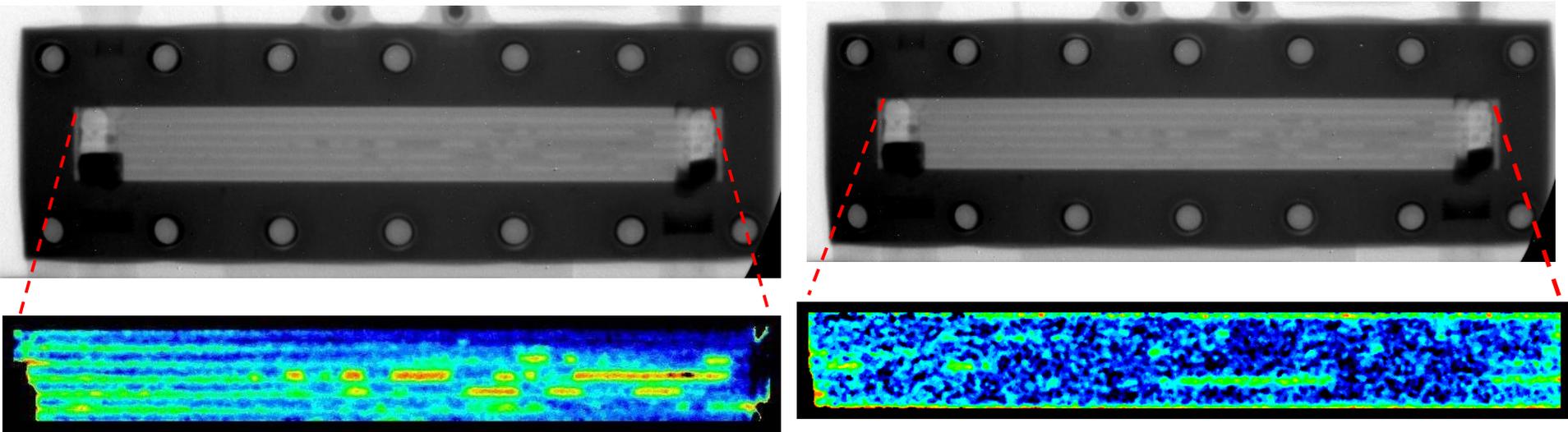
Radiation Science and Engineering Center

- Breazeale Nuclear Reactor
- Gamma Irradiation Facilities
- Hot Cells
- Radiation Detection and Measurement Facilities
- Neutron Beam Laboratory
- Radionuclear Application Laboratory
- The Angular Correlation Laboratory
- Low-Pressure Integrated Test Facility
- Support Facilities



Matt Mench--Radiation Science and Engineering Applications in Fuel Cells

- Quantifying and modeling liquid water distribution and dynamic behavior in polymer electrolyte fuel cells is critical for optimal performance, durability, and survivability under freeze/thaw conditions.
- Neutron imaging is an ideal tool for this research need, and PSU has been sponsored in this area for over three years with several major domestic and Asian automotive manufacturers.
- PSU has developed several unique capabilities in this technology.





RSEC Research Areas

- Existing
 - Neutron Activation Analysis
 - Neutron Imaging
 - Fast Neutron Irradiation
 - Cobalt-60 Gamma Irradiation
 - Perturbed Angular Correlation Spectroscopy
- Future
 - Neutron Depth Profiling
 - Cold Neutron Source
 - Cold Neutron Prompt Gamma Activation Analysis
 - Neutron Powder Diffraction
 - Nuclear Tracer Methods and Radiochemistry



Current Trends

- Nuclear Power is now recognized as **GREEN**
- President and Congress in favor of expansion of nuclear operating capacity
- Financial market is looking at new nuclear construction in favorable light
- Aging work force
- Many new, high quality, exciting jobs for graduates at all levels



Impact on PSU NucE Program

- Undergraduate
 - Enrollment growing at 12% (from 2000 – 2006)
 - GPA going up
 - Stronger students
 - ~100% placement – multiple job offers or grad school
- Graduate
 - Increased number of US students
 - Equal mix between PhD and Masters
 - Distance education MEng enrollments increasing
 - Graduate stipends are growing nationally
- Research funding grew from 2000 – 2004, now steady



**How are we doing with respect to
meeting our goals?**



Undergraduate Program

- Further strengthen and broaden the existing program to produce students with
 - A strong core knowledge in traditional nuclear engineering, and
 - An emphasis in either nuclear science or power engineering
 - Prepare students for industry
 - Prepare students for graduate studies
 - Power engineering
 - National Laboratories, nuclear medicine, radiology, etc.

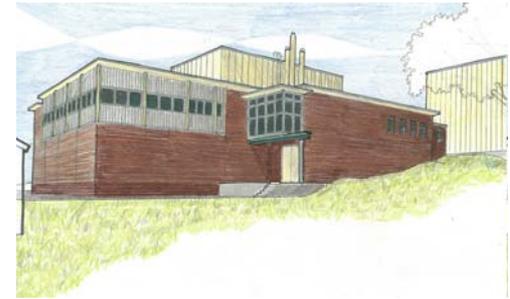


NE Graduate Program

- Increase graduate program size
- Move from small to big research projects
 - Significant funding is available in nuclear sciences
 - **Examples - NSF, DOE, Non-nuclear industry, DHS**
 - Look for opportunities to team with nuclear industry to become the “go to” place for research
 - **Examples - NRC rod bundle, Mahaffy’s and Ivanov’s code development**
- Hire post-doc students to work on projects with graduate students
- Grow our research around our strong facilities



RSEC Expansion



- Neutron beam hall to be expanded
- Add new research office space
- Architectural design is completed
- Now seeking funding - \$2.75 M for building
 - Expression of Interest Letter to DOE
 - Signed by Eve Pell, VP for Research
 - University Funding in Place
 - Contributions from a number of units
 - 30 Letters of support from internal and external users
- Will greatly expand research areas and user base
- **Funding picture now cloudy – still seeking funds but anticipate difficulty due to DOE NE restructuring**



Opportunities & Challenges

- Faculty size still limiting – new position will help
- Undergraduate Enrollment
 - Creates larger class sizes for required courses
 - Allows a wider range/number of technical electives
- Graduate
 - Tuition costs rising quickly
 - Keen competition for US students
 - Higher stipends
 - Seeking particular “hot” topic areas
- Higher quality students
 - Must/Can teach at a higher level
 - Permits more open-ended assignments
 - Highly sought for internships, permanent positions



Opportunities & Challenges

- Promote PSU students/Program
 - At Student ANS Conferences, PSU always
 - Has largest number of students
 - Wins awards
 - PSU students present at National ANS meetings
- Challenge to faculty is to maintain & enhance quality of the Program during enrollment growth



Opportunities & Challenges

- Recent changes in funding from DOE – NE will create challenges
 - Need to find replacement funding to support infrastructure
 - DOE/Industry Matching Grant Program
 - DOE INIE Program
 - Need to find funding for research and graduate student support
 - NEER and NERI Programs
 - DOE Fellowship programs



Conclusions

- Good time for PSU's NE Program
- NE well positioned to play a major role in national resurgence of nuclear power
 - Have strong relationships with industry and key government labs and agencies
 - Conducting research in key areas of interest
 - Good collaborations with other universities



Conclusions

- NucE Distance Education
 - Initially a way to offer graduate courses that were under enrolled
 - Now recognized and rapidly growing
 - Adding Naval Reactor students may add many new students
 - Challenge is to control/manage growth and maintain quality



Conclusions

- Undergraduate growth – faculty about at full capacity
- Experimental facilities at RSEC are being upgraded to have state-of-the-art capabilities
- NE curriculum being expanded to address growing needs of industry, national labs and government agencies



Conclusions

- New NucE faculty hire will be very pivotal in moving our Program forward
- We will have to meet the challenge of the DOE NE decision to dramatically cut funding to university nuclear engineering programs
- We will meet this challenge!



Questions?

Extra slides



J. S. Brenizer

- **Program Chair**
 - DOE INIE Big-10 Consortium Director
 - PI of \$2 million/year INIE contract
 - All Big-10 Nuclear Programs
 - Consortia Chair of DOE INIE Mini-Grant Project
- **Non-Destructive Testing (NDT)**
 - Neutron Imaging – Fuel Cells with Mench
 - Neutron Computed Tomography
- **Neutron Activation Analysis**
- **Health Physics**



Nuclear Computational Science Group Yousry Y. Azmy

- **Multi-Dimensional applications of radiation transport with DORT/TORT:**
 - Shielding analysis: Detailed dose map distributions
 - Criticality calculations: Reactor cores, stored fuel, safety analysis
 - Nuclear system modeling: Beam tube, cold source
- **Radiation transport & diffusion computational methods:**
 - Development & analysis of novel numerical methods
 - Development of highly accurate methods on unstructured grids
 - Development/implementation/analysis: novel solution algorithms
 - Development/implementation/performance-modeling of parallel algorithms for multiprocessing computers
- **Nonlinear dynamics of incompressible & natural convection fluid flow fields**



Gary L. Catchen

- Perturbed-Angular-Correlation (PAC)
 - Phase transitions in electronic ceramics
 - Effects of defects on magnetic ordering in intermetallics
 - Magnetic ordering in metallic nano-structures
- Mössbauer-effect spectroscopy
 - Characterizing iron phases for environmental remediation



Robert Edwards

- Advanced monitoring and control
 - optimal and robust control of nuclear reactors and power plants
 - BWR stability monitoring
 - Space nuclear thermal propulsion modeling and control
 - S-I hydrogen production cycle modeling and control
 - demonstration of monitoring and control
 - Penn State TRIGA research reactor
 - Low pressure Integral Test Facility
 - Remote internet interface to experiments
- Modeling and testing of power plant digital control systems
 - NRC sponsored research
 - one approach is to model control systems in SIMULINK and interface to thermal hydraulic safety codes for testing



L. E. Hochreiter

INTERESTS INCLUDE:

❖ **Reactor Engineering and Design**

- Fuel Rod Design, optimization
- Core Thermal/Hydraulics, Subchannel Analysis, Codes, Critical Heat Flux
- Reactor Safety Analysis, Codes, Models, transient, Design Basis, Severe Accident Analysis
- New Reactor Designs and Analysis

❖ **Two-Phase flow and Heat Transfer, Analysis, Development, Experiments**



Kostadin Ivanov

- **Coupled Three-Dimensional Neutronics/Thermal-Hydraulics System Transient Calculations**
- **Loading Pattern and Burnable Poison Placement Optimization**
- **Optimization of the Discharge Burnup and Cycle Length**
- **Coupled Local Neutronics/Thermal-Hydraulics/Mechanical Safety Analysis**
- **Monte Carlo Criticality and Depletion Calculations**
- **Accuracy Evaluation of Peak Exposure Predictions in the Current LWR Core Design Codes**
- **Improving the Accuracy of Few Group Diffusion Models with Embedded Transport Calculations**
- **Automated Generation of Cross-Section Libraries and Optimization of Coupled Core Models for Consistent Cycle and Transient Analysis**



John Mahaffy

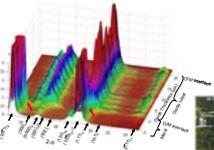
- TRAC/RELAP Advanced Computational Engine (TRACE)
- NRC's Current Safety Analysis Tool, used on ESBWR, AP1000, and existing plants.
 - Advanced Numerical Methods, Higher Order and Implicit
 - Additional Fields for Droplets
 - Improved Choked Flow Modeling
 - Improved Code Architecture
 - Interface for Distributed Parallel Computing
- Use of CFD for Nuclear Reactor Safety (NRS) Analysis (for OECD/NEA)
 - Best Practice Guidelines for NRS single phase applications
 - Development of an NRS CFD Assessment Matrix
 - Recommendations on Development Needs for Full Two-Phase CFD

Research in Materials for Nuclear Reactors: Arthur T. Motta

Fundamental Mechanisms of Corrosion of Zirconium Alloys

(Collaboration with Westinghouse and University of Michigan, Argonne, financed by DOE, I-NERI)

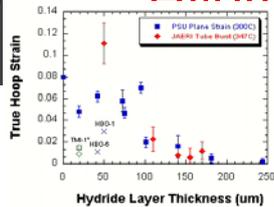
⇒ Use microbeam synchrotron radiation (Advanced Photon Source) and other advanced characterization techniques to discern difference in protective oxide structure for different alloys. Objective is to understand mechanistically what makes a Zr alloy better than another



Hydrogen Induced Degradation of Mechanical Properties of Zr Fuel Cladding during RIA at High Burnup

(Collaboration with CEA, SWRI, financed by NRC)

⇒ Develop techniques to impose correct stress states in deforming cladding and test their susceptibility to failure after hydriding. Objective is to determine the hydriding limits for high burnup cladding when submitted to an RIA.



Precipitate Stability of Oxide-dispersion Strengthened Steels under High Temperature Irradiation

(Collaboration with Argonne, financed by DOE-NEER)

⇒ Various Gen IV Reactors concepts call for use ODS steels for cladding and structural components. Irradiations with charged particles in-situ to very high doses





F. B. Cheung – ANS Fellow, ASME Fellow

- **Nuclear Reactor Thermal Hydraulics and Safety:** Rod Bundle Heat Transfer, Transient Reflood Phenomena, Light Water Reactors Thermal Hydraulics and Safety, Severe Accident Thermal Hydraulics
- **Severe Accident Management:** Long-Term Coolability of Core Melt, Molten Pool Heat Transfer, In-Vessel Retention Strategy, In-Vessel Core Catcher Design, External Reactor Vessel Cooling, Ex-Vessel Core Catcher Design, Ex-Vessel Cooling
- **Base Technology:** Downward-Facing Boiling Heat Transfer, Critical Heat Flux Phenomena, Heat Transfer Enhancement Using Micro-Porous Layer Coatings, Modeling of Upward Co-Current Two-Phase Flow and Steam Venting



Kenan Ünlü

- Neutron Activation Analysis
- Neutron Depth Profiling
- Analyzing soft error rates in semiconductor memories and field programmable gate arrays
- Investigation of preferential flow of water in sand samples using real time neutron radiography (Mark Deinert)
- Neutron radiography for water transport in polymer electrolyte fuel cells
- University Reactor Cold Neutron Sources
- Neutron detectors



Thermal Systems Activities

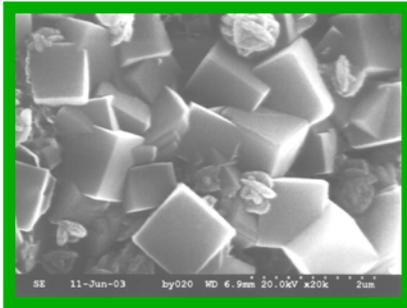
Drs. K.H. Kim and H. Perez-Blanco

- **Gas Turbines:** Continuous evaporative cooling of compressor gas.
- **Simultaneous Heat and Mass Transfer:** Modeling of droplet cloud dynamics and evaporation
- **Plasma Flow Control:** Effect of pulsed plasma on gas turbine losses and large coherent flow structure.

Barry E. Scheetz

Specialty – cementitious systems

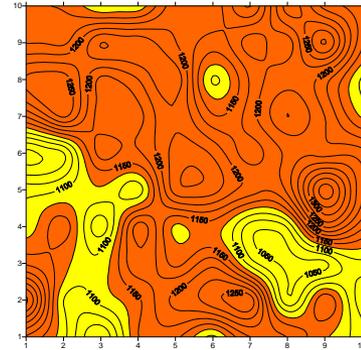
Microstructure of hydroceramic
Nuclear waste form



Waste management

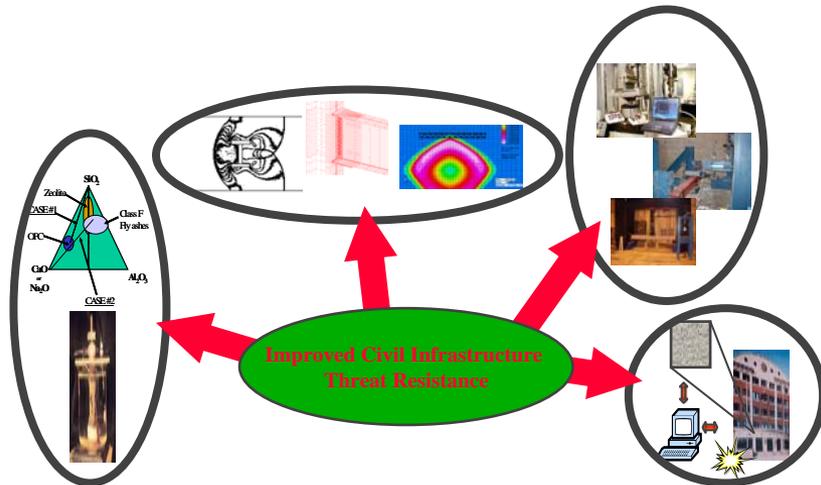
*Force protection of
critical infrastructure*

Dense concrete



Gamma transmission in
Shielding concrete

*Microstructure
control*



Seeded concrete microstructure

